Field Results from a Forest Catchment Located at Navasfríasis (Western Spain).

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Subject of the work

I will talk about Water balance, Biogeochemistry, Biogeochemical cycles, Soil, erosion, etc. from a forest experimental plot located in Navasfrías (Western Spain).

In summary:

**Forests & Waters** relationships.
Acknowledgements

The exposed data are a selection belonging to Projects supported by the European Union (MEDCOP, PROTOS, etc.); we thanks to the E. U. and our many collaborators their help.

We refer, in a final Annex, the list of papers that these data, here selected and exposed, can be found.

We thanks also the organizers of this meeting their kind invitation for attending.
Objective of the work

In this communication the selected results, dealing on biogeochemical cycles, water balance, budgets, soil fertility, soil erosion, and impact of liming, will be exposed.

The site studied is a forest experimental plot located in Navasfrías (Western Spain).
Situation of the area studied
General view (North to South) of the ‘Sierra de Gata’ Mountains, W. Spain
Site Studied

This site studied is located at Navasfrías, little village belonging to the Province of Salamanca, Western Spain.

The experimental area is only some km far from the Portuguese border.

This plot belongs to a rainfall gradient of oak forests. Navasfrías is the site with the highest precipitation of the transect.
Location of the experimental forest site here studied
Winter view of the forest studied
In all this area deciduous oak forests of *Quercus pyrenaica* are abundant.

In the selected the deciduous-oak *Quercus pyrenaica* is dominant (alike *Q. mongolica* of China).

An acidophil understory strata of the genera *Pteridium, Cytisus, Calluna, etc.* appears only in the open areas.
Biogeochemical approach (balance)
Early-spring view of the forest experimental plot of Navasfrías (Western Spain)
Understory strata of oak forest studied (ferns in summer)
Navasfrías has a Mediterranean (very dry summer), sub-humid, temperate climate.

Geology is Paleozoic, mainly granites, schists, and greywackes (acid rocks).

Dominant soils are dystric Cambisols and cambic Umbrisols, with patches of Leptosols.
## Characteristics of the forest sites

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Navasfrías</th>
<th>Villasrubias</th>
<th>Fuente-guinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude (m snm)</td>
<td>960</td>
<td>900</td>
<td>870</td>
</tr>
<tr>
<td>Main air temperature (°C)</td>
<td>10.4</td>
<td>9.0</td>
<td>12.9</td>
</tr>
<tr>
<td>Mean rainfall (mm/yr)</td>
<td>1580</td>
<td>872</td>
<td>720</td>
</tr>
<tr>
<td>Annual rainfall (1998; mm/yr)</td>
<td>1307</td>
<td>1045</td>
<td>782</td>
</tr>
<tr>
<td>Throughfall (canopy) (1998; mm/yr)</td>
<td>909</td>
<td>705</td>
<td>526</td>
</tr>
</tbody>
</table>
Catchment

\[ R = \text{AET} + \text{Stream} + \text{Drainage} \pm \text{SM} \]
We also selected there one small catchment (22 ha) where the experimental plot (1 ha) was included.

The experimental plot was initially fenced for avoiding external undesirable troubles.
The management of this forest was mainly clear cutting (old coppice for producing charcoal in the past) and cattle grassing (low cattle density, from spring to autumn).

As a consequence of that, tree density is about 820 trees ha$^{-1}$, being dominant the tree age of 60-yr old.
### Above-ground biomass (40-60 yr old)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Navasfrías</th>
<th>Villasrubias</th>
<th>Fuente-guinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tree density</strong> (trees/ha)</td>
<td>820</td>
<td>1043</td>
<td>738</td>
</tr>
<tr>
<td><strong>Mean tree height</strong> (m)</td>
<td>15.1</td>
<td>9.1</td>
<td>12.4</td>
</tr>
<tr>
<td><strong>Tree diameter</strong> (DBH; cm)</td>
<td>15.2</td>
<td>11.0</td>
<td>16.5</td>
</tr>
<tr>
<td><strong>Basal area</strong> (m²/ha)</td>
<td>15.6</td>
<td>13.5</td>
<td>21.2</td>
</tr>
<tr>
<td><strong>Total biomass</strong> (Mg/ha)</td>
<td>64.5</td>
<td>63.8</td>
<td>98.0</td>
</tr>
</tbody>
</table>
Methods

Different devices and sensors have been installed in the forest experimental plot (Navasfrías).

A catchment weir (little dam) has been build on the main intermittent water stream ('arroyo').
Water regimes (rainfall & soil drainage)

- Tundra
- Taiga
- Semiarid or arid
- Humid, temperate-continental to sub-humid Mediterranean
- Wet & dry Tropics
- Monsoon Tropical

Climatic conditions and soil moisture
Boxes for measuring the above-ground production (transect; Autumn view)
Climatic tower & sensors
Lysimeter types (with and without atmospheric-dust trap)

- Bulk precipitation
- Dusts plus rainfall
- Throughfall
Lysimeters for sampling throughfall & stemflow
Results from either the plot or the catchment approaches

According to the characteristics of the data, some of them are referred to the experimental plot (in general, mg g\(^{-1}\) or mg L\(^{-1}\)) and others to the entire catchment (20 ha, in ha\(^{-1}\)).

We also distinguish between compartment (Mg ha\(^{-1}\)) and flux (Mg ha\(^{-1}\) yr\(^{-1}\)).
The annual mean rainfall is about 1580 mm yr\(^{-1}\), but a wide inter-annual variability of amount and distribution of rains were observed.

Runoff is sporadic and very variable on time (but lower than 5 mm yr\(^{-1}\), almost negligible).
Daily rainfall from 1996 to 1999
Time variation of the rainfall

![Diagram showing rainfall variation over months with mean (29 yr) and years 1996/97, 1997/98, 1998/99.
Daily rainfall from 1991 to 1993

Rainfall (mm)

Navasfrías

Fuenteguinaldo
Water Fluxes in two deciduous-oak forest located in Western Spain

Annual distribution of rainfall in two oak forests (1990-1993).

<table>
<thead>
<tr>
<th>Water fluxes (L m(^{-2}) yr(^{-1}))</th>
<th>Navasfrías</th>
<th>Fuenteguinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual rainfall (mean)</td>
<td>1057</td>
<td>625</td>
</tr>
<tr>
<td>Interception (mean)</td>
<td>151</td>
<td>99</td>
</tr>
<tr>
<td>Throughfall (mean)</td>
<td>905</td>
<td>526</td>
</tr>
<tr>
<td>Runoff (mean)</td>
<td>3.9</td>
<td>0</td>
</tr>
<tr>
<td>PET* (mean)</td>
<td>792</td>
<td>818</td>
</tr>
<tr>
<td>Rainfall in May &amp; June</td>
<td>129</td>
<td>83</td>
</tr>
<tr>
<td>AET** (mean)</td>
<td>536</td>
<td>440</td>
</tr>
<tr>
<td>Winter drainage (mean; -1.1 m)</td>
<td>495</td>
<td>189</td>
</tr>
</tbody>
</table>

*PET: Potential evapo-transpiration; **AET: Actual evapo-transpiration.
Relationships with rainfall amounts

Precip.: Rainfall (mm);
Transc.: Throughfall (mm);
Intercep.: Canopy interception (mm).

<table>
<thead>
<tr>
<th>Período fenológico</th>
<th>Precipitación (mm)</th>
<th>Trascolación (mm)</th>
<th>(%)</th>
<th>Intercepción (mm)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>1477</td>
<td>1257</td>
<td>85</td>
<td>220</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>2274</td>
<td>2005</td>
<td>88</td>
<td>269</td>
<td>12</td>
</tr>
</tbody>
</table>

![Graph of Precipitation vs Throughfall](image)

The graph shows a linear relationship between precipitation and throughfall, with the equation $y = 0.888x - 266$ and $R^2 = 0.994$. The data points indicate a strong correlation between the two variables.
Biogeochemical cycles

The main vector of the bio-element cycles are the production and the circulating waters.

As an acid, oligo-trophic system, the amounts of bio-elements circulating above-ground are very scarce.
Bio-element fluxes to soil by throughfall (in kg ha\(^{-1}\) yr\(^{-1}\)) in two oak forests located in the “Sierra de Gata” mountains (Western Spain)

<table>
<thead>
<tr>
<th>Sites</th>
<th>C</th>
<th>N</th>
<th>Ca</th>
<th>Mg</th>
<th>P</th>
<th>K</th>
<th>Na</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navasfrías</td>
<td>96</td>
<td>3.0</td>
<td>12.8</td>
<td>4.71</td>
<td>0.70</td>
<td>8.4</td>
<td>4.94</td>
<td>0.44</td>
<td>0.27</td>
<td>0.25</td>
<td>1.7</td>
</tr>
<tr>
<td>Fuenteguinaldo</td>
<td>132</td>
<td>3.4</td>
<td>11.0</td>
<td>6.26</td>
<td>2.45</td>
<td>17.7</td>
<td>3.54</td>
<td>0.55</td>
<td>0.27</td>
<td>0.15</td>
<td>1.6</td>
</tr>
</tbody>
</table>
Evolution of the water quality of rainfall after a dry period (dust influence)

Accumulative amount (mm) of rainfall, after a dry period (summer)
### C fluxes above the soil

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Navasfrías</th>
<th>Villasrubias</th>
<th>Fuente-guinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual growth (mm/yr)</strong></td>
<td>4.7</td>
<td>5.0</td>
<td>6.4</td>
</tr>
<tr>
<td><strong>Trunk volume growth (m³/yr)</strong></td>
<td>12.6</td>
<td>7.9</td>
<td>16.5</td>
</tr>
<tr>
<td><strong>C sequestered annually by trunks (Mg C/ha, yr)</strong></td>
<td>2.3</td>
<td>1.8</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>Annual production. (Mg DM/ha, yr)</strong></td>
<td>2.60</td>
<td>2.83</td>
<td>4.09</td>
</tr>
<tr>
<td><strong>Flux C toward litter (Mg C/ha, yr)</strong></td>
<td>1.2</td>
<td>1.4</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Decomposition K (yr⁻¹)</strong></td>
<td>0.33</td>
<td>0.33</td>
<td>0.47</td>
</tr>
<tr>
<td>Parameters</td>
<td>Navasfrías</td>
<td>Villasrubias</td>
<td>Fuente-guinaldo</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>------------</td>
<td>--------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Sequestered C as biomass (Mg C/ha)</td>
<td>32</td>
<td>32</td>
<td>49</td>
</tr>
</tbody>
</table>
## Soil properties

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Navasfrías</th>
<th>Villasrubias</th>
<th>Fuente-guinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH (H₂O)</strong></td>
<td>4.9</td>
<td>4.6</td>
<td>5.4</td>
</tr>
<tr>
<td><strong>Org. C Ah₁</strong> (Mg C/ha)</td>
<td>84</td>
<td>67</td>
<td>42</td>
</tr>
<tr>
<td><strong>Org. C Ah₂</strong> (Mg C/ha)</td>
<td>42</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td><strong>Org. C Bw</strong> (Mg C/ha)</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td><strong>Soil C accumulation</strong> (Mg C/ha)</td>
<td>132 (0-65 cm)</td>
<td>85 (0-45 cm)</td>
<td>62 (0-60 cm)</td>
</tr>
<tr>
<td><strong>Base saturation (%)</strong></td>
<td>7.5</td>
<td>5.2</td>
<td>43</td>
</tr>
<tr>
<td><strong>Decomposition K epipedon Ah (yr⁻¹)</strong></td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
</tr>
</tbody>
</table>
C fluxes above-ground

A third of the annual production (2.6 Mg C ha\(^{-1}\) yr\(^{-1}\)) is mineralized when the litter is decomposed; the two thirds remained as stand litter on the soil (1.2 Mg C ha\(^{-1}\) yr\(^{-1}\)) and finally is incorporated as soil organic C (SOC). But this quantity of C is more or less equivalent to the SOC annually mineralized.

Then, the only C yearly sequestered in the aboveground biomass (climax) is of the C that is incorporated by trunks (2.3 Mg C ha\(^{-1}\) yr\(^{-1}\)).
Forest soil from Navasfrías (summer) (cambic Umbrisol)
Forest soil of Navasfrías (winter) (cambic Umbrisol)
Litter mineralization is slow because of the relative low temperature during winter and, mainly, during the dry summer, which stops the microbial activity and the soil organic matter degradation.

Values of the mineralization $K$ is low (0.33), either measured by litter-bags or by the ratio:

$$K = \frac{\text{Annual production}}{\text{accumulated SOM}}$$

Therefore, a non-continuous litter-layer of 5.25 Mg C ha$^{-1}$ is found on this forest soil.
Soil Fertility

N is not a limiting factor, as tested by additional fertilization.

In spite of the soil acidity and the low content of available P, this forest did not have symptoms of P deficiency (low P consume and micorrhizes were found).
DYNAMIC OF SOIL MOISTURE: Lysimeters at different soil depths
Dynamic of soil moisture

The soil moisture deeply varies along the year, according the rainfall regime.

During the summer the soil is completely dry till -40 cm depth; moisture content of the epipedon changes faster than that of soil deeper-horizons.
Soil lysimeters, by horizons.
Soil lysimeters for sampling zero-tension soil solutions
Suction pressure tubes for sampling soil solutions
Relationships with rainfall amounts

Precip.: Rainfall;
Dp: Deep drainage;
ETR: Actual evapo-transpiration.
Time evolution of soil moisture

Volumetric percentage (%) of soil moisture on soil depth (from 1990 to 1993).
Soil water variation during 1996
Comparison between soil-moisture results obtained by two methods (neutron probe vs. T.D.R.; and three depths)

By soil depths:

- 0-20 cm
- 20-40 cm
- 0-40 cm
According to the characteristics of the data, some of them are referred to the catchment (circa 22 ha).
Weir of the catchment
Sampling water from stream
Stream of the catchment
Hydrology

Runoff is sporadic and negligible.

The intermittent stream (*arroyo*) runs only wet years after an accumulative amount of 1000-mm, falls just after the dry season (summer).

Usually that corresponds to a mean annual rainfall higher than 1,200 mm yr$^{-1}$.)
Influence of rainfall on the stream pulses (soil water saturation)
Then, the water balance points out that the stream only runs in the normal or wet years, but it is compulsive that the distribution of rains maintains the soil saturated in water.

Than, there is scarce losses of bio-elements, the dry years functioning this ecosystem as a water-closed system.
### Water fluxes of the forest sites (inter-annual means)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Navasfrías</th>
<th>Villasrubias</th>
<th>Fuente-guinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evapotranspiration (mm/yr)</td>
<td>447</td>
<td>440</td>
<td>349</td>
</tr>
<tr>
<td>Interception (mm/yr)</td>
<td>398</td>
<td>340</td>
<td>256</td>
</tr>
<tr>
<td>Runoff (mm/yr)</td>
<td>2.1</td>
<td>3.0</td>
<td>0</td>
</tr>
<tr>
<td>Water loss by stream (mean, mm/a)</td>
<td>59</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water fluxes</td>
<td>(mm/yr)</td>
<td>(% Pb)</td>
<td>(% Pn)</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>---------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Bulk precipitation (Pb)</td>
<td>1572</td>
<td>100</td>
<td>N.d</td>
</tr>
<tr>
<td>PET</td>
<td>816</td>
<td>N.d.</td>
<td>N.d.</td>
</tr>
<tr>
<td>Throughfall</td>
<td>1384</td>
<td>88</td>
<td>N.d.</td>
</tr>
<tr>
<td>Interception</td>
<td>188</td>
<td>12</td>
<td>N.d.</td>
</tr>
<tr>
<td>Net precipitation (Pn)</td>
<td>1217</td>
<td>76</td>
<td>100</td>
</tr>
<tr>
<td>Epipedon drainage</td>
<td>1022</td>
<td>62</td>
<td>84</td>
</tr>
<tr>
<td>AET</td>
<td>495</td>
<td>35</td>
<td>41</td>
</tr>
<tr>
<td>Deep drainage</td>
<td>872</td>
<td>51</td>
<td>72</td>
</tr>
<tr>
<td>To stream</td>
<td>104</td>
<td>5,2</td>
<td>9</td>
</tr>
</tbody>
</table>
Balance of the bio-elements in the forest ecosystem studied

There is an absorption of bio-elements from the water solution (after the enrichment of them by the forest canopy and humus layer) when waters circulate throughout the soil horizons.

Finally, the soil water solution in the $C$ (lower) soil-horizon is cleaner than the bulk precipitation water.

As a consequence of this, the stream water is very clean (high quality: No sediments, no metals).
<table>
<thead>
<tr>
<th>Sites</th>
<th>DOC (kg ha(^{-1}) yr(^{-1}))</th>
<th>N</th>
<th>Ca</th>
<th>Mg</th>
<th>P</th>
<th>K</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navasfrías</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>68</td>
<td>32</td>
<td>0.42</td>
<td>6.8</td>
<td>1.5</td>
<td>2.2</td>
<td>5.1</td>
</tr>
<tr>
<td>Dry deposition</td>
<td>2</td>
<td>4.7</td>
<td>0.32</td>
<td>4.3</td>
<td>0.7</td>
<td>1.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Throughfall</td>
<td>90</td>
<td>3.0</td>
<td>0.69</td>
<td>12</td>
<td>4.5</td>
<td>7.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Stemflow</td>
<td>6</td>
<td>t</td>
<td>0.01</td>
<td>0.5</td>
<td>0.2</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Soil deep-drainage</td>
<td>27</td>
<td>-4.9</td>
<td>-0.04</td>
<td>1.7</td>
<td>2.5</td>
<td>4.5</td>
<td>-1.6</td>
</tr>
<tr>
<td>Fuente-guinaldo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>44</td>
<td>3.3</td>
<td>0.27</td>
<td>5.8</td>
<td>1.4</td>
<td>1.5</td>
<td>3.4</td>
</tr>
<tr>
<td>Dry deposition</td>
<td>17</td>
<td>5.1</td>
<td>0.86</td>
<td>4.3</td>
<td>2.9</td>
<td>6.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Throughfall</td>
<td>124</td>
<td>3.4</td>
<td>2.4</td>
<td>11</td>
<td>6.0</td>
<td>17</td>
<td>3.4</td>
</tr>
<tr>
<td>Stemflow</td>
<td>8</td>
<td>t</td>
<td>0.02</td>
<td>0.5</td>
<td>0.3</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td>Soil deep-drainage</td>
<td>71</td>
<td>-5.1</td>
<td>1.3</td>
<td>0.9</td>
<td>2.0</td>
<td>9.4</td>
<td>-0.9</td>
</tr>
</tbody>
</table>

(DOC: Dissolved organic C; a minus sign (-) means absorption)
Annual fluxes in a *Q. pyrenaica* oak forest (Navasfrías)

**Rainfall:**
- With dusts: 1520 mm
- With dusts: 1675 mm

**Throughfall:**
- **DOC:** 9.4
- **DON:** 1.1
- **DOP:** 0.009

**Throughfall:**
- **DOC:** 9.4
- **DON:** 1.1
- **DOP:** 0.009

**Litter production:** 260 g m⁻²

**Year:** 1996-97

**Aboveground**

**Flux units**
- Waters: L m⁻² yr⁻¹
- Dissolved: g m⁻² yr⁻¹

**Throughfall:** 1043 L m⁻² yr⁻¹

In mg/L (DOC: Dissolved organic C; DON: Dissolved organic N; DOP: Dissolved organic P)
Annual fluxes in a *Q. pyrenaica* oak forest (Navasfrías)

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Soil horizons</th>
<th>Belowground</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td><em>Ah</em></td>
<td>DOC 7.1</td>
</tr>
<tr>
<td>20</td>
<td><em>Bw</em></td>
<td>DON 0.29</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>DOP 0.008</td>
</tr>
<tr>
<td>60</td>
<td><em>CR</em></td>
<td>DOC 0.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DON N-D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DOP 0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DOC 0.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DON 0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DOP 0.0</td>
</tr>
</tbody>
</table>

**Soil drainage**

- 245 mm
- 46 mm
- 95 mm

**Stream Losses**

- 59 mm

In mg/L (DOC: Dissolved organic C; DON: Dissolved organic N; DOP: Dissolved organic P)

**Year:** 1996-97
Net Balance of DOC in three deciduous oak forest located in W Spain
(Data in kg C ha$^{-1}$ yr$^{-1}$)

**NAVASFRIAS**
- Throughfall: 1580 mm yr$^{-1}$
- Mean temperature: 10.4 °C

Net balance: +1.5 Mg C ha$^{-1}$ yr$^{-1}$

**FUENTEGUINALDO**
- Throughfall: 720 mm yr$^{-1}$
- Mean temperature: 12.9 °C

Net balance: +2.0 Mg C ha$^{-1}$ yr$^{-1}$
After the biogeochemical study, the C balance results in net gain of +1.9 Mg C ha\(^{-1}\) yr\(^{-1}\), mainly sequestered as trunk growth.

The base line for this forest system, according the current applied management, is the sum of 32 Mg C ha\(^{-1}\) plus 132 Mg C ha\(^{-1}\) results in a total of 164 Mg C ha\(^{-1}\).
## C Inputs to Ecosystems

<table>
<thead>
<tr>
<th>Annual C Inputs</th>
<th>Navasfrías</th>
<th>Villasrubias</th>
<th>Fuente-guinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C inputs by rainfall</strong> (kg C/ha, yr)</td>
<td>69</td>
<td>63</td>
<td>61</td>
</tr>
<tr>
<td><strong>C inputs by throughfall + stemflow</strong> (kg C/ha, yr)</td>
<td>97</td>
<td>118</td>
<td>132</td>
</tr>
<tr>
<td><strong>Trunk growth</strong> (Mg C/ha, yr)</td>
<td>2.3</td>
<td>1.8</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>TOTAL</strong> (Mg C/ha, yr)</td>
<td>2.4</td>
<td>1.9</td>
<td>3.9</td>
</tr>
</tbody>
</table>
## C Losses from the Ecosystems

<table>
<thead>
<tr>
<th>Annual C losses</th>
<th>Navasfrías</th>
<th>Villasrubias</th>
<th>Fuente-guinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses of C by SOM mineralization (kg C/ha, yr)</td>
<td>420</td>
<td>460</td>
<td>910</td>
</tr>
<tr>
<td>Losses of C by runoff (kg C/ha, yr)</td>
<td>2.0</td>
<td>2.4</td>
<td>0</td>
</tr>
<tr>
<td>Losses of C by drainage (kg C/ha, yr)</td>
<td>44</td>
<td>57</td>
<td>23</td>
</tr>
<tr>
<td>Losses of C by the stream (kg C/ha, yr)</td>
<td>1.0</td>
<td>N. d.</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL (Mg C/ha, yr)</td>
<td>0.47</td>
<td>0.52</td>
<td>0.93</td>
</tr>
</tbody>
</table>
## Internal fluxes of C

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Navasfrías</th>
<th>Villasrubias</th>
<th>Fuenteguinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production inputs</strong></td>
<td>1.21</td>
<td>1.35</td>
<td>1.91</td>
</tr>
<tr>
<td>Biomass (Mg C/ha)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Litter mineralization outputs</strong></td>
<td>0.36</td>
<td>0.44</td>
<td>0.90</td>
</tr>
<tr>
<td>(Mg C/ha)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Annual stand litter</strong></td>
<td>0.85</td>
<td>0.91</td>
<td>1.01</td>
</tr>
<tr>
<td>(Mg C/ha, yr)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sol mineralization outputs</strong></td>
<td>0.78</td>
<td>0.90</td>
<td>1.81</td>
</tr>
<tr>
<td>Litter + soil (Mg C/ha)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Annual difference</strong></td>
<td>0.06</td>
<td>0.01</td>
<td>-0.80</td>
</tr>
<tr>
<td>(Mg C/ha, yr)</td>
<td>(understory negligible)</td>
<td>(understory negligible)</td>
<td>(understory production)</td>
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</tbody>
</table>
## Net C annual-flux & total C sequestered: Base line

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>Navasfrías</th>
<th>Villasrubias</th>
<th>Fuente-guinaldo</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual net input of C (flux)</strong></td>
<td>+ 2.4</td>
<td>+ 1.9</td>
<td>+ 3.9</td>
</tr>
<tr>
<td>(Mg C/ha, yr):</td>
<td>(2.3)</td>
<td>(1.8)</td>
<td>(3.8)</td>
</tr>
<tr>
<td><strong>Tree growth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL C SEQUESTERED</strong></td>
<td>164</td>
<td>117</td>
<td>111</td>
</tr>
<tr>
<td><strong>Above-ground biomass + Soil</strong></td>
<td>32 + 132</td>
<td>32 + 85</td>
<td>49 + 62</td>
</tr>
<tr>
<td><strong>(Mg C/ha)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Base line</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Soil liming (on surface)

Liming had a late soil effect. Some soil properties (mainly exchangeable $\text{Ca}^{2+}$) had significant changes three years after the addition of the liming-product, with scarce impact on the superficial waters. Carbonate dissolution depends heavily from the amount of precipitation (& biological activity)

There was not evidence of impact on tree nutrition.
In addition, soil erosion is negligible.
### Characteristics of water sediments (after liming)

<table>
<thead>
<tr>
<th>Years</th>
<th><strong>Before liming</strong></th>
<th>1998-99</th>
<th>1999-2000</th>
<th>2000-01</th>
<th>2001-04</th>
<th>Mean (3 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stones (kg/ha, yr)</td>
<td>No app.</td>
<td>N. d.</td>
<td>0</td>
<td>0.1</td>
<td>0.5</td>
<td>4.0/3</td>
</tr>
<tr>
<td>Soil (kg/ha, yr)</td>
<td>No app.</td>
<td>N. d.</td>
<td>0.8</td>
<td>1.5</td>
<td>2.6</td>
<td>21.6/3</td>
</tr>
<tr>
<td>pH (H₂O)</td>
<td>5.0</td>
<td>5.8</td>
<td>N. d.</td>
<td>6.7</td>
<td>5.4</td>
<td>5.9</td>
</tr>
<tr>
<td>SOC (mg C/g)</td>
<td>80.0</td>
<td>58.2</td>
<td>44.6</td>
<td>44.4</td>
<td>76.2</td>
<td>103</td>
</tr>
<tr>
<td>C/N</td>
<td>23.0</td>
<td>15.9</td>
<td>17.2</td>
<td>17.3</td>
<td>16.6</td>
<td>26.1</td>
</tr>
<tr>
<td>Available Ca (mg/kg)</td>
<td>335</td>
<td>758</td>
<td>4150</td>
<td>8850</td>
<td>511</td>
<td>1856</td>
</tr>
<tr>
<td>Available P (mg/kg)</td>
<td>14</td>
<td>6.6</td>
<td>N. d.</td>
<td>1.4</td>
<td>8.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

*Mean of 3 repeats  **Determined in July 1998; limed on September 5, 1999.*


THANKS FOR YOUR ATTENTION!

QUESTIONS...?
<table>
<thead>
<tr>
<th>Año hidrológico</th>
<th>Flujos</th>
<th>(mm año⁻¹)</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Precipitación</td>
<td>1655</td>
<td>88.0</td>
</tr>
<tr>
<td>96-97</td>
<td>Trascolación</td>
<td>1456</td>
<td>76.8</td>
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<tr>
<td></td>
<td>Db</td>
<td>1272</td>
<td>64.2</td>
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<td></td>
<td>Dss</td>
<td>1063</td>
<td>53.9</td>
</tr>
<tr>
<td></td>
<td>Dp</td>
<td>892</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>Arroyo</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Precipitación</td>
<td>2104</td>
<td>88.0</td>
</tr>
<tr>
<td>97-98</td>
<td>Trascolación</td>
<td>1852</td>
<td>80.3</td>
</tr>
<tr>
<td></td>
<td>Db</td>
<td>1690</td>
<td>73.0</td>
</tr>
<tr>
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<td>Arroyo</td>
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<tr>
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<td>Precipitación</td>
<td>957</td>
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<td>Trascolación</td>
<td>844</td>
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<td>Db</td>
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</tr>
<tr>
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<td>Dss</td>
<td>467</td>
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</tr>
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<td>Dp</td>
<td>318</td>
<td>0.0</td>
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<tr>
<td></td>
<td>Arroyo</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Precipitación</td>
<td>1572</td>
<td>88.1</td>
</tr>
<tr>
<td>Media</td>
<td>Trascolación</td>
<td>1384</td>
<td>76.4</td>
</tr>
<tr>
<td></td>
<td>Db</td>
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<tr>
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<td>Arroyo</td>
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### Characteristics of SOC

<table>
<thead>
<tr>
<th>Parámetros</th>
<th>Unidades</th>
<th>Horizontes</th>
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</thead>
<tbody>
<tr>
<td>Contenido de humedad</td>
<td>(mg g⁻¹)</td>
<td>Ab₁</td>
</tr>
<tr>
<td>Pérdidas por ignición</td>
<td>(mg g⁻¹)</td>
<td>Ab₂</td>
</tr>
<tr>
<td>C orgánico</td>
<td>(mg g⁻¹)</td>
<td>Bw</td>
</tr>
<tr>
<td>N total</td>
<td>(mg g⁻¹)</td>
<td></td>
</tr>
<tr>
<td>H total</td>
<td>(mg g⁻¹)</td>
<td></td>
</tr>
<tr>
<td>C/N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C extraíble (C ácido/base)</td>
<td>(mg g⁻¹)</td>
<td></td>
</tr>
<tr>
<td>C extraíble (relativo)</td>
<td>(% del C total)</td>
<td></td>
</tr>
<tr>
<td>C ácido</td>
<td>(% del C extraíble)</td>
<td></td>
</tr>
<tr>
<td>C hidrosólico</td>
<td>(% del C extraíble)</td>
<td></td>
</tr>
<tr>
<td>C fúngico</td>
<td>(% del C extraíble)</td>
<td></td>
</tr>
<tr>
<td>C húmico</td>
<td>(% del C extraíble)</td>
<td></td>
</tr>
</tbody>
</table>

Values:
- **Ab₁**: 251, 204, 77, 4, 14, 19, 31, 40, 10, 9, 7, 74
- **Ab₂**: 213, 149, 52, 3, 13, 17, 23, 44, 13, 12, 6, 69
- **Bw**: 133, 100, 8, 0.6, 12, 14, 5, 63, 17, 24, 16, 44
**Ratio Throughfall/Bulk precipitation**

<table>
<thead>
<tr>
<th>Tc / Pg</th>
<th>χ</th>
<th>COD</th>
<th>Cl</th>
<th>CTD</th>
<th>NOD</th>
<th>N-NH₄⁺</th>
<th>N-NO₃⁻</th>
<th>NTD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996/97</td>
<td>1.5</td>
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<td>1997/98</td>
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<td>1.2</td>
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<td>1.6</td>
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</table>

<table>
<thead>
<tr>
<th>Tc / Pg</th>
<th>POD</th>
<th>Pi</th>
<th>PTD</th>
<th>Ca²⁺</th>
<th>Mg²⁺</th>
<th>Na⁺</th>
<th>K⁺</th>
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<td>4.7</td>
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<tr>
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<th>Mn</th>
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<tbody>
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<td>-</td>
<td>-</td>
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<td>1.5</td>
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