Pine stands of different years developing along the Latium coast are analysed considering plant and needle traits. The results underline that silvicultural practices reduce plant density favouring the natural growth pattern of the Pine: the largest structural changes are observed between 15 and 34 years old stands, by Pine stem height elongation and the increased canopy volume. Crown height increases up to 34 years then decreasing at 104 years old stands. LAI changes with stand density and Pine developmental stage. Pine biomass changes accordingly, reaching the highest value at 104 years old stands. Needles morphology varies significantly between one and two year old needles. LMA shows the highest value in 34 years old stands. SNM has the highest value in two years old needles. The discriminant analysis underlines that plant biomass and LAI are the most discriminant traits. The long-term monitoring may be easily achieved by LAI measurements which can be converted into biomass values by their correlation.

Key words: LAI, LAD, LMA, biomass, crown volume

Parole chiave: LAI, LAD, LMA, biomassa, volume della chioma

1. Introduction
Vegetation structure results from the interactions of several variables acting at different levels. Several reports identify leaf area index (LAI) as the most important variable for characterizing vegetation structure and functioning for global researches, including plant productivity (Gratani and Crescente 2000; Wang et al. 2007). Since LAI changes with forest type and developmental stages, maximum LAI is a good estimator of maximum biomass accumulation (Shao et al. 1995). Silvicultural practices determine changes in forest structure, interfering with self-regulating processes, and having considerable influence on its stability (Covone and Gratani 2006). Thus, new vision of landscape ecology requires long-term research to understand ecosystems dynamics, and management should allow specific conservation goals, according to environmental resources. Consequently, vegetation traits, including species composition and plant structure may be used to carry out ecosystems inventory giving information on the status, and the possible time-scale of plant response to perturbations. *Pinus pinea* L. is largely distributed in the Mediterranean basin; it is a heliophilous and thermophilous species, it is able to build stable forests on degraded lands (Plaisance 1977), and it has ecological, social and economic values (Court-Picon et al. 2004). The main objective of the present research was to analyse *P. pinea* L. structural plant and leaf traits changing with age, and in response to silvicultural practices.

2. Materials and Methods
2.1 Study area and stand structure
The study was carried out in the *Pinus pinea* L. plantations developing within the Castelporziano Estate (41°45’N; 12°26’E, Rome). The climate of the area was of Mediterranean type and most of its annual rainfall was distributed in autumn-winter. Pine stands of 15, 27, 34, and 104 years old were analysed in the years 1995-1997, and 400 m² each areas were randomly selected (4 areas per each age stand). Tinning was carried out in 15 and 34 years old stands (Management Plain of the Estate). Measurements of plant structure included: plant (H) and crown height (Hc), stem diameter at breast height (DBH), and stand density. Total basal area (TBA) was calculated. Crown volume (Vc) was calculated by approximating each crown to a simple geometric solid. Non destructive measurements
were carried out in the sample areas, where all plants were measured. Plant biomass (PB) was determined by destructive measurements carried out in three sub-sample areas (100 m² each), cutting at random three representative plants subdivided into stem, branches, and leaves. They were weighed in the field, and sub-samples were oven-dried at 105 °C to constant weight to realize the conversion of field fresh weight to dry weight. Dry weights of the harvested plants were multiplied for the total number of plants to obtain total stand biomass. Leaf area index (LAI) was estimated (per each age) by the “LAI 2000 Plant Canopy Analyzer” (LI-COR Inc., Lincon, USA). The correction factor \( R = 0.57 \) proposed by Stenberg et al. (1994) for conifer canopies was applied. Leaf area density (LAD) was calculated by the ratio of LAI and \( H_c \) (Küppers, 2003).

2.2 Leaf morphology

One and two years old needles (5 needles for 4 representative plants in each age stands) were collected in September from the external crown portion of each plant. Measurements included needle area (NA) by the Image Analysis System (Delta –T Devices, UK), dry mass (DM) when oven-dried at 80°C to constant mass, and length (NL). The leaf mass area (LMA) was calculated by the ratio between dry mass and needle area, and the specific needle mass (SNM) by the ratio between the dry mass and needle length. Needle thickness (NT) was measured by a digital calliper (Digilog).

2.3 Statistical analysis

Statistical differences in the considered parameters were determined by the analysis of variance (ANOVA) and Tukey test for multiple comparisons. Analysis of regression was carried out to evaluate the correlation among plant biomass and LAI. Moreover, structural plant and morphological needle traits were subjected to stepwise discriminant analysis to evaluate the most discriminant parameters among the different stand age. At each step, all traits were reviewed in order to evaluate which one contributed most to the discrimination, according to Menalled and Kelty (2001). All statistical tests were performed using a statistical software package (Statistica Statsoft, USA).

3. Results

3.1 Plant structure

Plant height ranged from 3.2±0.2 m (15 years old stands) to 23.2±0.4 m (104 year old stands) and crown height increased up to 27 years old plants, then significantly decreasing (15 %) (Fig. 1A); crown volume reached the highest value (101 m³) at 104 years old plant (Fig. 1B). Stand density ranged between 1600 ind ha⁻¹ (15 years old stands) to 74 ind ha⁻¹ (104 years old stands). Total plant biomass varied between 49±3 tons ha⁻¹ (15 years old stands) and 256±5 tons ha⁻¹ (104 years old stands) (Fig. 1C). ABT ranged from 8.4±0.06 m² ha⁻¹ (15 years old stands) to 41.9±0.20 m² ha⁻¹ (104 years old stands). LAI had the highest value (3.1) in the 34 years old stands, decreasing 52% in 104 years old ones. LAD had the highest values (1.01±0.07 m⁻¹) in 15 years old stands and the lowest (0.23±0.02 m⁻¹) in 27 years old ones (Fig. 1D).

3.2 Needle morphology

Needle morphology varied significantly between one and two years old needles: two years old leaves had a significantly higher mass (181%), area (133%) and length (88 %) than one years old ones (Tab. 1). NT had the same trend. LMA showed the highest value (35.7±1.8 and 42.4±1.7 mg cm⁻² in one and two years old needles, respectively) at 34 years. SNM had the highest value in two years old needles.

3.3 Statistical analysis

A significant (p<0.05) correlation between plant biomass and LAI was found (plant biomass= -112LAI² + 463LAI-253, \( R = 0.50 \)). The Discriminant analysis showed that plant biomass, LAI, \( V_c \), \( H \), DM and NL were the most discriminant traits (Wilks’s lambda was 2.1 \( 10^{-7} \), 4.8 \( 10^{-7} \), 7.2 \( 10^{-8} \), 2.4 \( 10^{-8} \), 2.2 \( 10^{-8} \) and 1.9 \( 10^{-8} \), respectively).
Fig. 1. Structural traits (mean value ± S.E.) of the considered Pine stands: H = plant height; Hc = crown height; Cv = crown volume; PB = plant biomass; LAI = leaf area index; LAD = leaf area density. For each considered traits mean values with different letters are significantly different (ANOVA, \( p < 0.05 \)).

<table>
<thead>
<tr>
<th>Traits</th>
<th>Needle Age (years)</th>
<th>Stand Age (years)</th>
<th>Mean value</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM (mg)</td>
<td></td>
<td>15</td>
<td>36.7±2.2</td>
<td>1741.4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>119.6±12.9</td>
<td>118.7±12.4</td>
<td></td>
</tr>
<tr>
<td>NA (cm²)</td>
<td>1</td>
<td>1.2±0.2</td>
<td>1.2±0.1</td>
<td>1309.7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.8±0.4</td>
<td>2.8±0.3</td>
<td></td>
</tr>
<tr>
<td>NL (mm)</td>
<td>1</td>
<td>6.9±0.6</td>
<td>6.5±0.4</td>
<td>1533.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12.5±0.9</td>
<td>12.9±0.8</td>
<td></td>
</tr>
<tr>
<td>LMA (mg cm²)</td>
<td>1</td>
<td>35.7±1.8</td>
<td>35.3±1.7</td>
<td>707.6</td>
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<tr>
<td></td>
<td>2</td>
<td>42.4±1.7</td>
<td>40.5±1.1</td>
<td></td>
</tr>
<tr>
<td>SNM (mg cm⁻³)</td>
<td>1</td>
<td>6.0±0.4</td>
<td>6.3±0.3</td>
<td>1831.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9.5±0.4</td>
<td>9.2±0.4</td>
<td></td>
</tr>
<tr>
<td>NT (mm)</td>
<td>2</td>
<td>1.20±0.05</td>
<td>1.18±0.50</td>
<td>639.6</td>
</tr>
</tbody>
</table>

Table 1. Morphological traits (mean value ± S. E.) of 1 and 2 years old needles of the considered Pine stands. DM = dry mass; NA = needle area; NL = needle length; LMA = leaf area mass; SNM = specific needle mass; NT = needle thickness. Mean value of 1 and 2 years old needle and F test value are shown.
4. Discussion

The results on the whole underline that silvicultural practices reduce plant density, favouring the natural growth pattern of the *P. pinea*: the largest structural changes are observed between 15 and 34 years old plants, by the increased stem height and canopy volume. Crown height increases up to 34 years decreasing 15% at 104 years old. LAI changes with stand density and developmental stage. The highest LAI is reached in 34 years old stand, decreasing 52% in 104 years old stand, by the second tinning, and the value is in accordance to the results of Escudero and Mediavilla (2003). Pine biomass, and ABT changed accordingly, and they are in accordance to the results of Arévalo et al. (2005). Maximum LAI might be used as a good estimator of maximum biomass accumulation by the significant correlation between the two variables. LMA varies significantly between one and two years old needles showing the highest value (35.7±1.8 and 42.4±1.7 mg cm⁻² in one and two years old needles, respectively) at 34 years of age, by its highest leaf biomass accumulation capability. SNM has the highest value in two years old needles, indicating the reserves dynamic in evergreen needles (Kimura 1992). There are significant correlations among the considered plant and needle traits. Moreover, the discriminant analysis underlines that plant biomass and LAI are the most discriminant traits and that *P. pinea* stands of different age have a pattern of separation along the two canonical functions, correlated to biomass and LAI. Many predictions of future climate include an expectation that changes in average value of climatic variables may modify the intensity and interaction of environmental stresses on plants. Consequently, properties of vegetation may be used to carry out ecosystem inventories giving information on the status and impact of stress factors on natural resources. The long-term monitoring may be easily achieved by LAI measurements which can be converted into biomass values by their correlation; LAI may also be used to monitor early symptoms of stress on forests.

References


