SCIENTIFIC REPORT STSM

'The effect of pre-commercial thinning on the relationship between coarse roots and stem growth of stone pine (*Pinus pinea* L.)'

NWFP COST Action FP1203: European Non-Wood Forest Products Network

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1. Purpose of the STSM

The growth distribution (allocation pattern) between above and belowground components has not been deeply studied. Nevertheless, its knowledge could have great importance in environments with limited water/nutrient resources, because forest management may help plants to minimize the negative effects of water/nutrient reduction. Variation in the allocation patter could have a great impact in species as stone pine (*Pinus pinea* L.), mainly in fructification processes due to the high economic value of its pine cones.

So the main purpose of the Short Term Scientific Mission was to acquire some expertise in the analysis of growth partitioning trends (allometric analysis) in order to answer some question on this topic:

i) How is the relationship between the growth pattern of coarse roots and stem in *Pinus pinea*?

ii) Does competition released by thinning modify the growth allocation between root and shoot in *Pinus pinea*?

iii) How do climate conditions (dry years) modify biomass allocation to root versus shoot in *Pinus pinea*?

2. **Description of the work carried out during the Short Term Scientific Mission**

2.1. Data

40 trees coming from a pre-commercial thinning and pruning trial experiment were sampled for growth ring study and biomass estimation.
The experimental treatments were applied in autumn of 2006 and trees were sampled in autumn of 2013 when they were 17 years-old.
The aboveground part was cut and the root system excavated and extracted and both fractions were weighted. Measurements of diameter at the breast height (1.30 m) and total height were recorded, and sample disks were collected from the dbh and the main coarse roots (20-30 cm from their offset at the trunk) (Figure 1).
There were 9 trees sampled from unthinned- no pruned plots, 9 from unthinned and pruned plots, 10 from thinned and no pruned plots and 12 from thinned and pruned plots.
Annual growth ring width was measured in every sample disk, having each tree a combination of root and shoot growth series.

Figure 1. Sample disks from the diameter at the breast height and main roots where annual ring growth were measured.

Figure 2 is showing the annual ring width for each sample. Stem ring width varied from a minimum of 0.6 mm year^{-1} to a maximum of 17.4 mm year^{-1} and root ring width ranged from 0.1 to 10.9 mm year^{-1}.

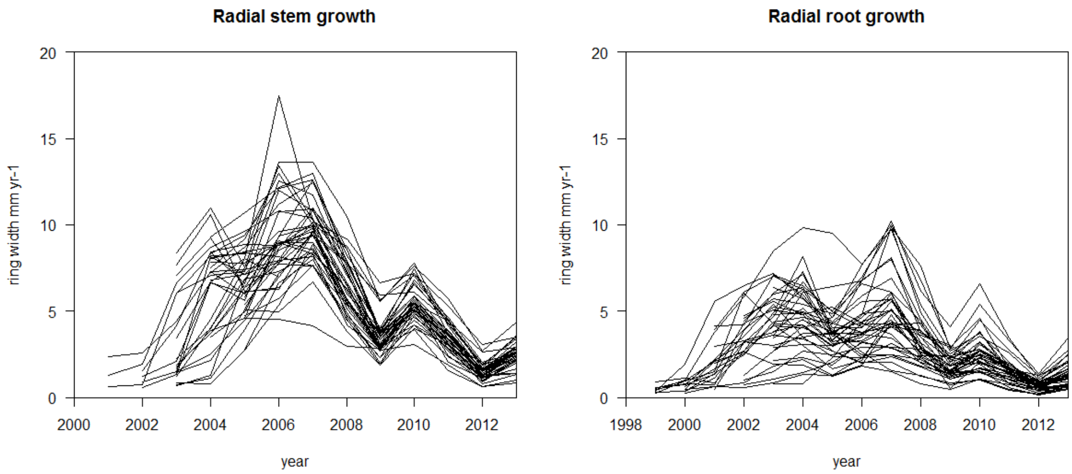

Figure 2. Courses of annual ring width for stem (left) and coarse roots (right)

In 2009 growth was reduced both from the stem and roots. Climatic conditions for this year showed that it was an arid year following the de Martonne (1926) index classification (index value of 11.04; annual precipitation= 237 mm; mean temperature: 12.3 ºC), being a dry and hot year. Allometric relationship could be compared for this dry year and the previous and subsequent years. Ring growth width range in 2009 was between 1.8 and 6.6 mm year^{-1} for stem and 1.1-4.4 mm year^{-1} for roots.

2.2. Methods

In order to answer the first question, root-shoot diameter was reconstructed using the annual growth increments and the diameters collected at the sample time. Temporal diameter series were presented in a double logarithmic scale and the slope of the series was compared with the isometric line (slope = 1), through fitting a linear mixed effect model (equation 1), having into account the data structure (plot, tree, root)

$$\ln(droot_{ijk}) = a_0 + a_1 \cdot \ln(dshoot_{ijk}) + \varepsilon_{ijk} \qquad [1]$$

where the indices *i*, *j*, *k* stand for plot, tree and root, respectively, *droot* is the root diameter and *dshoot* is the stem diameter.

The effect of the silvicultural treatments (thinning and pruning) in the relationship between root:shoot diameter was identified through the inclusion of these factors in the mixed model.

The modification of the annual root:shoot allometry was studied using the annual value of the slope for this relationship. The slope was calculated using the equation 2 (Pretzsch, 2010) for each tree and year. Then, the arithmetic mean for the slope was calculated by year for all trees together and finally by treatment in order to do comparisons.

$$\alpha'_{y,x} = \frac{\ln(y_{i+1}) - \ln(y_i)}{\ln(x_{i+1}) - \ln(x_i)} = \frac{\ln(y_{i+1}/y_i)}{\ln(x_{i+1}/x_i)} \quad [2]$$

where y_i is the root diameter in the year *i* and y_{i+1} is the root diameter in the year *i+1*; x_i is the stem diameter in the year *i* and x_{i+1} is the stem diameter in the year *i+1*.

Lloret et al. (2011) indices of resistance, recovery and resilience were used to compare the performance of trees under drought stress, in order to know the influence in diameter growth. These indices were calculated in each tree for the growth of the stem diameter and the root diameter, in relation with the growth of the year 2009 (dry year). *Resistance* (growth performance during the drought period) was calculated as the ratio between the growth in the dry year and the growth during the pre-drought period (mean of the growth of the previous two years). *Recovery* (ability to recover relative to the damage experienced during disturbance) was the ratio between the mean growth of the post-drought period (two years) and the growth in the dry year. *Resilience* (ability to return to the pre-drought growth level) was the ratio between the mean growth of the post-drought period (two years) and the mean growth of the previous period (two years).

All the statistical evaluations were conducted with the R software v.3.1.2 (R Development Core Team, 2014).

3. First results

3.1. Root:shoot allometry

The root-shoot diameter allometry is showed in figure 3. From this figure it is possible to identify that the slope of the trajectories is near the expected value of 1. A linear mixed effect model (equation 1) was fitted in order to find the mean slope. The found value was 0.94 (±0.02; p-value<0.0001). So, the relative growth rate of the root is lower that the growth rates of the corresponding shoot.

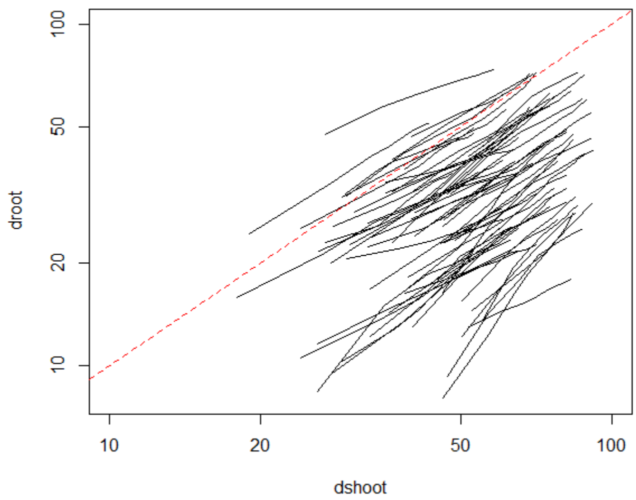

Figure 3. Relationship between root diameter (droot) and stem diameter (dshoot) in logarithmic scale. The dashed red-line is the line with slope =1 (isometric growth).

3.2. Treatment influence in the root:shoot allometry

In order to know if the root:shoot relationship may be modified by silvicultural operations, the selected treatments (pruning and thinning) were included in the mixed model analysis. Inclusion of all of them was significant. Results showed that the model slope value was 0.85 (±0.03; p-value<0.0001); thinning increases the slope value in 0.17 (±0.04; p-value<0.0001); pruning decreases the slope in 0.18 (±0.04; p-value<0.0001) and the interaction thinning:pruning increasing the slope value in 0.26 (±0.05; p-value<0.0001). Figure 4 is showing the graphical behavior of the relationships by treatment.

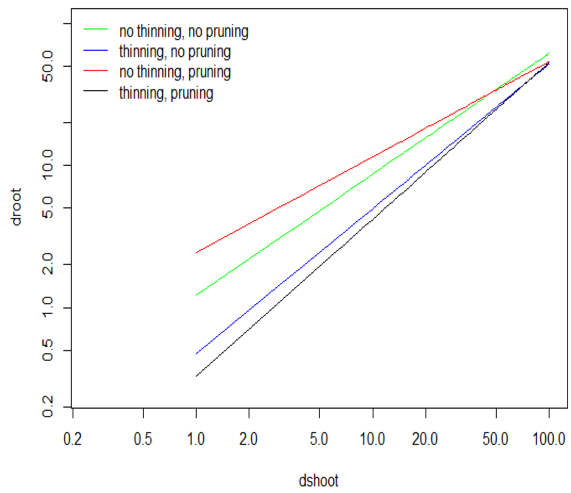

Figure 4. Models fitted for the different applied treatments.

Results were also showing that the intercept value was influenced by the treatments. There were an intercept reduction when thinning is applied (-0.95±0.23; p-value=0.0090), an intercept increase when pruning is applied (0.69±0.25; p-value=0.0404) and the interaction of thinning and pruning showed an intercept reduction of -1.05 (±0.33; p-value=0.0242). So, trees from thinned stands showed a lower ratio between diameter of the root: diameter of the shoot, although they presented a higher relative investment into root growth.

The inter-annual course of the allometric coefficients for the relationship between root:shoot is showed in the figure 5. Figures are lower than the expected 1.0 value (isometric growth between root and stem) except for the year 2013, so trees invested more resources in stem growth of than in root growth.

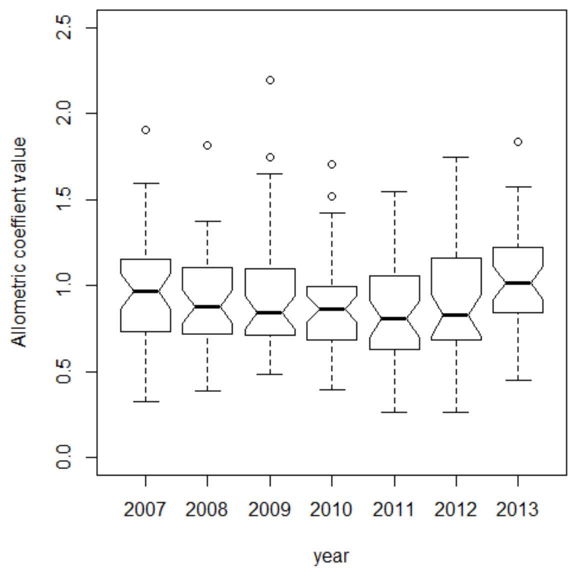

Figure 5. Distribution of the root-shoot allometry by year
for the studied trees (mean ± standard error).

Table 1 presents the values by treatment. Results from this table show that allometric values are higher in trees coming from thinned plots than unthinned plots. Also, thinned and pruned trees show a value higher than 1.0 each year, meaning these trees are investing more resources to root diameter growth that stem diameter growth.

Table 1. Annual value of the allometric coefficient by treatment and year and Tukey HSD test for mean comparison between treatments.

	2007	2008	2009	2010	2011	2012	2013
Unthinned + No pruned	0,8129 a	0,8127 a	0,7990 a	0,7594 a	0,7912 a b	0,7353 a	0,9346 a
Thinned + No pruned	1,2331 b	1,0150 a	0,9605 a b	0,8515 a	0,8332 a b	0,9352 a b	0,9312 a
Unthinned + Pruned	0,7559 a	0,7901 a	0,7842 a	0,7018 a	0,6529 a	0,7346 a	0,9011 a
Thinned + Pruned	1,0259 a b	1,0078 a	1,2003 b	1,1474 b	1,0061 b	1,1726 b	1,2661 b

3.3. Allometry modification by drought

Figure 2 is showing that the stem and root ring-growth in 2009 were reduced. Precipitation was lower than the mean in this year and temperature was higher than the mean value. Reduction of growth diameter was also identified in 2012, but the year 2009 was selected because is closer to the date when the treatments were applied and could be feasible to find some treatment effects in allometry.

Figures 5 (general trend for all trees) and table 1 (trees by treatment) did not show any significant variation in the tendency for the values of the allometric coefficient in the year 2009 (dry year) in comparison with previous and following years.

Comparison of the performance of trees to the drought of the year 2009 was done using indices of resistance, recovery and resilience indices (Lloret *et al.*, 2011). Values for these indices are shown in table 2.

Table 2. Resistance, recovery and resilience indices by treatment.

Indices	**Growth**	**Unthinned + No Pruned**	**Thinned + No Pruned**	**Unthinned + Pruned**	**Thinned + Pruned**
Resistance	Shoot	0.42 (0.15)	0.50 (0.12)	0.41 (0.06)	0.40 (0.08)
Recovery		1.50 (0.28)	1.17 (0.22)	1.48 (0.33)	1.33 (0.20)
Resilience		0.57 (0.26)	0.44 (0.06)	0.54 (0.08)	0.54 (0.11)
Resistance	Root	0.41 (0.09)	0.43 (0.12)	0.43 (0.08)	0.45 (0.12)
Recovery		1.41 (0.32)	1.05 (0.22)	1.30 (0.33)	1.23 (0.31)
Resilience		0.52 (0.15)	0.61 (0.09)	0.49 (0.12)	0.49 (0.13)

Both shoot and root diameter growth was reduced to values of 40-50% of the previous period (resistance values),

Resilience values show that there was a reduction of 43-56% in stem growth and 39-51% in root growth. Part of this decrease could be attributed to the decreasing age-related curve of the annual diameter increment (Figure 2). A detrended analysis could be applied in order to confirm this trend and to find differences between treatments.

4. **Future collaboration with host institution**

This Short Term Scientific Mission allowed to strengthen and consolidate the previous existing collaboration between the Chair for Forest Growth and Yield of the Technische Universität München (TUM) (Freising, Germany) and the Forest Research Centre of the Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA).

5. **Foreseen publications resulting from the STSM**

The results could help in understanding the growth partitioning between root and shoot in *Pinus pinea* in relation with the widespread silvicultural treatments applied (thinning and pruning). For this reason, we are considering to write a manuscript to submit to a SCI journal during this year. A tentative title could be '*Effect of pre-commercial thinning on the coarse root-shoot allometry of Pinus pinea* L.'

References

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