

# Evaluation of aboveground and belowground phytomasses of cork oak trees (*Quercus suber*) and aboveground phytomass of shrubs at Ain Snoussi, Tunisia\*

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\* This paper was funded in the frame of the research project *Sustainable silvo-pastoral management models in Mediterranean forests: Application on cork oak forest in Spain (Cadiz) and Tunisia (Ain Draham)*. We are grateful to the Spanish Agency for International Cooperation (AECI) and the Tunisian Ministry of Research which have contributed funding to this research. We would also like to thank the reviewers for their contribution.

## ABSTRACT

The overstory and understory aboveground phytomasses of a cork oak forest located in the Ain Snoussi region (northwest Tunisia) were quantified in order to estimate terrestrial C storage. Separating different tree components, measurements of phytomasses as well as allometric parameters were taken on trees located in different plots. Fitted allometric equations allowed the best predictive variables of tree component phytomasses to be selected. Tree diameter at breast height (DBH) was the best predictive parameter. Cork oak trees sequestered about 426.477 t CO<sub>2</sub> ha<sup>-1</sup> above and underground. The increments in different components of cork oak trees were calculated through chronological age. To evaluate shrub phytomass and yield, dry above-ground phytomass of shrubs for each type of plant was calculated by applying direct and indirect methods to data for various biometric variables, including height and maximum and minimum diameters. The results showed that the shrubs' phytomass in this terrestrial ecosystem was about 9.053 t CO<sub>2</sub> ha<sup>-1</sup>.

**Key words:** phytomass, *Quercus suber* L., shrubs, net carbon dioxide fixation, Tunisia.

## 1. INTRODUCTION

In recent decades, the increase in atmospheric concentration of greenhouse gases such as carbon dioxide and methane is the consequence of man's harmful activities (e.g., vegetation clearing, burning of fossil fuels). These greenhouse gases absorb thermal infrared radiation emitted from the earth's surface and warm the earth. This natural process is certainly essential for life to exist since it maintains a mean temperature of 15 °C, instead of -18 °C. However, the increase in greenhouse gases is bringing about a global climate change or "global warming", possibly causing more extreme weather patterns (droughts, (sand) storms, floods, cyclones), continental ice sheet thawing, rising sea level, adaptation problems in native vegetation to the fast climate change (lack of natural regeneration, desertification), and epidemiological effects (changes in infested area and in virulence of biotic agencies).

Plants, especially forest trees, take carbon dioxide (CO<sub>2</sub>) from the atmosphere through photosynthesis, and store ("sink") carbon in living (leaves, branches, trunk, roots) and dead organic matter (leaf litter and other decomposing matter) above and below the ground. This natural process, known as sequestration, helps to minimize global warming.

In 1997, industrialized countries signed the Kyoto Protocol, an agreement aimed at tackling global climate change and reducing emissions. Following the agreement, carbon sequestration, especially in forest phytomass, has been systematically evaluated.

Estimation of carbon sequestration in Mediterranean forests is rare. The main purpose of this paper was to quantify the carbon storage in the overstory and understory aboveground phytomasses of a cork oak forest located in northwest Tunisia, an emerging country conscious of the global warming problem. The annual phytomass of the different components of cork oak trees and shrubs were also estimated.

## 2. MATERIAL AND METHODS

### 2.1. STUDIED SITE

The studied forest was located at Ain Snoussi (Altitude: 150-650 m) in the Kroumirie region. It covered a surface of 3.735 ha and cork oak trees occupied only 2.424 ha. The mean annual rainfall was 1.006 mm and the mean annual temperature was 17,5 °C, while the mean minimum temperature of the coldest month and the mean maximum temperature of the hottest month were 7,2 °C and 31,4 °C, respectively. According to the biogeographic climate classification of Emberger (Emberger, 1955), the site belongs to a humid Mediterranean climate.

### 2.2. METHODOLOGY

Ninety-one circular plots were randomly selected for this study. Each plot occupied a surface of 400 m<sup>2</sup>.

Diameters at breast height (DBH) of cork oak trees located in each plot were measured in order to establish the graph of diameter distribution in terms of trees per unit area (hectare).

Tree chronological age was assessed on 59 standard trees by counting growth rings in woody sections chopped at 30 cm of stem height. A mathematical relationship (linear, parabolic, polynomial, power, logarithmic or exponential) was afterward fitted between chronological age and diameter at breast height (DBH).

### 2.2.1. Cork oak phytomass estimation

Phytomass of individual cork oak tree components (trunk, branches, twigs, leaves, trunk and branch corks, and roots) was estimated through the mathematical relationships already fitted between these component phytomasses and DBH, established in a stand (Ben Metir) close to the studied site (Sebei *et al.*, 2001) (Table 1) which has same climate. Moreover, the canopy covering, density and basal area in Ain Snoussi and Ben Metir stands were comparable.

**TABLE 1.** Fitted allometric equations for cork oak tree phytomass components (Y in Kg) in relation to diameter at breast height (DBH in cm) in Ben Metir plots

| Above-ground phytomass | Equations                        | N (a) | r (b)    | Number |
|------------------------|----------------------------------|-------|----------|--------|
| Trunk wood             | $Y=0,7487DBH^{1,8579}$           | 12    | 0,964*** | (1)    |
| Trunk cork             | $Y=0,2387DBH^{1,9555}$           | 12    | 0,955*** | (2)    |
| Branch wood            | $Y=0,1949DBH^{1,6027}$           | 11    | 0,987*** | (3)    |
| Branch cork            | $Y=0,1275DBH^2-0,6083DBH+3,3126$ | 12    | 0,956*** | (4)    |
| Twigs                  | $Y=0,0743DBH^2-0,7362DBH+6,5845$ | 11    | 0,951*** | (5)    |
| Leaves                 | $Y=0,502DBH-1,7336$              | 12    | 0,990*** | (6)    |
| Roots                  | $Y=0,4912DBH-1,6631$             | 12    | 0,992*** | (7)    |
| Reproduction cork      | $Y=0,119DBH^{1,9625}$            | 6     | 0,978*** | (8)    |

(a) Number of samples.

(b) Values were significantly different from zero at level  $\alpha=0,001$

FUENTE: Sebei *et al.*, 2001.

At stand level, tree component phytomasses per hectare were estimated by applying the relationships to each DBH class and taking into account the number of trees per DBH class:

$$B = \sum n_i b_i \quad (9)$$

$n_i$  and  $b_i$  are, respectively, the number of cork oak trees and the tree component phytomasses corresponding to the DBH class  $i$ .

The percent of carbon in cork oak tree dry matter is about 47,5% (Montero *et al.*, 2003), so the calculated phytomasses were converted into C storage through a multiplicative coefficient of 0,475. Afterwards, the sequestered CO<sub>2</sub> was obtained by multiplying the amount of C storage per 3,67 (= 44/12). Carbon sequestration was estimated only using annual production of trees and shrubs. Saprophyte respiration and soil organic matter were not considered in this study.

### 2.3. CORK OAK PHYTOMASS PRODUCTIVITY

The phytomass components of the 59 harvested trees were unfortunately not measured. For this reason, the DBH-Age relationship established for the 59 trees was used to estimate the age of 12 trees which had already been harvested in a nearby stand at Ben Metir (Sebei *et al.*, 2004) and mathematical relationships between age and tree component phytomasses were afterwards fitted.

DBH-Age relationship was used to convert DBH classes into age classes, and Age-Tree component phytomass relationships helped to estimate annual phytomass for each age class.

Cork is harvested every twelve years. At the stand level and during the last twelve years, the annual phytomass per hectare of the different tree components were estimated by applying the following formula:

$$\frac{\Delta cB}{\Delta t} = \sum_i n_i \frac{cb_i}{12} \text{ for reproduction cork} \quad (10)$$

$\frac{cb_i}{12}$  (kg yr<sup>-1</sup>) is the annual reproduction cork yield of class  $i$  mean tree deduced from the central DBH  $D_i$  of class  $i$ .

$$\frac{\Delta B}{\Delta t} = \frac{1}{12} \sum_i n_i [b_{i,t} - b_{i,t-12}] \text{ for leaves and perennial components} \quad (11)$$

$b_{i,t-12}$  and  $b_{i,t}$  are, respectively, component phytomasses (in kg) of a mean cork oak tree of class  $i$  at the beginning time ( $t - 12$ ) and at the end ( $t$ ) of the cork stripping rotation.

## 2.4. SHRUB PHYTOMASS

Vegetation development was not the same in the studied forest. Because C storage differs according to the state of vegetation development, two plots of 400 m<sup>2</sup> large per state of vegetation degradation (low, medium and high) were included in estimates of C storage and productivity of Ain Snoussi forest. The plant maximum height, largest and smallest crown diameters, as well as plant shape were monitored.

One squared parcel 5 m in size was randomly selected in each plot in order to estimate total aboveground shrub phytomass. All the plants were chopped off at ground level; the wood as well as the leaves were separated and weighed. To determine the dry weight of the whole plant, one sample of leaves and another of wood from each plant were dried at 75° C for 4 days.

Allometric equations predicting aboveground shrub phytomass were afterward developed for the eight dominant species of the maquis. Sixty-nine plants were used for this purpose. These plants were split up as follows: 15 *Erica arborea*, 12 *Phillyrea angustifolia*, 11 *Myrtus communis*, 7 *Arbutus unedo*, 6 *Viburnum tinus*, 6 *Cistus salviifolius*, 6 *Daphne gnidium* and 6 *Urginea maritima*.

The plant biovolume was estimated through two possible morphotype functions (Blanco and Navarro, 2003):

$$\text{Conical morphotype: } V = \frac{1}{3} \pi \times h \times \frac{D_m^2}{4} \quad (12)$$

$$\text{Semi-spherical morphotype: } V = \frac{4}{3} \pi \times h \times \frac{D_m^2}{4} \quad (13)$$

Where  $h$  is the maximum height and  $D_m$  the average of maximum and minimum crown plant diameters.

The productivity of the shrubs was estimated using the age of *Arbutus unedo* plants as the age of the studied scrubland. This age was determined through ring counting on tree woody disks chopped off at the base of the main stem. It was impossible to analyze the age of the other species because of grazing and shrub clearing by local inhabitants.

A relationship between biovolume of *Arbutus unedo* and age was fitted and applied for all *Arbutus unedo* plants in the studied plots. Afterwards, the medium age was calculated.

The productivity (kg/ha/year) was estimated using the following formula:

$$\text{Productivity} = \frac{\text{Shrub Biomass (t / ha)}}{\text{medium age of shrubs (years)}} \times 1000 \quad (14)$$

Measurements and samplings were done in the spring.

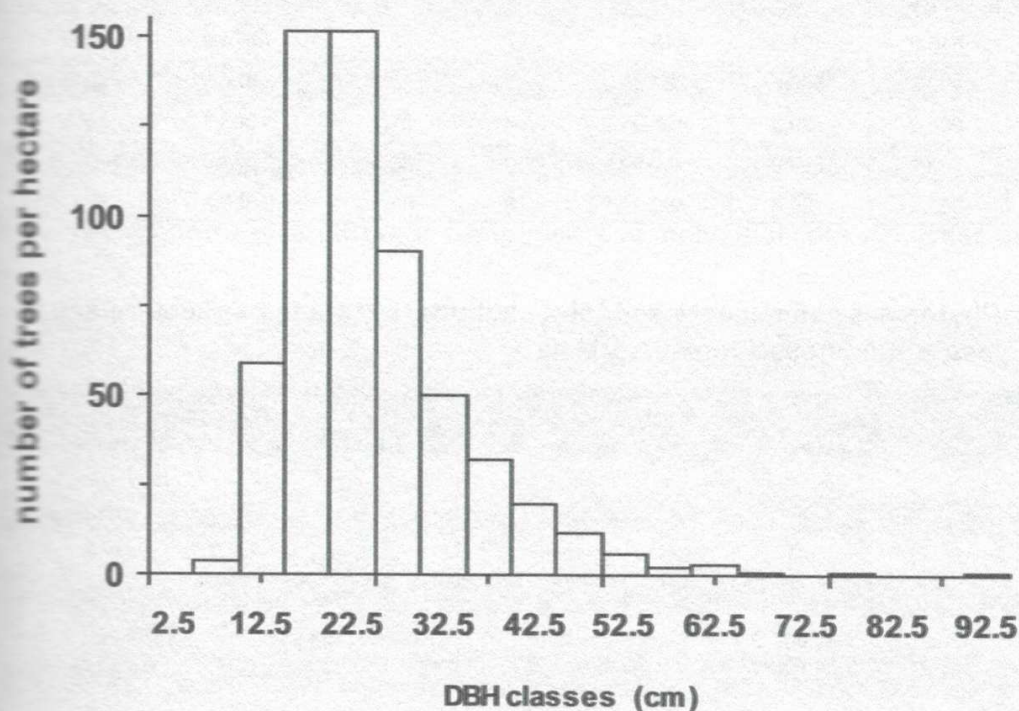
## 2.5. STATISTICAL TREATMENTS

Mathematical relationships fitted between phytomasses and tree or shrub parameters (Age, DBH) were performed using Microsoft® Excel 2000® software. The best fit was selected by considering the correlation coefficient (Dagnelie, 1975).

## 3. RESULTS

Figure 1 shows the DBH distribution of trees in terms of trees per hectare for the 91 studied plots in Ain Snoussi forest. The largest numbers of oak trees belonged to 20 and 25 cm DBH classes. The DBH distribution did not approximate the normal bell-shaped curve; it was rather dissymmetrical with a typically abrupt slope on the left-hand side of the diagram. This may have been caused by the continual loss of small trees from overgrazing and competition. The minimum and maximum DBH classes were 10 cm and 92,5 cm, respectively.

**FIGURE 1.** Diameter distribution in terms of mean numbers of cork oak trees per hectare in the 91 studied plots in Ain Snoussi forest



Component phytomasses and total phytomass (above and below-ground) in individual cork oak trees per DBH class estimated through the relationships in Table 1 were shown in Table 2. The aboveground part of the cork oak tree contained a larger phytomass and sequestered a larger  $\text{CO}_2$  amount than the underground part. The trunk stored up the largest phytomass and  $\text{CO}_2$  amounts, whereas leaves and twigs sequestered smaller amounts.

Component phytomasses and total phytomass of cork oak trees at stand level were shown in Table 3. The cork oak trees located in the studied ecosystem stored about 426,477 t  $\text{CO}_2$  per hectare ( $234 \text{ t DM ha}^{-1}$ ) 81,4% of which was sequestered in the above-ground part of the trees. A large amount of  $\text{CO}_2$  was stored in trunk and branch corks.

**TABLE 2.** Phytomass components and total phytomass storage in individual cork oak trees per DBH class in Ain Snoussi forest (kg DM (dry matter)/tree)

| DBH class<br>(cm) | Above-ground phytomass (kg DM/tree) |       |       |          |            |        | Total<br>above-ground<br>(kg DM) | Root<br>Phytomass<br>(kg DM) | Total<br>phytomass<br>(kg DM) |
|-------------------|-------------------------------------|-------|-------|----------|------------|--------|----------------------------------|------------------------------|-------------------------------|
|                   | Trunk                               |       |       | Branches |            |        |                                  |                              |                               |
|                   | Word                                | Cork  | Word  | Cork     | Twigs-2 cm | Leaves |                                  |                              |                               |
| 10                | 10.3                                | 8.5   | 5.0   | 4.4      | 1.7        | 1.7    | 31.6                             | 6.2                          | 37.8                          |
| 15                | 29.0                                | 23.6  | 13.6  | 7.8      | 3.9        | 3.8    | 81.7                             | 16.9                         | 98.6                          |
| 20                | 54.9                                | 44.8  | 27.1  | 14.0     | 6.0        | 5.9    | 152.7                            | 32.7                         | 185.4                         |
| 25                | 87.8                                | 71.7  | 45.2  | 23.1     | 7.9        | 7.8    | 243.5                            | 53.6                         | 297.1                         |
| 30                | 127.3                               | 103.9 | 68.0  | 34.8     | 9.8        | 9.7    | 353.5                            | 79.4                         | 432.9                         |
| 35                | 173.3                               | 141.6 | 95.1  | 49.1     | 11.6       | 11.5   | 482.2                            | 110.3                        | 592.5                         |
| 40                | 225.7                               | 184.3 | 126.4 | 66.0     | 13.5       | 13.2   | 629.1                            | 146.0                        | 775.1                         |
| 45                | 284.1                               | 232.0 | 162.0 | 85.4     | 15.3       | 15.0   | 793.8                            | 186.7                        | 980.5                         |
| 50                | 348.6                               | 284.7 | 201.8 | 107.2    | 17.0       | 16.7   | 976.0                            | 232.3                        | 1208.3                        |
| 55                | 419.1                               | 342.1 | 245.7 | 131.5    | 18.7       | 18.3   | 1,175.4                          | 282.7                        | 1,458.1                       |
| 60                | 495.4                               | 404.4 | 293.6 | 158.1    | 20.4       | 20.0   | 1,391.9                          | 337.9                        | 1,729.8                       |
| 65                | 577.4                               | 471.4 | 345.5 | 187.1    | 22.1       | 21.6   | 1,625.1                          | 398.0                        | 2,023.1                       |
| 70                | 665.1                               | 543.0 | 401.5 | 218.4    | 23.7       | 23.2   | 1,874.9                          | 462.9                        | 2,337.8                       |
| 80                | 857.2                               | 700.0 | 525.0 | 287.8    | 27.0       | 26.5   | 2,423.5                          | 607.1                        | 3,030.6                       |
| 95                | 1,186.6                             | 968.9 | 739.3 | 409.0    | 31.8       | 31.1   | 3,366.7                          | 859.2                        | 4,225.9                       |

**TABLE 3.** Phytomass components and total phytomass storage per DBH class in Ain Snoussi forest (t DM ha<sup>-1</sup>)

| DBH class (cm) | Number of trees per hectare | Total above-ground (t DM ha <sup>-1</sup> ) | Root Phytomass (t DM ha <sup>-1</sup> ) | Total phytomass (t DM ha <sup>-1</sup> ) |
|----------------|-----------------------------|---------------------------------------------|-----------------------------------------|------------------------------------------|
| 10             | 4                           | 0.127                                       | 0.025                                   | 0.152                                    |
| 15             | 59                          | 4.820                                       | 0.998                                   | 5.818                                    |
| 20             | 151                         | 23.071                                      | 4.943                                   | 28.014                                   |
| 25             | 151                         | 36.769                                      | 8.094                                   | 42.863                                   |
| 30             | 90                          | 31.807                                      | 7.153                                   | 39.960                                   |
| 35             | 50                          | 24.110                                      | 5.516                                   | 29.626                                   |
| 40             | 32                          | 20.131                                      | 4.674                                   | 24.805                                   |
| 45             | 20                          | 15.876                                      | 3.735                                   | 19.611                                   |
| 50             | 12                          | 11.712                                      | 2.788                                   | 14.500                                   |
| 55             | 6                           | 7.052                                       | 1.696                                   | 8.748                                    |
| 60             | 2                           | 2.784                                       | 0.676                                   | 3.460                                    |
| 65             | 3                           | 4.875                                       | 1.194                                   | 6.069                                    |
| 70             | 1                           | 1.875                                       | 0.463                                   | 2.338                                    |
| 80             | 1                           | 2.424                                       | 0.607                                   | 3.031                                    |
| 95             | 1                           | 3.367                                       | 0.859                                   | 4.226                                    |
| Total          | 583                         | 190.799                                     | 43.421                                  | 234.220                                  |

A power equation fitted the best tree chronological age (A) in function of DBH:

$$A = 18.339DBH^{0.4844} \quad (n=59, r=0.644***)$$

(15)

This equation was used to convert DBH into Age and again fit equations of cork oak tree phytomass components as a function of age (Table 6). A power equation best fitted above-ground phytomass, as well as trunk wood and cork, roots, and reproduction cork. A parabolic equation was the best fit for branch wood and cork, and linear equation for twigs and leaves.

**TABLE 4.** Fitted equations of cork oak tree phytomass components (Y in Kg) as a function of tree age (A in years) or DBH (in cm; only for reproduction cork)

| Compartments           | Equations              | N (a) | r (b)    | Number |
|------------------------|------------------------|-------|----------|--------|
| Above-ground phytomass | $Y=0,0026A^{2,632}$    | 12    | 0,926*** | (16)   |
| Trunk wood             | $Y=0,0006A^{2,7099}$   | 12    | 0,916*** | (17)   |
| Trunk cork             | $Y=0,0015A^{2,2724}$   | 11    | 0,966*** | (18)   |
| Branch wood            | $Y=0,01714A^2$         | 12    | 0,917*** | (19)   |
| Branch cork            | $Y=0,00924A^2$         | 11    | 0,958*** | (20)   |
| Twigs                  | $Y=0,001A^2+0,0269A$   | 12    | 0,972*** | (21)   |
| Leaves                 | $Y=0,0009A^2+0,0374A$  | 12    | 0,980*** | (22)   |
| Roots                  | $Y=0,0003A^{2,77}$     | 6     | 0,974*** | (23)   |
| Reproduction cork      | $Y=0,0098DBH^{1,4756}$ | 8     | 0,972*** | (24)   |

(a) Number of samples.

(b) Values were significantly different from zero at level  $\alpha=0,001$

\*\*\*  $\alpha=0,001$ .

**TABLE 5.** Annual phytomass in different components of individual cork oak trees in Ain Snoussi (mean: kg DM/tree/yr)

| Tree<br>number | Above-ground annual phytomass components (kg DM/ tree/yr) |      |          |      |            |        | Roots (kg<br>DM/tree/yr) | Annual total<br>phytomass<br>(kg DM/tree/yr) |                       |
|----------------|-----------------------------------------------------------|------|----------|------|------------|--------|--------------------------|----------------------------------------------|-----------------------|
|                | Trunk                                                     |      | Branches |      |            |        |                          |                                              | Total<br>above-ground |
|                | Wood                                                      | Cork | Wood     | Cork | Twigs<2 cm | Leaves |                          |                                              |                       |
| 101            | 1,57                                                      | 0,67 | 1,55     | 0,83 | 0,11       | 0,11   | 4,94                     | 1,05                                         | 5,99                  |
| 102            | 2,37                                                      | 1,03 | 1,91     | 1,03 | 0,14       | 0,13   | 6,61                     | 1,43                                         | 8,04                  |
| 103            | 3,05                                                      | 1,42 | 2,22     | 1,20 | 0,15       | 0,15   | 8,19                     | 1,81                                         | 10,00                 |
| 104            | 3,71                                                      | 1,84 | 2,49     | 1,34 | 0,17       | 0,16   | 9,71                     | 2,18                                         | 11,89                 |
| 105            | 4,34                                                      | 2,28 | 2,73     | 1,47 | 0,18       | 0,18   | 11,18                    | 2,54                                         | 13,72                 |
| 106            | 4,95                                                      | 2,74 | 2,94     | 1,59 | 0,19       | 0,19   | 12,60                    | 2,89                                         | 15,49                 |
| 107            | 5,55                                                      | 3,21 | 3,14     | 1,69 | 0,20       | 0,20   | 13,99                    | 3,24                                         | 17,23                 |
| 108            | 6,12                                                      | 3,70 | 3,31     | 1,79 | 0,22       | 0,21   | 15,35                    | 3,58                                         | 18,93                 |
| 109            | 6,68                                                      | 4,21 | 3,48     | 1,87 | 0,23       | 0,21   | 16,68                    | 3,92                                         | 20,60                 |
| 110            | 7,23                                                      | 4,72 | 3,63     | 1,96 | 0,23       | 0,22   | 17,99                    | 4,25                                         | 22,24                 |
| 111            | 7,76                                                      | 5,24 | 3,77     | 2,03 | 0,24       | 0,23   | 19,27                    | 4,58                                         | 23,85                 |
| 112            | 8,27                                                      | 5,78 | 3,90     | 2,10 | 0,25       | 0,24   | 20,54                    | 4,91                                         | 25,45                 |
| 113            | 8,77                                                      | 6,32 | 4,02     | 2,17 | 0,26       | 0,24   | 21,78                    | 5,23                                         | 27,01                 |
| 114            | 9,24                                                      | 7,42 | 4,25     | 2,29 | 0,27       | 0,26   | 24,23                    | 5,87                                         | 30,10                 |
| 115            | 10,11                                                     | 9,13 | 4,54     | 2,45 | 0,29       | 0,27   | 27,79                    | 6,81                                         | 34,60                 |

For shrubs, Table 7 shows the wide range of biometric values of the sampled plants. A greater variability was observed in biometric measures of *Phillyrea angustifolia*, *Myrtus communis* and *Arbutus unedo* plants.

The component productivity was estimated using formula (10) for reproduction cork and (11) for leaves and perennial components of both individual trees (Table 5) and stand levels (Table 6).

This equation was used to convert DBH into Age and again fit equations of cork oak tree phytomass components as a function of age (Table 6). A power equation best fitted above-ground phytomass, as well as trunk wood and cork, roots, and reproduction cork. A parabolic equation was the best fit for branch wood and cork, and linear equation for twigs and leaves.

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**TABLE 5.** Annual phytomass in different components of individual cork oak trees in Ain Snoussi (mean: kg DM/tree/yr)

| Tree<br>number | Above-ground annual phytomass components (kg DM/ tree/yr) |      |          |      |            |        | Roots (kg<br>DM/tree/yr) | Annual total<br>phytomass<br>(kg DM/tree/yr) |                       |
|----------------|-----------------------------------------------------------|------|----------|------|------------|--------|--------------------------|----------------------------------------------|-----------------------|
|                | Trunk                                                     |      | Branches |      |            |        |                          |                                              | Total<br>above-ground |
|                | Wood                                                      | Cork | Wood     | Cork | Twigs<2 cm | Leaves |                          |                                              |                       |
| 101            | 1,57                                                      | 0,67 | 1,55     | 0,83 | 0,11       | 0,11   | 4,94                     | 1,05                                         | 5,99                  |
| 102            | 2,37                                                      | 1,03 | 1,91     | 1,03 | 0,14       | 0,13   | 6,61                     | 1,43                                         | 8,04                  |
| 103            | 3,05                                                      | 1,42 | 2,22     | 1,20 | 0,15       | 0,15   | 8,19                     | 1,81                                         | 10,00                 |
| 104            | 3,71                                                      | 1,84 | 2,49     | 1,34 | 0,17       | 0,16   | 9,71                     | 2,18                                         | 11,89                 |
| 105            | 4,34                                                      | 2,28 | 2,73     | 1,47 | 0,18       | 0,18   | 11,18                    | 2,54                                         | 13,72                 |
| 106            | 4,95                                                      | 2,74 | 2,94     | 1,59 | 0,19       | 0,19   | 12,60                    | 2,89                                         | 15,49                 |
| 107            | 5,55                                                      | 3,21 | 3,14     | 1,69 | 0,20       | 0,20   | 13,99                    | 3,24                                         | 17,23                 |
| 108            | 6,12                                                      | 3,70 | 3,31     | 1,79 | 0,22       | 0,21   | 15,35                    | 3,58                                         | 18,93                 |
| 109            | 6,68                                                      | 4,21 | 3,48     | 1,87 | 0,23       | 0,21   | 16,68                    | 3,92                                         | 20,60                 |
| 110            | 7,23                                                      | 4,72 | 3,63     | 1,96 | 0,23       | 0,22   | 17,99                    | 4,25                                         | 22,24                 |
| 111            | 7,76                                                      | 5,24 | 3,77     | 2,03 | 0,24       | 0,23   | 19,27                    | 4,58                                         | 23,85                 |
| 112            | 8,27                                                      | 5,78 | 3,90     | 2,10 | 0,25       | 0,24   | 20,54                    | 4,91                                         | 25,45                 |
| 113            | 8,77                                                      | 6,32 | 4,02     | 2,17 | 0,26       | 0,24   | 21,78                    | 5,23                                         | 27,01                 |
| 114            | 9,24                                                      | 7,42 | 4,25     | 2,29 | 0,27       | 0,26   | 24,23                    | 5,87                                         | 30,10                 |
| 115            | 10,11                                                     | 9,13 | 4,54     | 2,45 | 0,29       | 0,27   | 27,79                    | 6,81                                         | 34,60                 |

For shrubs, Table 7 shows the wide range of biometric values of the sampled plants. A greater variability was observed in biometric measures of *Phillyrea angustifolia*, *Myrtus communis* and *Arbutus unedo* plants.

The component productivity was estimated using formula (10) for reproduction cork and (11) for leaves and perennial components of both individual trees (Table 5) and stand levels (Table 6).

**TABLE 6.** Annual phytomass in dry matter (DM) per hectare in different components of cork oak trees in Ain Snoussi forest (kg DM/ha/yr)

| Age classes (years) | Number of trees per hectare | Total above-ground part (kg DM/ha/yr) | Roots (kg DM/ha/yr) | Total increment (kg DM/ha/yr) |
|---------------------|-----------------------------|---------------------------------------|---------------------|-------------------------------|
| 58                  | 4                           | 19,743                                | 4,184               | 23,927                        |
| 68                  | 59                          | 389,703                               | 84,643              | 474,346                       |
| 78                  | 151                         | 1,236,525                             | 273,478             | 1,510,003                     |
| 87                  | 151                         | 1,465,951                             | 328,903             | 1,794,854                     |
| 95                  | 90                          | 1,005,876                             | 228,376             | 1,234,252                     |
| 103                 | 50                          | 630,108                               | 144,518             | 774,626                       |
| 109                 | 32                          | 447,743                               | 103,602             | 551,345                       |
| 116                 | 20                          | 307,013                               | 71,597              | 378,610                       |
| 122                 | 12                          | 200,183                               | 47,013              | 247,196                       |
| 128                 | 6                           | 107,933                               | 25,510              | 133,443                       |
| 133                 | 2                           | 38,547                                | 9,164               | 47,711                        |
| 139                 | 3                           | 61,616                                | 14,727              | 76,343                        |
| 144                 | 1                           | 21,785                                | 5,233               | 27,018                        |
| 153                 | 1                           | 24,230                                | 5,873               | 30,103                        |
| 166                 | 1                           | 27,790                                | 6,814               | 34,604                        |
| Total               | 583                         | 5,984,748                             | 1,353,633           | 7,338,381                     |

**TABLE 7.** Biometric variable ranges as well as shape of the selected species in scrubland of Ain Snoussi

| Species                          | Height (m) | Mean Diameter Dm (m) | Shape          | Volume (m <sup>3</sup> ) | Dry matter (g)  |
|----------------------------------|------------|----------------------|----------------|--------------------------|-----------------|
| <i>Erica arborea</i> L.          | 0,4-1,8    | 0,30-1,67            | Conical        | 0,011-1,059              | 33,31-2.930,37  |
| <i>Phillyrea angustifolia</i> L. | 0,2-3,2    | 0,15-2,25            | Conical        | 0,001-3,313              | 10,81-9.526,68  |
| <i>Myrtus communis</i> L.        | 0,3-3,1    | 0,95-4,40            | Semi-spherical | 0,510-251,319            | 27,10-38.270,24 |
| <i>Arbutus unedo</i> L.          | 0,4-5,0    | 0,35-3,10            | Conical        | 0,024-3,284              | 10,81-9.526,68  |
| <i>Viburnum tinus</i> L.         | 1,4-3,4    | 1,90-3,40            | Conical        | 1,512-6,605              | 64,65-10.509,75 |
| <i>Cistus salviifolius</i> L.    | 0,1-0,4    | 0,18-0,33            | Semi-spherical | 0,006-0,167              | 2,86-11,50      |
| <i>Daphne gnidium</i> L.         | 0,3-0,9    | 0,20-0,55            | Conical        | 0,003-0,071              | 10,51-107,87    |
| <i>Urginea maritima</i>          | 0,1-0,8    | 0,07-0,75            | Conical        | 0,0002-0,110             | 5,25-73,33      |

At the age of 103 years, the dry matter storage in the trunk of individual cork oak trees represented about 61% of the total annual above-ground phytomass (Table 5).

At stand level (Table 6), yields at 78 and 87 age classes were higher. The annual above-ground phytomass during the 78-87 age period was about 2.702,476 kg ha<sup>-1</sup> yr<sup>-1</sup>, with a total above-ground increment of 5.984,748 kg ha<sup>-1</sup> yr<sup>-1</sup>.

Power and polynomial equations best fitted dry shrub phytomass as a function of apparent biovolume (Table 8). Predictive equations were polynomial and linear for *Phillyrea angustifolia* and *Myrtus communis*. Unfortunately, the quality of fit for *Arbutus unedo* and *Cistus salviifolius* equations was not good and it will be necessary to take more plant samples for this study in the future.

The estimated above-ground shrub phytomass in sampled plots through mathematical fitted relationships was about 6,173 t DM ha<sup>-1</sup>. The total phytomasses of leaves and wood were 0,687 and 5,586 t DM ha<sup>-1</sup>, respectively. Leaves represented only 12,30% of shrub wood.

**TABLE 8.** Mathematical relationships between wood and leaf phytomasses (Y in kg DM) of sampled species and apparent biovolume (V in m<sup>3</sup>)

| Species and components           |        | Equations              | N  | r        | R     | Number |
|----------------------------------|--------|------------------------|----|----------|-------|--------|
| <i>Erica arborea</i> L.          | Wood   | $Y=2,5891V^{0,983}$    | 15 | 0,940*** | 0,687 | (25)   |
|                                  | Leaves | $Y=0,6305V^{0,6863}$   | 15 | 0,862*** | 0,715 | (26)   |
| <i>Phillyrea angustifolia</i> L. | Wood   | $Y=-0,1479V^2+2,903V$  | 11 | 0,827**  | 0,999 | (27)   |
|                                  | Leaves | $Y=0,0409V^2+0,2152V$  | 11 | 0,875*** | 0,984 | (28)   |
| <i>Myrtus communis</i> L.        | Wood   | $Y=0,00002V^2+0,1293V$ | 11 | 0,999*** | 0,885 | (29)   |
|                                  | Leaves | $Y=0,0183V$            | 11 | 0,996*** | 0,788 | (30)   |
| <i>Arbutus unedo</i> L.          | Wood   | $Y=2,9929V^{0,8311}$   | 7  | 0,512NS  | 0,867 | (31)   |
|                                  | Leaves | $Y=0,3089V^{0,5739}$   | 7  | 0,553NS  | 0,952 | (32)   |
| <i>Viburnum tinus</i> L.         | Wood   | $Y=0,369V^{1,1105}$    | 6  | 0,889*   | 0,867 | (33)   |
|                                  | Leaves | $Y=0,0162V^{1,7124}$   | 6  | 0,968**  | 0,952 | (34)   |
| <i>Cistus salviifolius</i> L.    | Wood   | $Y=0,0271V^{0,3651}$   | 5  | 0,512NS  | 0,201 | (35)   |
|                                  | Leaves | $Y=0,022V^{0,4205}$    | 5  | 0,760NS  | 0,321 | (36)   |
| <i>Daphne gnidium</i> L.         | Wood   | $Y=0,0271V^{0,3651}$   | 6  | 0,950**  | 0,930 | (37)   |
|                                  | Leaves | $Y=0,022V^{0,4205}$    | 6  | 0,680NS  | 0,753 | (38)   |
| <i>Urginea maritima</i>          | Leaves | $Y=0,0271V^{0,3651}$   | 6  | 0,928**  | 0,490 | (39)   |

NS: Not significant at 5% level.

\* $\alpha=0,05$  \*\*  $\alpha=0,01$  \*\*\*  $\alpha=0,001$

A relationship was established between biovolume (V m<sup>3</sup>) and Age (A yr.); the predictive equation has a power form:

$$V=21,109A^{0,0641} \quad (n=3, r=0,998^*) \quad (40)$$

This relationship was applied for all *Arbutus unedo* plants studied in the six sampled plots. Then, a mean age was calculated; the studied scrubland was found to be about 22 years old.

By applying formula (14), the estimated shrub productivity was 278,438 kg DM ha<sup>-1</sup> yr<sup>-1</sup>.

In a shrubland located in El Monte Can Villalonga, Spain, Navarro-Cerillo (2003) reported that 1 kg of shrub dry matter contained about 0,400 Kg of C storage. Most of the inventoried species in Ain Snoussi maquis were also present in El Monte Can Villalonga (*Phillyrea angustifolia*, *Erica arborea*, *Viburnum tinus*, *Cistus salviifolius* and *Arbutus unedo*). The use of this coefficient for Ain Snoussi shrubs resulted in an estimated shrub C storage of 2,469 t ha<sup>-1</sup>. The carbon dioxide sequestered in shrubs was about 9,053 t CO<sub>2</sub> ha<sup>-1</sup>.

The C and CO<sub>2</sub> productivity of the studied forest was 111,375 kg ha<sup>-1</sup> yr<sup>-1</sup> and 408,376 kg CO<sub>2</sub> ha<sup>-1</sup> yr<sup>-1</sup>, respectively.

In summary, the cork oak forest ecosystem in Ain Snoussi sequestered about 79,063 t CO<sub>2</sub> ha<sup>-1</sup> underground (CO<sub>2</sub> storage in shrub roots was not estimated) and a considerable amount aboveground (356,467 t CO<sub>2</sub> ha<sup>-1</sup>). The stand density was 583 trees/ha. Trees stored most of the carbon dioxide.

## 4. DISCUSSION

The stored phytomass in a forest ecosystem mainly depends on the type of forest, its chronological age, its health and environmental factors. The studied cork oak forest of Ain Snoussi is considered a mature forest of about 78-87 years old (most of the trees belong to the 20-30 cm DBH class) and is in a humid Mediterranean climate. The total phytomass per hectare of the cork oak trees in the studied forest was estimated at

about 234 t DM ha<sup>-1</sup>. It was higher than that of a closer and older forest located at Ain Draham which is approximately 113 years old (139 t DM/ha) (Sebei *et al.*, 2001; Sebei *et al.*, 2004). When plants are young, the total phytomass of the stands is accordingly large, and declines later as the plants grow and get older (Larcher, 1995). Therefore, for a better phytomass accumulation in trees and a good cork production, an old cork oak forest should be regenerated. In another study of cork oak forest phytomass accumulation undertaken at Saint Hilari in Spain, characterized by a humid Mediterranean climate with Atlantic tendencies and a better seasonal precipitation distribution, the estimated aboveground phytomass of the cork oak trees (328 t DM ha<sup>-1</sup>; Robert *et al.*, 1996) was higher than that of the studied Ain Snoussi forest (191 t DM ha<sup>-1</sup>).

Total annual aboveground cork oak phytomass was assessed in Ain Snoussi at 5,98 t DM ha<sup>-1</sup> yr<sup>-1</sup>. At a nearby site in Ain Draham, an old stand of cork oak was estimated at 2,37 t DM ha<sup>-1</sup> yr<sup>-1</sup> (Sebei *et al.*, 2004). As can be seen, the cork oak increment was twice as much in a mature stand (study case) as that in an old stand (Ain Draham). Whereas, in a young stand (approximately 31 years old) such as that in Sicily, Italy, the annual aboveground phytomass was considerably less, only about 1,1 t DM ha<sup>-1</sup> yr<sup>-1</sup> (Leonardi *et al.*, 1992).

For shrub phytomass estimation, two methods can be used. The first method consists of taking shrub samples in a square area and estimating shrub phytomass using the shrub cover (Leonardi *et al.*, 1992, Bakkali *et al.*, 2001, and Sebei *et al.*, 2001). The second method, used in the present study case, is the biovolume method and was applied also by Kayouli and Bulgen (2001), Blanco and Navarro (2003) and Navarro (2003). The first method has the inconvenience to over- or under-estimates shrub phytomass, especially when the small sampled surface area (1-4 m<sup>2</sup>) is respectively covered by large or small plants. The second method generally gives a better shrub phytomass estimation since it takes into account the different shapes of all the growing species present in the studied site.

The shrub phytomass estimated in Ain Snoussi was 6,2 t DM ha<sup>-1</sup>. Sebei *et al.* (2001) assessed 22,4 t DM ha<sup>-1</sup> in the Ben Metir site where grazing was considered lower than that in the Ain Snoussi stand. Kayouli and Bulgen (2001) gave about 0,77 t DM ha<sup>-1</sup> yr<sup>-1</sup> of shrub increment which is higher than the Ain Snoussi shrub increment (0,28 t DM ha<sup>-1</sup> yr<sup>-1</sup>). This low annual shrub phytomass could be explained by overgrazing in the studied forest.

Estimation of dry matter production of a plant community is still difficult and imprecise. Recently, progress has been made in obtaining data by harvesting techniques and remote spectral analysis (Larcher, 1995). These techniques should be used in the future for a better estimation of net primary production and carbon sequestration.

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