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Wood Biomass Production from a 10-Year Old Plantation of Fraxinus Angustifolia Vahl in Greece

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Abstract: The native species *Fraxinus angustifolia* Vahl. (narrow-leaf ash) is a fast growing noble hardwood and it is an interesting and important tree species for the country. It has high sprouting ability, relatively heavy wood (700-750 kg/m^3 - air dried) and it is recommended for energy plantations. Under the frame of the European research program FRAXIGEN (EVK2-CT-2001-00180), eight natural populations were identified all over continental Greece and selected for research. In March 2006, an experimental plantation was established using provenances (13-20 trees/provenance) with 2 year-old seedlings in a planting density 1,110 plants/ha (3 x 3 m), in the area of Messia (Kilkis) near the banks of Axios river. In December 2016, biometric parameters (height, diameter at breast height/DBH, diameter at the base/DB, total height) as well as the production of fresh and dry wood biomass, based on the mean tree of each provenance, were recorded. In the recording, each provenance was represented with 13-20 trees, depending on the availability of the plants established. The mean tree of each provenance was cut and then the fresh and dry weight and the moisture content were measured. The moisture content was calculated by oven drying of fresh samples. Four categories of woody biomass were defined based on diameter/thickness of trunks/branches, as following: category (I) >12 cm (mainly stem wood), category (II) 8-12 cm (thick branches), category (III) 4-8 cm (medium branches) and category (IV) <4 cm (thin branches). In relation to diameter (DBH), results showed significant differences between provenances: provenance 14FAN developed the largest diameter (15.9 cm) whereas provenance 09FAN the smallest (12.6 cm). In relation to the basal diameter (DB), significant differences were also found: provenance 14FAN gave the largest diameter (20.6 cm) whereas provenance 09FAN the smallest (16.5 cm). However, despite of these differences, at this stage, almost all provenances depicted significant diameter growth. In relation to the total height, results did not show much difference between provenances probably due to the high competition between trees. The moisture content was calculated and ranged between 30.8-33.7% (of the fresh weight), depending upon provenance and biomass category. Regarding the total fresh biomass, it was ranged from 82-157 kg/tree while the dry biomass from 54-107 kg/tree (or 60-118.8 tns/ha), depending on provenance. Assuming an average colorific value 19 MJ/kg ξύλου, the total thermal energy of the produced biomass per ha ranged from 1,140,000 MJ (or 316,920 kWh) for the provenance 08FAN up to 2,249,600 MJ (or 625,000 kWh) for the provenance 14FAN. Regarding biomass categories, important is that the category of thin branches (IV/<4 cm) gave relatively high values of dry biomass ranged from 34.20% to 39.92% of the total dry weight. The correlation between diameter at breast height (DBH) and total dry weight (T.D.W.) was not found significant ($p = 0.079$) with $r^2 = 0.427$. On the other hand, the correlation between diameter at base (DB) and the T.D.W. was significant ($p = 0.020$) with $r^2 = 0.624$ and the linear model was: T.D.W. = -109.104 + 9.983 DB. Based on this model the T.D.W. of a standing plantation can be estimated. The research keeps on, while the plantation acts as pilot experiment (the first in the country) for production of woody biomass of the tested species.

Key words: forest plantation, narrow-leaf ash, biometric parameters, woody biomass, energy use

1. Introduction

Woody biomass for energy use produced from plantations of fast growing forest trees, known as short rotation forestry (S.R.F.), has been studied from the beginning of the 60s after the worldwide oil crisis [1-3]. During the last decades, however, there is a high interest for research on this field due to the need to alter the energy model of Europe with a target to produce 20% of the total energy from renewable energy sources by 2020.

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The short rotation tree plantations (S.R.P.) are usually established on agricultural lands, on out of use or abandoned lands, on lands in the margins of forest — graze lands and riverine lands as well. In these plantations, usually, very dense planting space (5,000 up to 40,000 plants/ha) — but in some cases this can be reduced up to 1,100 plants/ha — depending upon the rotation period and the expected final products. Furthermore, the rotation period is exceptionally small (in comparison to that of the traditional forestry) and can be reduced up to 3-5 years. After the first production period, and depending upon the sprouting ability of the species, the plantation can be subjected to a second rotation cycle (or more cycles) without the need for a new planting.

Biomass production can vary between species, varieties and clones with a wide range of production (dry weight) which can range from 8 up to 35 35 t/ha/έτος [1, 3], depending on the number of trees/ha [4, 5], the local conditions and cultivation care [6-8]. Biomass production of fast growing trees depends upon many factors, the most important listed as follows [1, 2, 4]: 1) forest tree species, 2) provenance, variety or clone, 3) planting space, 4) experimental design and mixture (pure or mixed plantations), 5) planting material (seedlings or cuttings), 6) cultivation care (plowing, fertilizing, irrigation, phytosanity, pruning, thinning), and 7) soil and climate conditions.

One of the most important decisions before the establishment of a tree plantation (S.R.F.) is the selection of the forest tree species. The species that are commonly used for this purpose are the poplars (*Populus* spp,) [1, 3, 9]), willows (*Salix* spp.) [5, 10] and eucalypts *(Eucalyptus* spp.) [6, 11] because of their fast growth — particularly during the first years of the plantation. Besides, it is difficult to make conclusions which species is the most appropriate for the plantation establishment — since biomass production depends upon soil conditions and local climate. The most recent data demonstrate that on good soils, species of the genera *Populus* and *Salix* are the most appropriate. However, trials with new fast growing species are recommended not only for species selection for each site but also to avoid the disadvantages of the monoculture. In many cases results show that a plantation with more than one species in mixture can give more production but also other advantages (e.g., higher disease resistance and resistance to extreme weather phenomena, a variety of wood products) [12]. Thus, apart from poplars. willows and eucalypts, new research has been focused on other tree species such as *Paulownia* spp. [8, 13], *Ulmus* spp. (elm) [14], *Robinia pseudoacacia* (black locust) [15], *Acacia* spp. (acacia) [16] and *Fraxinus* spp. (ash) [17].

In parallel with the right selection of the species for planting, emphasis should be given on the origin of genetic material that will be used for plantation establishment. However, such a decision is difficult to be taken because of the high genetic variability (inter-population and intra-population) of the forest tree species and their differentiation in relation to provenance environment [18]. Thus, the genetic composition of the populations of the most forest species, which varies between provenances, can be the main factor that determines the wood production of a plantation.

The native forest species *Fraxinus angustifolia* Vahl. (narrow-leaf ash) is a fast growing noble species and its natural distribution includes almost the whole sub-mediterranean vegetation zone and it is extended up to the Caspian Sea [19] (Fig. 1). It belongs to the family Oleaceae and is one of the three native ash species in Europe (*Fraxinus excelsior*, *F. angustifolia*, *F. ornus*) [20, 21]. It is a diploid species ($2n = 46$) and presents high genetic variability within populations and between populations (to less extend) [19, 22]. Its wood is relatively heavy (700-750 kg/m^3), it has high heating value and durability during combustion (as fuelwood). It has a valuable wood with values more than 800 €/m^3 (sawn timber). The species is optimum for woody biomass production and green biomass (for fodder) as well. It has high stump sprouting ability and stem sprouting as well. It is ideal for the restoration and improvement of riparian ecosystems and other wetlands and temporary flooding soils [19, 20]. The species has been included in the list of forest species for afforestation of agricultural lands (and it can be subsidized). The tree species has not been used before in S.R.F. plantations in Greece while in Turkey it has been used in provenance trials for biomass production [23]. In Europe, the relative species *Fraxinus excelsior* has been used and it is (today) used widely [19, 24].

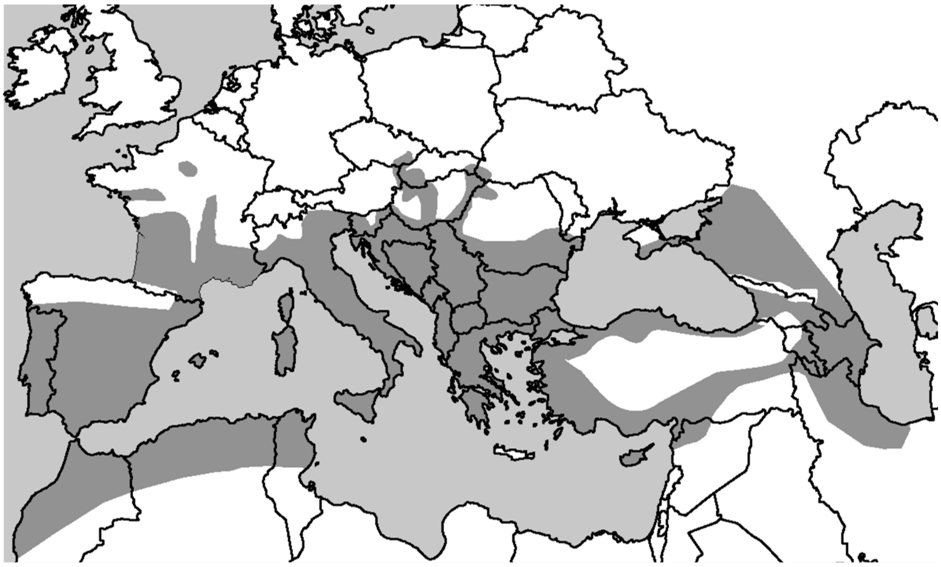


Fig. 1 Geographic distribution of the species Fraxinus angustifolia in Europe (Fraxigen, 2005).

In this work the results of the first field trial of a bio-energy plantation of the species *Fraxinus angustifolia* in Greece are presented. The aim of this study was to investigate the possibility to use this species in the country to a large scale for the production of wood biomass.

2. Methodology

In the frame of the European project FRAXIGEN (EVK2-CT-2001-00180), eight natural populations were identified all over continental Greece and selected for the study (Table 1, Fig. 2). The populations were selected on the basis of the dominance of the species within stands whereas the seed trees were selected randomly but keeping a minimum distance of 50 m (between trees). The planting material (seeds) collected from 20-25 individuals per population in June 2003 with average phenotypic characteristics. Seeds were transferred to the laboratory where they prepared for sowing (4-month cold stratification, peat/thin sand — 1:1).

Table 1 Geographic characteristics of the native populations of Fraxinus angustifolia selected for the study.

Population code (provenance)	Population (Area)	Latidude (°)	Longitude (°)	Altitude (m)
08FAN	Melia	40.58.30	26/07/40	155-170
09FAN	Komotini	41.07.25	25.28.00	10-15
11FAN	Doirani	41.13.24	22.47.12	50
12FAN	Ierissos	40.23.10	23.53.44	10-20
13FAN	Omolio	39.53.33	22.37.11	16-20
14FAN	Evia	38.51.24	23.25.24	120
15FAN	Louros	39.10.34	20.45.56	50
16FAN	Kalavrita	38.00.51	22.05.33	870

Fig. 2 Map showing selected provenances of *Fraxinus angustifolia* for the study. ◇: Area of the established trial.

2.1 Plantation Establishment

In March 2006, an experimental plantation was established in the area of Mesia (Kilkis prefecture)/Greece near the banks of Axios river (Latitude 40°53'16", Longitude 22°36'41", altitude 19 m) (Fig. 2 & 3) using 13-20 plants per provenance. In some provenances, due to their use in other experiments, it was not possible to produce 20 plants thus they were represented with less plants. The experimental design included three replications where provenances randomly planted within each replication. In the outer 2 lines (zone) the provenance 15FAN was used. Two year-old seedlings were planted at 3×3 m spacing (1.111 plants/ha).

During the 10 year growth period of the plantation the following works were carried out: 1) weed control (the first 3 years) using mechanical means, 2) irrigation for the first 3 years during the summer periods (3-4 times/year). Due to the appropriateness of the soil (sandy-loamy with enough moisture during the summer) it was not considered further irrigation of the trial.

2.2 Biometric Measurements

In February 2016, after 10 years from the establishment, measurements of all trees in the plantation were carried out in order to record the growth and wood biomass production. Specifically, the diameter at breast height (DBH), the diameter at the base of stem (DB) (8-10 cm above the ground — in order to avoid trunk defects) and the total height of trees were measured. Based on biometric parameters (DBH and DB), the mean tree (for biomass production) of each provenance was identified.

Then, the method of the mean tree was used: between the individuals of each provenance, one individual with the mean biometric parameters (DBH, DB) was identified for further calculation of the total above ground biomass. Thus, eight (8) trees were selected for felling and calculation of wood biomass which was classified into four categories as following (Table 2, Fig. 3): (I) mainly stemwood, (II) thick branches, (III) medium thickness branches, and (IV) thin branches. The fresh wood biomass for each

Fig. 3 Experimental plantation of Fraxinus angustifolia for wood biomass production in Mesia – Kilkis(banks of Axios river) – Greece. Above left - the plantation at 5-year-old, above right - 10 year-old. Bellow (left and right) - felling works and recording of the mean trees.

Table 2 Categories of woody biomass.

Category	Description	Diameter
I	Main stem wood (possibility for fuelwood production)	> 12 cm
II	Thick branches (possibility for fuelwood production)	8-12 cm
III	Medium size/thickness branches	4-8 cm
IV	Thin branches	< 4 cm

category was weighted (separately) immediately after cutting and then samples were transferred to the laboratory for drying (70-75°C, 48 hours/until constant weight). Before oven-drying, wood samples above 4 cm diameter were split (by cross sections) into pieces (4-5 cm thickness) to facilitate drying process.

After drying, data recording of the dry weight (DW) was carried out and the moisture content of fresh biomass was calculated.

2.3 Statistics

During the recording each provenance represented by 13-20 trees, depending upon the availability of the plants of each provenance. Comparison of biometric means (DBH, DB and total height/H) was done by the Scheffe's test (unbalance data) at $p \leq 0.05$.

The mean production of dry biomass was calculated by the method of the mean tree. According to this method, the trees (in the plantation) that have the mean values of biometric parameters are felled down and then the fresh and dry weight are calculated. The calculation of biomass production/ha was done by simple conversion. Furthermore, the sample of the eight selected mean trees was used for the estimation of the relationship between the total dry biomass/tree and the biometric parameters DBH and DB by using linear regression models.

3. Results and Discussion

In general, the growth of the trees in the experimental plantation was satisfactory and the survival reached 100%. After the 10-year growth, the mean DBH of the plantation was calculated and found 14.0 cm, the DB to 18.1 cm whereas the mean total height reached 9.2 m (Table 3). In regards to the DBH, results' analysis showed significant differences ($p < 0.05$) between provenances: provenance 14FAN achieved the largest DBH (15.9 cm) while provenances 09FAN and 16 FAN the smallest (12.6 cm, both). Significant differences ($p < 0.05$) were also found for the basal diameter (DB) with provenance 14FAN giving the highest values (20.6 cm) whereas provenance 09FAN the lowest (16.5 cm). However, despite of these differences, most of the provenances showed significant diameter growth. In relation to the total height, results did not show significant differences ($p > 0.05$), probably due to dense planting and therefore strong completion (between trees).

The total dry biomass of the mean tree of the whole plantation was calculated to 71 kg/tree (105 kg fresh weight with 32% mean moisture content). Interestingly, category IV (thin branches) gave the highest dry weight (26 kg/tree, total mean value/all provenances) but also the highest moisture content (about 34%) whereas the dry weight of the rest categories was found less than 20 kg (total mean) per individual tree (Fig. 4). Conversion of DW to hectare for the different categories and provenances are shown in Fig. 4a.

Table 3 Mean biometric parameters of the tested provenances at the end of the 1st rotation period.

Population code	No. of trees	DBH (cm) (mean.± s.e.)	Base diameter (DB) (cm) (mean.± s.e.)	Total height (m) (mean.± s.e.)
08FAN	13	13.6±0.65 ^{ab}	17.3±0.88 ^{ab}	8.3±0.35 ^{a}
09FAN	13	12.6±0.76 ^{a}	16.5±0.81 ^{a}	9.8±0.89 ^{a}
11FAN	20	13.5±0.74 ^{ab}	17.6±0.85 ^{ab}	8.5±0.24 ^{a}
12FAN	20	14.5±0.65 ^{ab}	17.7±0.64 ^{ab}	8.9±0.25 ^{a}
13FAN	19	14.2±0.42 ^{ab}	18.7±0.43 ^{ab}	9.3±0.28 ^{a}
14FAN	15	15.9±0.37 ^{b}	20.6±0.50 ^{b}	9.6±0.36 ^{a}
15FAN	20	14.4±0.39 ^{ab}	18.7±0.46 ^{ab}	9.7±0.25 ^{a}
16FAN	14	12.6±0.55 ^{a}	17.1±0.79 ^{ab}	9.3±0.34 ^{a}
Σύνολο/μ.ο.	134	14.00±0.22	18.1±0.25	9.2±0.13

*Means followed by the letter/superscript don not differ significantly ($p > 0.05$) μεταξύ τους (Scheffe's test).

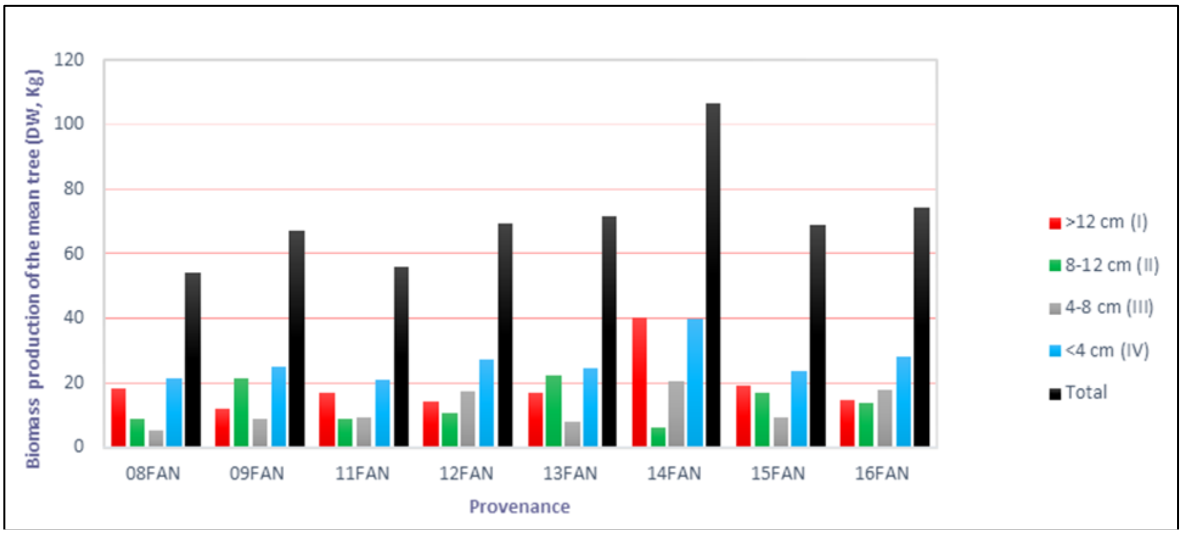
The total mean dry wood biomass (above ground) of the plantation was calculated to 78,8 t/ha at the end of the rotation period (10 years). However, the mean production varied between provenances: the most productive reached 118.4 t/ha (14FAN - Evia) whereas the least productive 60 t/ha (08 FAN-Melia). In regards to energy transforming, assuming a mean calorific value 19 MJ/kg dry wood, the total energy of the produced biomass per hectare ranges from 1,140,000 MJ (or 316,920 kWh) for provenance 08FAN and up to 2,249,600 MJ (or 625,000 kWh) for the provenance 14FAN.

The moisture content (MC) (% fresh weight) was not much different for the total fresh biomass of the provenances (Table 4). In regards to wood biomass categories, category IV gave the highest MC (33.9% FW).

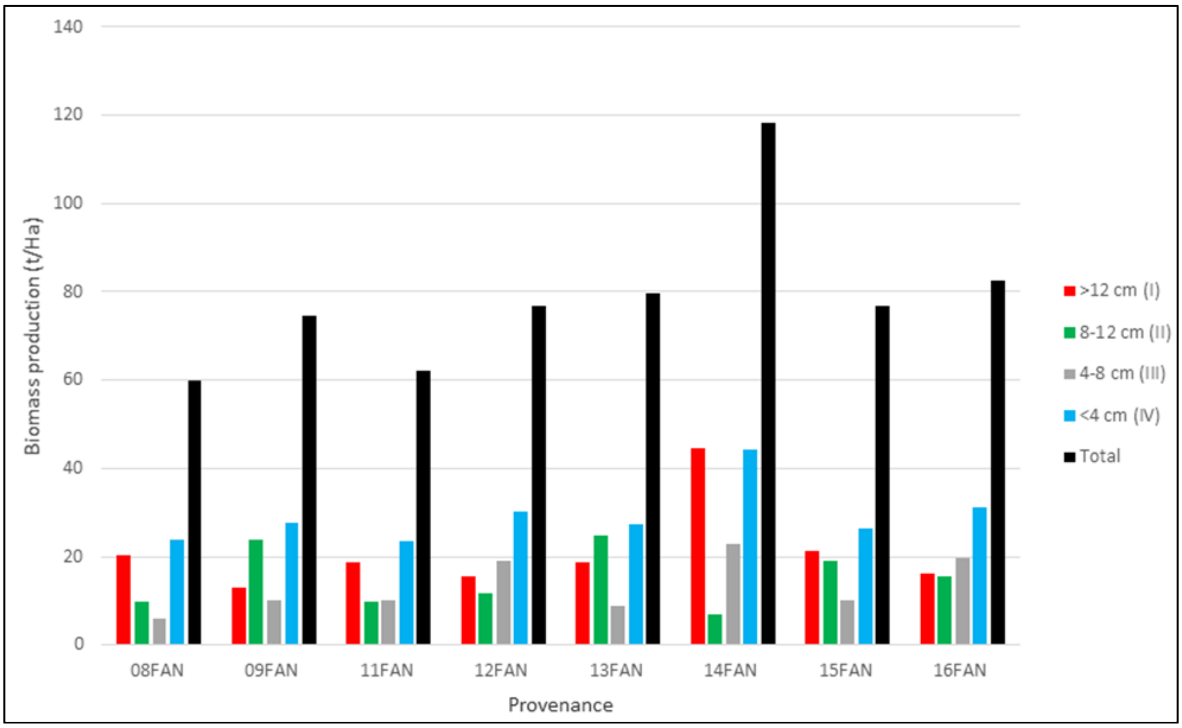
Additionally, the relationship of BBH with the total dry weight (T.D.W.) of the mean trees was not found significant ($p = 0.079$) with $r^2 = 0.427$ with a linear model TDW = -61,669 + 9,547 DBH. On the other hand, the relationship of the basal diameter (DB) with the total dry weight (TDW) was significant ($p = 0.020$) with $r^2 = 0.624$ and the linear model calculated: TDW = -109,104 + 9,983 DB (depended variable: TDW).

In other experimental plantations with poplars and 10 years rotation period, there was found biomass production ranging from 117 t/ha up to 146 t/ha [25] but including the biomass of the root system (a percentage about 20%-30% of the total). The production of dry wood biomass of S.R.P. (short rotation plantations) of fast growing species varies to a great extend [26, 27]. For example, in the central Europe, it was reported [29] above ground production

8-12 t/year/ha [28] or 20 t/year/ha in poplar plantations in Italy. The biomass production of the narrow-leaf ash plantation, if compared with that of the poplar plantations lacks behind. However, in order to come to the final conclusions for the profit of such a plantation it should be taken into account and other factors, for example the necessary expenses for the maintenance of the plantation. In our case with narrow-leaf ash the expenses are very small (in comparison to poplar, for example) due to less demands of the species for water, and therefore less irrigation (assuming the plantation is planted in appropriate environments), and less other expenses related to the whole plantation (cultivation, maintenance).



(a)



(b)

Fig. 4 1) Mean values of wood biomass of the felled mean trees (a), and conversion to ha (b). 2) 08FAN, …16 FAN: tested provenances of Fraxinus angustifolia. 3) I, II, III, IV: biomass categories.

Furthermore, the 10 year rotation period selected for the present study, gives the potential to the land owner (investor) to produce a large range of products. In fact, the production of fuelwood (category I, mainly stemwood) reached 27 kg fresh weight/individual (mean of all provenances) while the best provenance produced 58.5 kg. As it shown in Fig. 3, a large part of the production of the category I (30.3 t/ha) and II (22.4 t/ha), has sufficient sizes and can be put into the fuelwood/charcoal market (with possible higher profit for the investor) and make his investment less risky in case of fluctuations of biomass values offered in the market (e.g., pellet values).

Additionally, the possible use of the species in a large scale for the production of woody biomass it should take into account and the fact that the use of ash in S.R.F. could contribute to the enhancement of biodiversity in the agro-forestry landscape [30]. The benefits of the possible use of the studied species should not be only the production ability of the species but the fact that the use of the species in a large scale can contribute to the improvement of local biodiversity and also enhance the ecological services of the agro-forestry ecosystems, such as nutrient cycle [28], reduction of some chemical pollutants in the soil [31] or increase the resistance of the ecosystem against various pathogenic organisms [12]. Furthermore, they can enhance biodiversity by providing habitats for many endemic flora species, mycoflora and fauna in the lowlands and riverine ecosystems.

The State support (through incentives or subsidies) is also a very important factor, and even if there is good financial profit of tree plantations of short rotation period [27]. The State support, however, should be based on a national/regional well-organized system of subsidies (based on the production and not on the planted area as used to be and also happens now), and the land owner/investor should not based on this only. Financial restrictions that have to do with the land use changes should be removed, sustainability plans should be enhanced and technical advices should be available to the farmers and other investors [27].

This is the first study of narrow-leaf ash in S.R.F. and should continue to a large scale. In the future, the Forest Research Institute (Greece), should plan a genetic improvement programme of the species with selection of the best phenotypes from the provenances achieve the highest wood biomass production.

4. Conclusions

The first experimental planting (in Greece) — ten year-old rotation period - of *Fraxinus angustifolia* Vahl. demonstrated interesting results in relation to wood biomass production. The total dry weight of the mean tree of each provenance was found to differ between the tested provenances with a range from 54 up to 107 kg about. This biomass converted to hectare showed that the total dry weight ranges from 60 t (provenance 08FAN/Melia) up to 118.4 t about (provenance 14FAN /Evia). With an average colorific value of 19 MJ/kg wood, the total energy of produced biomass per ha ranges from 1,138,350 MJ (or 316,460 kWh) for the provenance 08FAN up to 2,248,190 MJ (ή 625,000 kWh) for the provenance 14FAN.

The 10 year-old rotation period selected for this research gives the potential to the land owner to produce a range of final products (e.g., pellet, briquettes, fuelwood, paper pulp) and reduce the risk of changes of the market values. Furthermore, the possible use of the species in large scale for the production of wood biomass should take into account the fact that the use of narrow-leaf ash in such plantations can contribute to the enhancement of biodiversity (particularly in the lowlands and riverine areas).

The analysis of the results demonstrated significant differences between the provenances for DBH and base diameter (DB). However, despite the differences, most of the provenances showed significant diameter growth at the end of the rotation period. In relation to the total height, results did not show significant differences between provenances. The relationship between DBH and the total dry weight did not found significant ($p = 0.079$, $r^2 = 0.427$) whereas the relationship between DB and the total dry weight was significant ($p = 0.020$, $r^2 = 0.624$) with the linear model as follows: Total Dry Weight (T.D.W.) = -109.104 + 9.983 DB. Based on this linear model the T.D.W. of a biomass plantation of *Fraxinus angustifolia* can be predicted with simple measuring the base diameter (DB) (for this study area and planting space). Additionally, this experimental plantation can be useful for the calculation of the biomass production at the second production cycle (rotation period).

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