A systematic review on the intra-specific association between water-use efficiency and productivity in forest tree species

[A dissertation submitted for the partial fulfillment of the degree of Master in Mediterranean Forestry and Natural Resources Management]

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CERTIFICATION

This is to certify that Most Jannatul Fardusi has prepared this thesis paper entitled **"A systematic review on the intra-specific association between water-use efficiency and productivity in forest tree species"** under my supervision and submitted to the University of Lleida, Spain in partial fulfillment of the requirement for **Master in Mediterranean Forestry and Natural Resources Management.** I do hereby approve the style and content of this thesis paper.

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ABBRAVIATION AND ACRONYMS

WUE	Water- use efficiency
WUE_i	Intrinsic water- use efficiency
$\delta^{13}C$	Carbon isotope composition
VPD	Vapor pressure deficit
g_s	Stomatal conductance
c_c	chloroplastic CO_2 concentration
c_i	Intercellular CO_2 concentration
c_a	Atmospheric CO_2 concentration
MA	Meta-analysis

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ABSTRACT

The physiological process of plant at leaf level; intrinsic water- use efficiency (WUE_i, the ration of carbon fixed to stomatal conductance) is usually consider as a major factor to explain primary production and adaptedness in arid and semi-arid areas under environmental stress (i.e. drought). The analysis of carbon isotope composition ($\delta^{13}C$) in plant tissues offers an integrated estimation of WUE_i during carboxylation and partitioning. Several studies demonstrated genotypic (i.e. intraspecific) variability in growth parameters (tree height, diameter or biomass) and also in WUE_i for many species. Some species showed positive correlation between $\delta^{13}C$ and growth and some shows negative correlation between them. As a consequence, the nature and magnitude of the correlation between WUE_i and productivity and their ultimate source of variation (i.e. differences in stomatal conductance or assimilation rate) remains unclear. To study the correlation between WUE_i and productivity we used meta-analysis. We tested several effects: growth trait (height, diameter or biomass), functional type (conifer, hardwood, shrub, evergreen or deciduous), genetic material (populations, families or clones), biome (Mediterranean, temperate, sub-tropical or boreal), testing condition (field, greenhouse or nursery), testing environment (optimal or suboptimal), experimental treatment (irrigated or droughted), ontogeny stage (seedlings, saplings or adult trees) on that association. We found that the correlation between $\delta^{13}C$ and growth parameter was significant (height r= 0.39, diameter r= 0.002, biomass= 0.74). We also found the association between $\delta^{13}C$ and growth in conifers (r= 0.32), broadleaves (r= 0.15), shrubs (r= 0.92), evergreen (r= 0.31), deciduous (r=0.42), populations (r= 0.38), families (r= 0.22), clones (r= 0.42), Mediterranean (r= -0.13), subtropical (r= 0.32), temperate (r= 0.47), boreal (r= 0.99), field (r= 0.21), greenhouse (r= 0.62), nursery (r= 0.39), optimal (r= 0.34), suboptimal (r= -0.12), irrigated (r= 0.50), droughted (r= 0.66), seedlings (r= 0.55), saplings (r= -0.17), adult trees (r= 0.26). Finally, we can conclude that biomass production was strongly driven by WUE_i while height was not strongly driven by that. We also can conclude that productivity was strongly driven by WUE_i in shrubs, boreal biome, greenhouse, drought and seedlings. Therefore the productivity could be depended on the variation in CO_2 assimilation rate rather than stomatal conductance in these effects.

Key words: *Intrinsic water use efficiency, Carbon isotope composition, intraspecific variation, growth, meta-analysis*

CHAPTER ONE: INTRODUCTION

1. Introduction

1.1 Back ground

Growth of trees is the result of the interactions among major processes such as photosynthesis, water relations, long-distance transport, respiration and mineral nutrition (Lambers *et al.*, 1998). Growth rates are estimated by the increment in total biomass, diameter and height per unit time. The growth can be defined at cellular level, at whole plant level and/or at physiological level. Cellular level growth includes cell division, cell enlargement and cell maturation into different tissues of a plant. Whole plant level growth includes incorporation of carbon- derived compounds into different organs (i.e. stem, roots or leaves) of a plant. At the physiological level growth processes depends on carbohydrates supply by photosynthesis followed by biochemical reactions and growth also depends on turgor pressure highly related with water availability (Kozlowski *et al.*, 1991). Growth habits respond both to physical surroundings (i.e. site, disturbance, and weather) and other trees competition for the same growing space (Oliver & Larson, 1996). Foresters are especially interested in wood production that is the consequence of secondary growth from vascular cambium and responsible for thickening of tree stems, branches and roots. Tree architecture and height reflect the environmental condition at the time of primary growth (Oliver & Larson, 1996). However, plant also shows intra- specific genetic variation in their growth characteristics due to the differences among and within populations, families or clones, in addition to growth variability caused by the environment (i.e. among different biomes) (Kozlowski *et al.*, 1991).

In forest, tree growth is usually expressed in terms of productivity. There is a well-established relationship between productivity and water use (i.e. amount of water evapotranspired) (Waring & Running, 2007; Chapin *et al.*, 2002). For terrestrial ecosystems, over 40% of vegetated area has the problem of water availability as a key limiting factor for plant growth, while another 33% of the area does not have enough water available for plant growth due to constraints of cold temperatures and frozen water (Tian *et al.*, 2010). Plant can adapt to water stress conditions in different ways such as by increasing water uptake from soil, reducing water losses and increasing water- use efficiency (WUE) etc (Waring & Running, 2007). Opening of stomata increases water loss, and CO_2 diffuses easily into the intercellular space. Reduced stomatal conductance (g_s) in response to water stress reduces water losses and CO_2 concentration in intercellular cavities of leaves (c_i), relative to atmospheric CO_2 concentration (c_a), and thus contributes to reductions in CO_2 at the site of carboxylation in the chloroplasts (c_c) (Warren, 2007; Grant *et al.*, 2006)..

Under future climate change scenarios, in which water scarcity will be a limiting factor for plant growth and terrestrial ecosystem productivity worldwide, particularly in arid and semi-arid regions (Knapp *et al.*, 2001), the study of dependence of productivity on water availability can help us to understand the importance of an improved plant water use efficiency for plant growth especially in limited water availability scenarios.

1.2 Water- use efficiency and intrinsic water- use efficiency

Plants react to their environment and the response of plants is species- specific. Regulation of water losses by transpiration per unit carbon gain (fixation) during photosynthesis also varies depending on species. The ratio of CO_2 fixation (A) and transpiration (E) is called water- use efficiency (WUE). Intrinsic water-use efficiency (WUE_i) is the ratio of net assimilation (A) to stomatal conductance (g_s) at the stomata level. Therefore, we can define WUE_i follows:

$$WUE_i = A / g_s \qquad \text{(I)}$$

The concentration of CO_2 is higher outside of the leaf than inside, while for water vapor, there is a higher concentration of water inside the leaf. In the leaf, a concentration gradient of either water vapor (w_i- w_a) or CO_2 (c_a- c_i) emerges between the air outside and the air inside, and g_s to either water vapor (g_w) or CO_2 (g_c). Therefore, the equation (I) can be expressed by the formula:

$$WUE_i = A / g_s = \{g_c (c_a - c_i)\} / g_w (w_i - w_a) \qquad \text{(II)}$$

$$WUE_i \approx 0.6\, c_a (1 - c_i/c_a) / (w_i - w_a) \qquad \text{(III)}$$

Where 0.6 refers to the comparative diffusivities of CO_2 and water in air, and the WUE_i is a negative function of $c_i/c_{a.}$

Farquhar(1989) stated that the value of c_i/c_a is near 0.7 in non- stressed plant.

1.3 Carbon isotope composition

The stable carbon isotopes such as ^{12}C and ^{13}C are found in the earth's atmosphere with a relative abundance of 99 % and 1% respectively. The relative proportional abundance of ^{13}C in plant is less than does of the air (Farquhar, 1989), indicating that plants discriminate against ^{13}C during photosynthesis (Rowell *et al.*, 2009). The isotopic ratio of $^{13}C/^{12}C$ in C_3 plants varies mainly due to discrimination during diffusion and enzymatic processes. The ratio $^{13}C/^{12}C$ of a sample is determined by mass spectrometry and referred to the limestone Pee Dee Belemnite (PDB) standard, usually expressed in carbon isotope composition ($\delta^{13}C$) and it is an indicator of WUE_i at leaf level. Thus,

$$\delta^{13}C\ (‰) = (Rp\ /Rs- 1)\ x\ 1000$$

Where, Rp is the $^{13}C/^{12}C$ ratio measured in plant sample and Rs is the ratio of the standard and ‰ is per mil.

The $\delta^{13}C$ analysis of plant tissue has been used to estimate long-term WUE (Sun *et al.*, 1996; Ehleringer, 1991; Farquhar & Richards, 1984) and genetic variation in c_i/c_a for WUE_i (Johnsen *et al.*, 1999; Condon & Richards 1992). This approach offers an integrated estimation of the ratio of CO_2 concentration of chloroplastic to atmospheric (c_c/c_a) during the carboxylation (Voltas *et al.*, 2008; Farquhar & Richards, 1984). The assessment of intraspecific variation under a common environment is a traditional approach to study genetic variation in forest trees. Under common environmental condition (i.e. common garden test), genetic differences between chloroplastic and intercellular CO_2 concentration (c_c-c_i) may be assessed and leaf (or other tissues) carbon isotope ratios provide information about processes integrated over the whole life of the leaf (or the alternative tissues).

1.4 Relationship between WUE_i and productivity

Forest productivity and WUE_i are correlated at multiple levels. There are two general types of relationships between productivity and $WUE_{i.}$ One type is that more productive plant species have higher WUE_i than the less productive ones (Gyenge *et al.*, 2008). The other type is that high WUE_i results from low water- use and consequently, this results in low productivity (Condon *et al.*, 2004). The ratio c_i/c_a is very important as it is a function of A and $g_{s.}$ From the equation (III) we can assume that WUE_i is a negative function of c_i/c_a. WUE_i can be enhanced through a lower value of c_i/c_a, that is, through higher A and lower g_s or combination of both (Condon *et al.*, 2002). Therefore, there will be an increase in A per unit leaf area if c_i/c_a gets lower as a result of increasing photosynthetic capacity. Moreover, also decreases if c_i/c_a gets lower due to closing leaf stomata. The changes in stomatal conductance affect $\delta^{13}C$ and it maintain a positive or flat relationships with WUE_i (Seibt *et al.*, 2008).

1.5 Scaling up from tissue to whole-plant level

The direct estimation of WUE at the whole-tree level by estimating time-integrated transpiration and biomass accumulation is difficult (Kruse *et al.*, 2012), especially for adult trees. It is not a practicable method for large phenotypic populations of plants for estimation of their genetic parameters. At the intraspecific level, single measurement of $\delta^{13}C$ of plant material can be used to estimate WUE_i. WUE_i measured at the leaf-level processes are involved in whole-plant WUE. Screening of differences in WUE_i among tree genotypes is facilitated by the time- and/or crown-integrative nature of leaf or tree- ring $\delta^{13}C$ (Marguerit *et al.*, 2014). Most studies determine $\delta^{13}C$ in plant leaves. However, we should keep in mind that different tissues of a given plant area composed of different chemical constituents and so the type of information regarding WUE may differ. Many scientists try to find the relevant differences in isotope composition among plant organs. Fortunately, variations in the chemical composition of plant tissues are relatively constant, so this source of error is overcome by comparing values from the same plant parts (Ferrio *et al.*, 2003).

Intra-specific genetic variation in $\delta^{13}C$ of trees have been studied for many species, involving for example populations (Correia *et al.*, 2008; Cregg *et al.*, 2000; Nguyen-Queyrens *et al.*, 1998; Lauteri *et al.*, 1997; Zhang & Marshall, 1994; Zhang *et al.*, 1993), families (Marguerit *et al.*, 2014; Aletà *et al.*, 2009; Xu *et al.*, 2003) or clones (Xue *et al.*, 2013; Xu *et al.*, 2000; Hawkins *et al.*, 2010; Sun *et al.*, 1996). Carbon isotope composition ($\delta^{13}C$) and tree growth are often correlated. This correlation is negative for some species (Robson *et al.*, 2012; Aletà, *et.al.*, 2009; Voltas *et al.*, 2008; Le Roux *et al.*, 1996). In contrast, some other species show a positive correlation between $\delta^{13}C$ and growth (Marguerit *et al.*, 2014; Hawkins *et al.*, 2010; Prasolova *et al.*, 2003; Prasolova *et al.*, 2000). The intra- specific negative correlation between $\delta^{13}C$ and growth of plant is endorsed to genetic variation in stomatal conductance *(Pita et al.*, 2001) and the positive correlation is endorsed to genetic variation in CO_2 assimilation rate (Xu *et al.*, 2000; Johnsen *et al.*, 1999; Johnsen & Major, 1995). However, the use of $\delta^{13}C$ to determine genetic variability in WUE_i is limited because it does not provide exact information on the ultimate source of changes in WUE, either stomatal conductance or assimilation rates (Scheidegger *et al.*, 2000; Farquhar & Richards, 1984).

To elucidate the general patterns of the relationship between WUE_i and productivity at the intra-specific level, we used a meta-analysis (MA) approach to investigate the correlation between $\delta^{13}C$ and growth. For example the relationship between WUE_i and biomass production under elevated CO_2 has been investigated through meta-analysis (Temme *et al.*, 2013). However, the general influence of WUE_i on productivity at the intra-specific level has not been yet investigated through meta-analysis. Therefore, we are interested to find out the general taxonomic patterns of the relationship between WUE_i and productivity with the help of $\delta^{13}C$. To proceed on purpose of the study, we gathered information of correlation between $\delta^{13}C$ and growth trait (such as height, diameter, or biomass) for forest trees and shrubs species from the existing published articles and one unpublished dataset. We have adopted the MA approaches it summarizes results of existing studies conducted till now, which will facilitate to find out the patterns of the relationship between $\delta^{13}C$ and growth through the magnitude of a statistic such as the correlations coefficient. Furthermore it will help us to test the influence of individual parameter on the statistics (Hedges & Kuyper, 2015).

1.6 Research objectives

1. To evaluate the intra-specific association between $\delta^{13}C$ and productivity using growth trait of plant such as height, diameter and biomass.
2. To determine the nature and magnitude of the correlation between WUEi and productivity across functional types or biomes, among others.
3. To interpret the effect of the testing environment (optimal and suboptimal, irrigated vs. droughted) on the general association between WUE_i and productivity at the intra-specific level.
4. To extract general patterns of association between these factors to investigate the adaptive relevance (or otherwise) of WUE_i in forest systems.

1.7 Research Questions

1. Is there any general association between $\delta^{13}C$ and growth patterns across forest species?
2. What is the nature of the correlation between WUE_i and productivity?
3. What is the effect of testing environment on the association between WUE_i and productivity?
4. Does the correlation vary across functional types, biomes and testing conditions, among others?

CHAPTER TWO: MATERIALS AND METHODS

2.1 Data Collection

We searched published articles from the databases ‘web of science’, ‘scopus’, ‘science direct’ and ‘google scholar’ by following the instruction of Russo (2007). For electronic literature search we used the terms: (“genotypic variation” OR “genetic variation” OR “genetic differentiation” OR “genetics” OR “intraspecific variability” OR “population differences” OR “Genotype” OR “water use efficiency” OR “Carbon isotopic discrimination” OR “carbon isotope composition” OR “genetics of water- use efficiency” OR “genetic variation in water-use efficiency” OR “water deficit condition”) AND (“relation to tree growth” OR “growth” OR “biomass production” OR “productivity” OR “height” OR “diameter” OR “volume”) AND(“tree” OR “Seedling” OR “forest”).

We found 80 articles, and preselected 64 articles based on title, abstract and introduction making explicit mention to the relationship between WUE_i and productivity. References from each article were systematically examined for additional suitable papers which were then incorporated into the bibliographic database. Then, we selected papers reporting intra-specific correlations between $\delta^{13}C$ or $\Delta^{13}C$ and growth traits. We did not select those papers that show correlations involving less than 5 genetic entities. Finally, we had 37 articles in our dataset published from 1994 to 2014, and 1 unpublished dataset provided by Jordi Voltas from a nursery experiment in 2010 involving *Pinus pinaster*. Some studies represented mean values of growth parameters and $\delta^{13}C$ as a table or graph. In this case, we extracted the mean value from table and graphs by using Plot Digitizer 2.6.6 and transformed the mean value to produce correlation coefficients between $\delta^{13}C$ and growth (Rosenthal, 1995).

If correlation involving $\delta^{13}C$ was reported for two or more growth parameters in the same paper, we included each correlation as an individual study in the dataset. Apart from this, when correlations were available for more than one species, diverse genetic materials or different experimental conditions or several trial sites or various treatments in the same paper we counted them as an independent study. The dataset grouping included: growth trait (height, diameter or biomass), functional type (conifers, broadleaves or shrubs, evergreen or deciduous), genetic material (populations, families or clones), biome (Mediterranean, temperate, sub-tropical or boreal), testing condition (field, greenhouse or nursery), testing environment (optimal or suboptimal), experimental treatment (irrigated or droughted), ontogeny stage (seedlings, saplings or adult trees). We also considered factors or variables such as number of genetic entities involved, availability of $\delta^{13}C$ or $\Delta^{13}C$ values, and plant part (leaves or wood) analysed for estimating WUE_i. Additionally, we changed the correlation coefficient sign if WUE_i was estimated by $\Delta^{13}C$. Finally, the correlation coefficients (positive or negative) between $\delta^{13}C$ and growth traits and the sample size were carried forward to the meta-analysis (MA), with the following variants:

a) Meta- analysis 1 (MA_1) performed on correlations between $\delta^{13}C$ and plant growth parameters. We included 58 correlations between $\delta^{13}C$ and height from 25 studies, 48 correlations between $\delta^{13}C$ and diameter from 24 studies, and 32 correlations between ($\delta^{13}C$) and biomass from 9 studies in the analysis.
b) MA_2 performed on correlations between $\delta^{13}C$ and growth in conifers, broadleaves and shrubs. The analysis included 97 correlations between $\delta^{13}C$ and growth in conifers from 26 studies, 30 correlations between $\delta^{13}C$ and growth in broadleaves from 7 studies, and 12 correlations between $\delta^{13}C$ and growth in shrubs from 4 studies.
c) MA_3 on correlations between $\delta^{13}C$ and growth in evergreen and deciduous. We tested 86 correlations between $\delta^{13}C$ and growth in evergreen from 25 studies, and 51 correlations between $\delta^{13}C$ and growth in deciduous from 13 studies.
d) MA_4 on correlation between $\delta^{13}C$ and growth according to the type of genetic material. For populations, 71 correlations were collected from 13 studies. For families, 36 correlations from 14 studies. And for clones, 33 correlations from 9studies.
e) MA_5 on correlation between $\delta^{13}C$ and growth according to the type of biome. We split the dataset according to the biome. The dataset had 32 correlations for Mediterranean from10 studies, 25 correlations for subtropical from 10 studies, 72 correlations for temperate from 14 studies, and 8 correlations for boreal from 3 studies.
f) MA_6 on correlation between $\delta^{13}C$ and growth according to the type of testing condition. We investigated 93 correlations between $\delta^{13}C$ and growth in field from 30 studies, 41 correlations between $\delta^{13}C$ and growth in greenhouse from 6 studies, and 5 correlations between $\delta^{13}C$ and growth in nursery from 2 studies.
g) MA_7 on correlation between $\delta^{13}C$ and growth according to the type of testing environment. We examined 57 correlations between $\delta^{13}C$ and growth in optimal from 23 studies, and 31 correlations between $\delta^{13}C$ and growth in sub optimal from 14 studies.

h) MA_8 on correlation between $\delta^{13}C$ and growth according to the type of experimental treatment. We detected 25 correlations between $\delta^{13}C$ and growth in irrigated from 8 studies and 26 correlations between $\delta^{13}C$ and growth in droughted from 7 studies.

i) MA_9 on correlation between $\delta^{13}C$ and growth according to the type of ontogenic stage. We used 79 correlations between $\delta^{13}C$ and growth in seedlings from 19 studies, 29 correlations between $\delta^{13}C$and growth in saplings from 9 studies, and 32 correlations between $\delta^{13}C$ and growth in adult trees from 11studies.

2.2 Data analysis

The individual correlation coefficient (r) and sample size (i.e. number of genetic entities) (n) were tabulated for each MA (see Appendices 1-25). We used the Fisher Z-transformation to calculate an effect size for each individual study: z= 0.5 log [(1+r)/ (1-r)]. Larger weights are assigned to studies with larger sample sizes. The range of r is between -1 and +1, z is $-\infty$ to $+\infty$. A positive z value means a positive association between $\delta^{13}C$ and growth.

There are two types of models for meta-analysis to calculate Global Estimated Correlation Coefficient (GE r) effect size. In a random effect meta-analysis model, the true effect size is random. In fixed effect meta-analysis model the value is fixed and studies share a common effect size. To choose between fixed or random effect models we computed two measures of Heterogeneity for each meta-analysis to assess whether the validity of the effect size is homogeneous (and thus we can consider a fixed-effect meta-analysis) or rather the effect size is heterogeneous (and we need to consider a random effect meta-analysis) (Borenstein *et al.* 2009). In particular, for each meta-analysis we computed the statistic Q (Q is Cochran's statistic) as a measure of heterogeneity (Whitehead, 2003). However, the Q test only informs us about the presence or the absence of heterogeneity, but it does not report on the extent of such heterogeneity. Therefore, recently, the I^2 has been used to quantify the degree of heterogeneity in a meta-analysis (Huedo-Medina *et al.*, 2006). The I^2 can be interpreted as the percentage of the total variability in a set of effect sizes due to true heterogeneity, that is, to between-studies variability. The percentages of I^2 around 25% (I^2 = 25), 50% (I^2 = 50), and 75% (I^2 = 75) is considered as low, medium, and high heterogeneity, respectively (Higgins & Thompson, 2002).

If the Q-test result is found significant and I^2 value shows greater percentage, then we have chosen a random effects model rather than a fixed effect model. Both models combined the effect size across all studies to present the global estimated correlation coefficient (GE r) effect size. The GE r provides the average relationship between $\delta^{13}C$ and growth. Effects were considered significantly different from zero by Z-test with 95% confidence interval (ci). Multiple tests were conducted with the same datasets. We conducted all the analyses using the *metafor* statistical package (Viechtbauer, 2010) for the R statistical environment (R Development Core Team, 2007).

CHAPTER THREE: RESULTS

3.1 Heterogeneity test

The Q statistic for most of the effect tests was highly significant (P<0.0001) with a medium to high I^2 value except in nursery effect test. The heterogeneity test for nursery was not significant (p= 0.2533) and have low Q and I^2 values of 5.34 and 25% respectively (Table 3.1). Based on the heterogeneity test, we used fixed effect model for nursery and random effect model for the rest of the meta- analysis tests.

Table 3.1: Test of heterogeneity for each effect. n: number of individual comparisons. Q: test of heterogeneity value. I^2: total heterogeneity/ total variability

Effect tested	n	Q	pval	I^2
Height	58	564.38	<0.0001	89.9
Diameter	48	280.92	<0.0001	83.27
Biomass	32	208.82	<0.0001	85.15
Conifers	97	290.32	<0.0001	66.9
Broadleaves	30	878.93	<0.0001	96.7
Shrubs	12	53.718	<0.0001	79.52
Evergreen	86	263.20	<0.0001	68.09
Deciduous	51	956.16	<0.0001	94.77
Population	71	672.77	<0.0001	89.60
Family	36	413.19	<0.0001	91.53
Clone	33	105.24	<0.0001	69.59
Mediterranean	32	271.31	<0.0001	88.5
Subtropical	25	76.67	<0.0001	68.7
Temperate	72	693.66	<0.0001	89.76
Boreal	8	23.47	0.0014	70.18
Field	93	544.29	<0.0001	83.1
Greenhouse	41	514.68	<0.0001	92.23
Nursery	5	5.34	0.2533	25.22
Optimal	57	208.34	<0.0001	73.12
Suboptimal	31	339.08	<0.0001	91.15
Control	25	319.12	<0.0001	92.48
Drought	26	204.23	<0.0001	87.76
Seedlings	79	723.48	<0.0001	89.22
Saplings	29	307.05	<0.0001	90.88
Adult tree	32	95.86	<0.0001	67.66

3.2 Carbon isotope composition ($\delta^{13}C$) vs. plant growth traits (MA_1)

First of all, we estimated global estimated correlation coefficient (r= 0.27, 95% CI 0.15- 0.38) to test the influence of WUE_i on general tree growth pattern at intra specific level. Then we divided the dataset according to type of growth trait (height, diameter or biomass) to evaluate each study. Height and biomass were positively associated with $\delta^{13}C$ having global estimated correlation values of 0.39 and 0.74 respectively (Table 3.2). Biomass showed a stronger correlation than height had shown. But $\delta^{13}C$ did not show a significant association with diameter (figure 3.1). It is clear from the distribution of studies (figure 3.1) that there is no trend in 65% studies. While among rest of the studies, half of the studies have a positive trend and other half of the studies has negative trend. Therefore, overall estimated r showed zero value; there had been no association between diameter and $\delta^{13}C$.

We also observed a high positive z-transformed effect size on the correlation between diameter and $\delta^{13}C$ in study 23 (Zhang *et al.*, 1996) and 32 (Johnsen *et al.*, 1999), and a high negative z-transformed effect size in study 44 (Aletà *et al.*, 2009) as shown in figure 3.1 (see also appendix 2). The studies 23 and 32 were conducted on *Pseudotsuga menziesii* and *Picea mariana* respectively. *B*oth of them have a sample size of 18. And study 44 was conducted on *Juglans regia* with a sample size of 22.

Table 3.2: Tested effect description of MA_1 on association between $\delta^{13}C$ and growth traits. GE r: global estimated correlation coefficient. SE: standard error. zval: Z-test. ci: 95% confidence interval.

Effect tested	GE r	SE	zval	Pval	ci.lb	ci.ub	r back transform
Height	0.39	0.08	4.36	<0.0001	0.21	0.56	0.37
Diameter	0.002	0.08	0.02	0.9814	-0.16	0.17	0.0019
Biomass	0.74	0.10	7.15	<0.0001	0.54	0.95	0.63

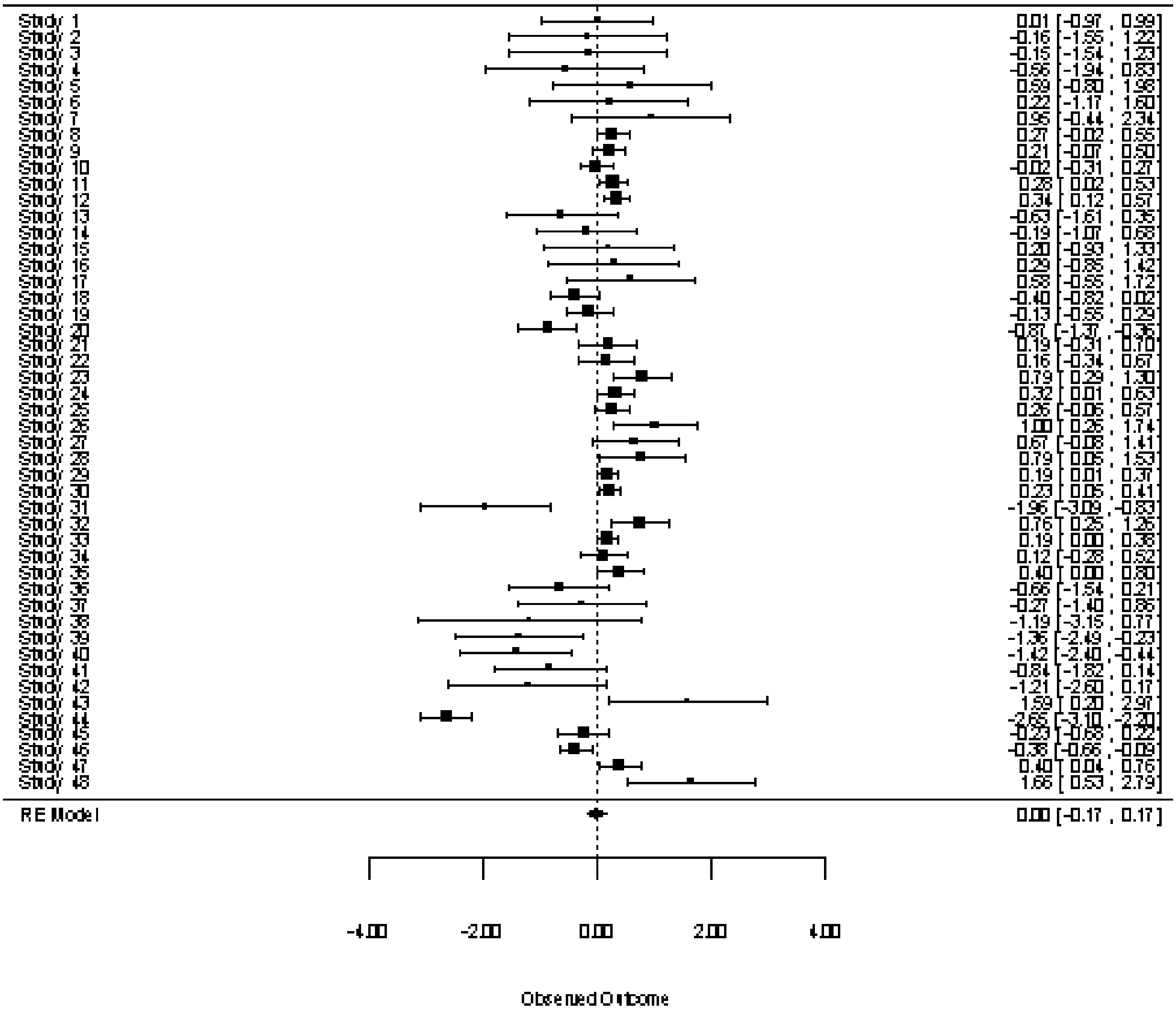

Figure 3.1: Z-transformed effect size and 95% confidence intervals (error bars) of individual studies correlating $\delta^{13}C$ and diameter.

3.3Carbon isotope composition ($\delta^{13}C$) vs. growth in conifers, broadleaves and shrubs (MA_2)

At intra- specific level, plant growth was positively associated with $\delta^{13}C$ in conifers and shrubs species. But the global estimated correlation (r= 0.92) was higher in shrubs than in conifers (r= 0.32) (see table 3.3). In the contrary, growth was not significantly associated with $\delta^{13}C$ in broadleaves and GE r value was not different from zero (Figure 3.2). Because, about 43% studies showed a positive trend on the association between $\delta^{13}C$ and plant growth in broadleaves while rest of the studies had negative or no trend between them (Figure 3.2). From the distribution of studies in figure 3.2, we can see that studies 3 to 14 showed high positive z-transformed effect size. These studies had been conducted on *Castanea sativa* by

Lauteri *et al.*, (2004) with 48 sample size in each study. The studies 16, 17, 23, 24 and 25 showed highly negative z-transformed effect size. Pita, (2001) conducted two studies (study 16 and 17) on *Eucalyptus globules* with a sample size of 6 and 7 respectively. Moreover, Aleta *et al.*, (2009) conducted study 23, 24, and 25 on *Juglans regia* with 22 sample size. In general, if the sample size of a study is higher, it influences a lot on the z-transformed effect size.

Table 3.3: Tested effect description of MA_2 on association between $\delta^{13}C$ and growth in conifers, broadleaves and shrubs.

Effect tested	GE r	SE	Zval	pval	ci.lb	ci.ub	r back transform
Conifers	0.32	0.04	7.94	<0.0001	0.24	0.40	0.31
broadleaves	0.15	0.20	0.77	0.4411	-0.23	0.55	0.15
Shrubs	0.92	0.28	3.21	0.0013	0.36	1.49	0.73

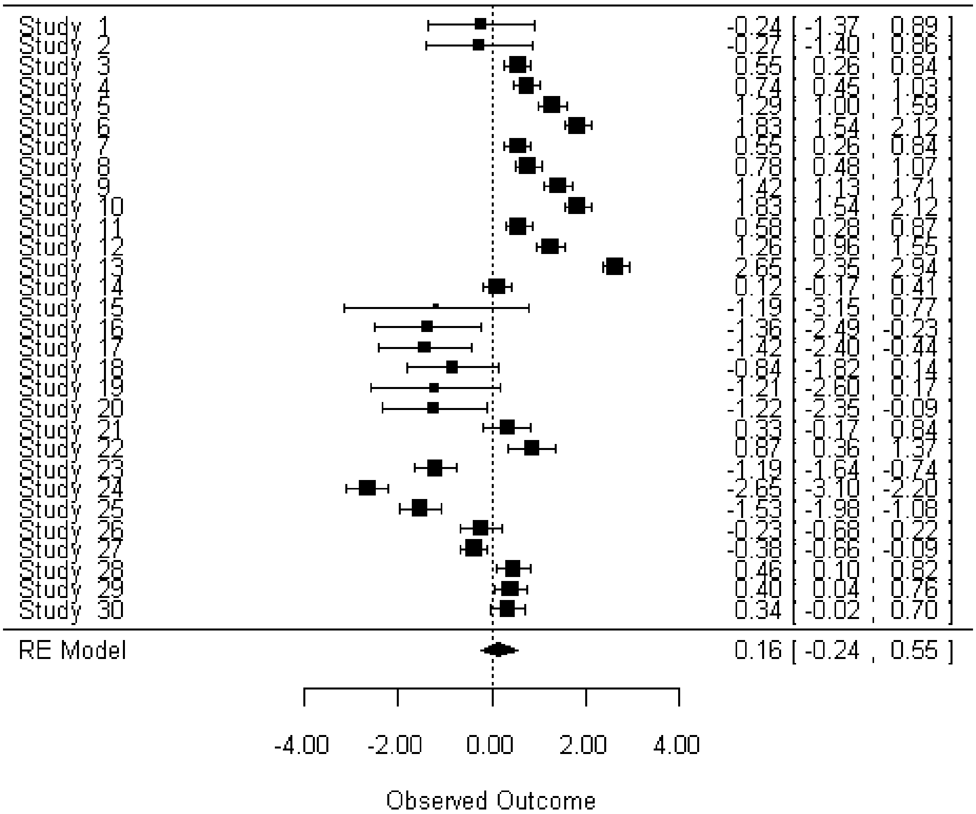

Figure 3.2: Z-transformed effect size and 95% confidence intervals (error bars) of individual studies correlating $\delta^{13}C$ and growth in broadleaves.

3.4 Carbon isotope composition ($\delta^{13}C$) vs. growth in evergreen and deciduous species (MA_3)

In the MA_2, we observed that global estimated r for broadleaves was not significant. However, in MA_3 we included broadleaves and shrubs species in deciduous dataset in order to check the relationship of $\delta^{13}C$ vs. growth on a combined scale for all types of these species. The result of MA_3 showed that the $\delta^{13}C$ had been significantly and positively associated with growth in evergreen and deciduous species. The global estimated correlation coefficient (r) between $\delta^{13}C$ and growth was 0.31 and 0.42 in evergreen and deciduous species respectively (Table 3.4). The number of studies on evergreen species were higher (86) and most of the studies had similar effect size between studies in the MA_3 (Figure 3.3 a). On the other hand, deciduous species showed more variability among studies (figure 3.3 b), even though there had been less number of studies (51). In general, the results showed higher consistency between studies in evergreen than between studies in deciduous.

Table 3.4: Tested effect description of MA_3 on association between $\delta^{13}C$ and growth in evergreen and deciduous.

Effect tested	GE r	SE	zval	pval	ci.lb	ci.ub	r back trans
Evergreen	0.31	0.04	6.86	<0.0001	0.22	0.39	0.29
Deciduous	0.42	0.14	3.02	0.0026	0.15	0.69	0.39

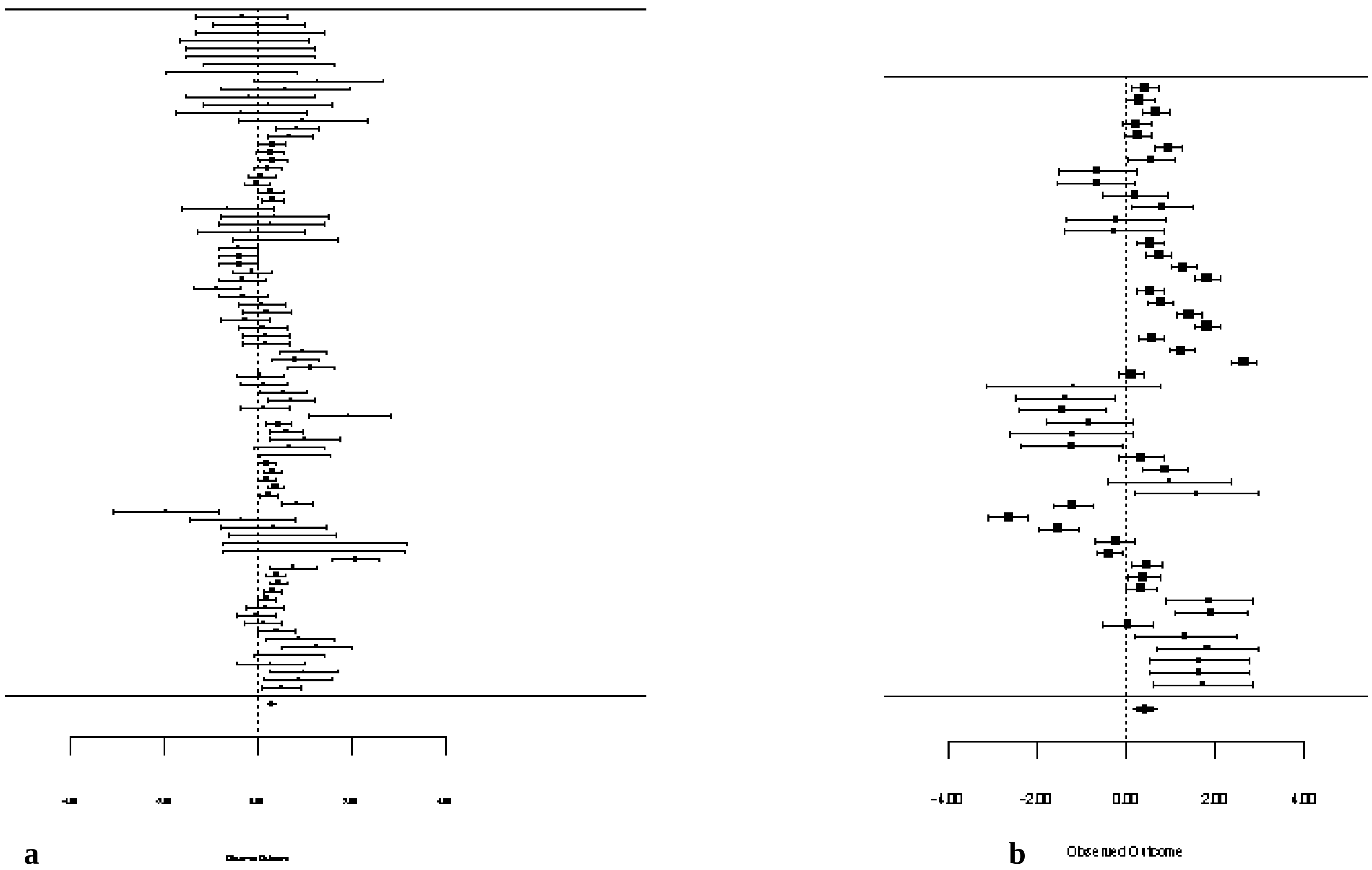

Figure 3.3: Z-transformed effect size and 95% confidence intervals (error bars) of individual studies correlating $\delta^{13}C$ and growth in (a) evergreen and (b) deciduous.

3.5 Carbon isotope composition ($\delta^{13}C$) vs. growth according to the type of genetic material (MA_4)

We divided the dataset according to the type of genetic material to test their effect on the association between $\delta^{13}C$ and plant growth. The results showed that the growth had been positively associated with $\delta^{13}C$ in all type of genetic materials (Table 3.5). But among all, families showed less positive relation (r= 0.22). We again divided the dataset according to growth trait and tested its effect within each genetic material. The $\delta^{13}C$ was more positively associated with biomass than with height in both populations and families. Conversely, the association between $\delta^{13}C$ and height in clones showed more positive correlation than biomass in clones (Figure 3.4). Diameter showed no association with $\delta^{13}C$ among all the genetic material.

Table 3.5: Tested effect description of MA_4 on association between $\delta^{13}C$ and growth in the type of genetic material.

Effect tested	GE r	SE	zval	pval	ci.lb	ci.ub	r back trans
Populations	0.38	0.09	4.06	<0.0001	0.19	0.56	0.36
Families	0.22	0.10	2.21	0.00267	0.002	0.42	0.22
Clones	0.42	0.08	5.10	<0.0001	0.25	0.58	0.39

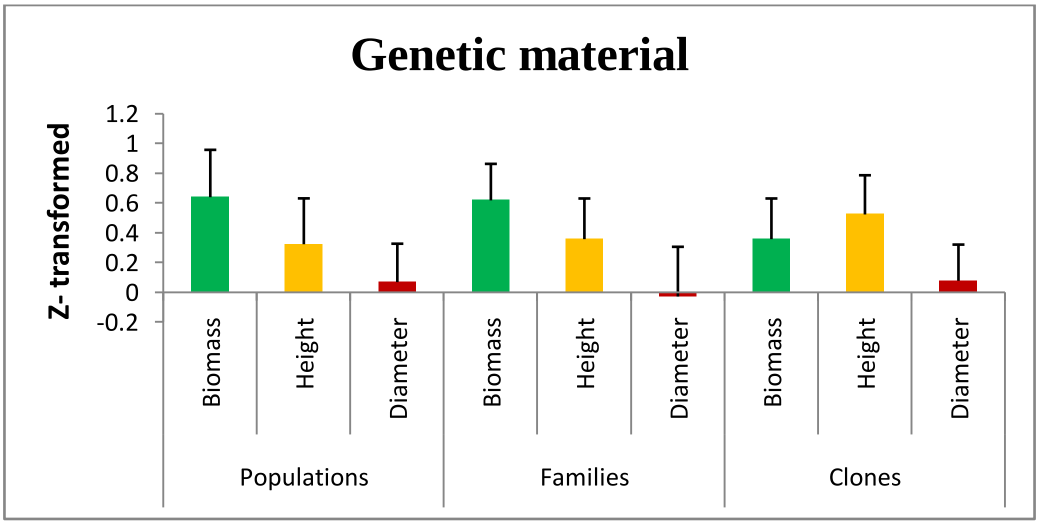

Figure 3.4: Z-transformed effect size and 95% confidence intervals (error bars) of studies correlating $\delta^{13}C$ and growth trait in genetic material.

3.6 Carbon isotope composition ($\delta^{13}C$) vs. growth according to biome type (MA_5)

The result showed a significant ($p<0.0001$) global estimated correlation between $\delta^{13}C$ and growth in all types of biome except Mediterranean. Among the different types of biome, the GE r for subtropical, temperate and boreal was 0.32, 0.47 and 0.99 respectively.

In Mediterranean biome, about 69% studies showed no trend between $\delta^{13}C$ and growth. While among others 31% studies, half studies showed a positive trend and other half of the studies a showed negative trend (Figure 3.5). Therefore, the overall estimated correlation was not significant and the value was not different from zero which means that there were no association between $\delta^{13}C$ and growth in Mediterranean. High positive z-transformed effect size was exhibited by studies 13, 14 (Aranda*et al.*, 2010) and 26 (Voltas, 2010 (unpublished)). All the three studies were conducted on *Pinus pinaster*. However, studies 29, 30 and 31 (Aletà *et al.*, 2009) conducted on *Juglans regia* displayed a highly negative z-transformed effect size.

Table 3.6: Tested effect description of MA_5 on association between $\delta^{13}C$ and growthin biome type.

Effect tested	GE r	SE	zval	pval	ci.lb	ci.ub	r back trans
Mediterranean	-0.13	0.13	-0.98	0.3222	-0.39	0.13	-0.13
Subtropical	0.32	0.05	5.57	<0.0001	0.21	0.44	0.31
Temperate	0.47	0.08	5.34	<0.0001	0.29	0.64	0.44
Boreal	0.99	0.22	4.53	<0.0001	0.56	1.42	0.76

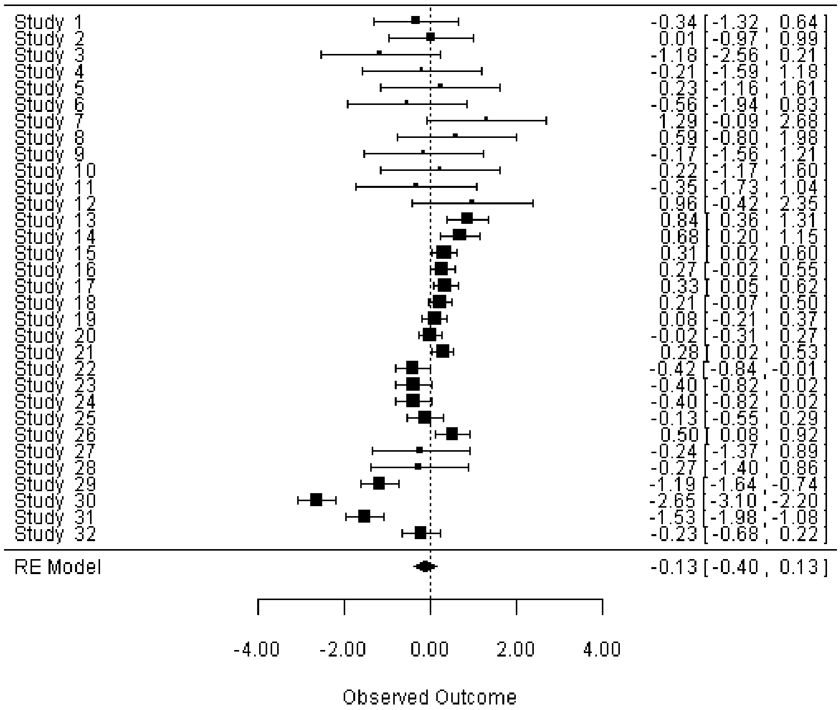

Figure 3.5: Z-transformed effect size and 95% confidence intervals (error bars) of individual studies correlating $\delta^{13}C$ and growth in Mediterranean.

3.7 Carbon isotope composition ($\delta^{13}C$) vs. growth according to testing condition (MA_6)

We conducted the random effect model for field and greenhouse treatments while fixed effect model was carried out for nursery. Plant growth was positively associated with $\delta^{13}C$ in all testing condition. But, growth of the plant showed relatively weak association with $\delta^{13}C$ in field (r= 0.21) compared to nursery (0.39) and greenhouse (r= 0.62).

Table 3.7: Tested effect description of MA_6 on association between $\delta^{13}C$ and growth in testing conditions.

Exp Conditions	GE r	SE	zval	pval	ci.lb	ci.ub	r back trans
Field	0.21	0.06	3.52	0.0004	0.09	0.32	0.20
Greenhouse	0.62	0.11	5.34	<0.0001	0.39	0.84	0.55
Nursery	0.39	0.12	3.05	0.0023	0.14	0.64	0.37

3.8 Carbon isotope composition ($\delta^{13}C$) vs. growth according to testing environment (MA_7)

The global average r was positive (0.34, at 95% CI ranging from 0.22 to 0.47) for the association between $\delta^{13}C$ and plant growth in optimal environment. Conversely, this association showed no significant difference from zero in suboptimal environment. From the distribution of studies in figure 3.7, we can observe that more than 41% studies did not represent any trend between $\delta^{13}C$ and plant growth, while among the rest of studies, half studies had a positive trend and other rest of the studies had a negative trend in suboptimal condition. Therefore, overall estimated r showed no significant association; there was no relationship between plant growth and $\delta^{13}C$ in suboptimal environment.

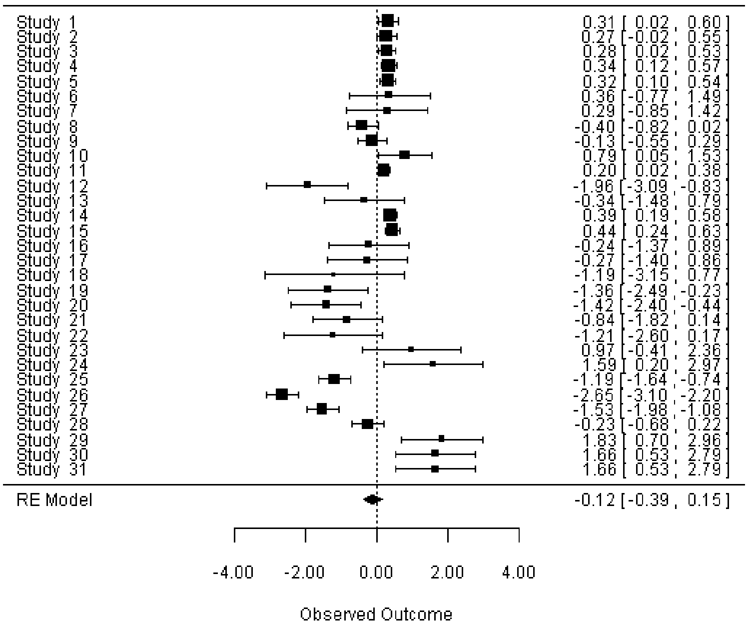

Figure 3.6: Z-transformed effect size and95% confidence intervals (error bars) of individual studies correlating $\delta^{13}C$ and growth in suboptimal environment.

3.9 Carbon isotope composition ($\delta^{13}C$) vs. growth according to experimental treatment (MA_8)

Most of the studies investigated the effect of $\delta^{13}C$ on tree growth in two treatments; irrigated and drought. Both treatments had a significant and positive effect on the association between $\delta^{13}C$ and plant growth. The result showed higher global estimated r value in drought treatment than in irrigation treatment (Table 3.6). From the distribution of studies in figure 3.8, we can see that only study 5 (Zhang *et al.*, 1996) in irrigated treatment represents the negative z- transformed effect size. Conversely, study 21 (Lauteri *et al.*, 2004) represented the highest positive z- transformed effect size (2.65) out of all studies carried out in irrigated treatment. However, most of the studies (62%) represented higher positive z- transformed effect size in drought treatment.

Table 3.8: Tested effect description of MA_8 on association between $\delta^{13}C$ and growthin experimental treatments.

Effect tested	**GE r**	**SE**	**Zval**	**pval**	**ci.lb**	**ci.ub**	**r back transform**
Irrigated	0.50	0.15	3.31	0.0009	0.21	0.79	0.46
Droughted	0.66	0.12	5.41	<0.0001	0.42	0.91	0.58

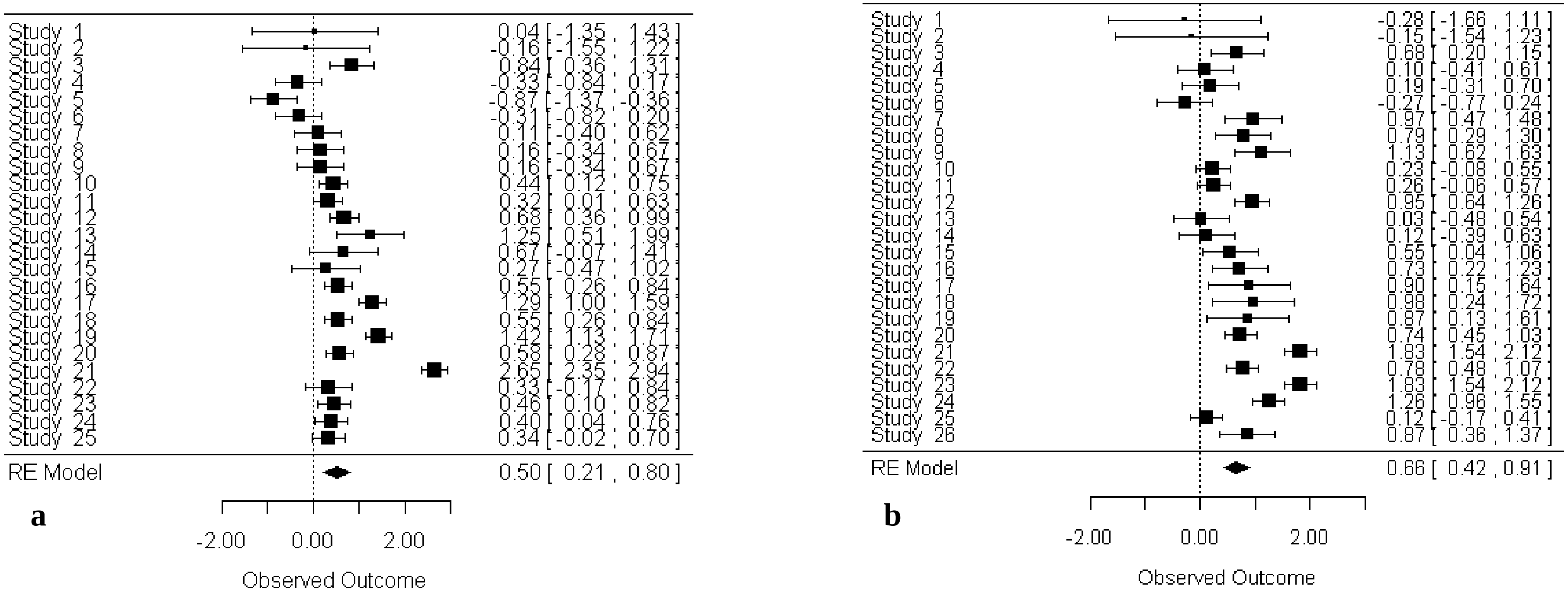

Figure 3.7: Z-transformed effect size and 95% confidence intervals (error bars) of individual studies correlating $\delta^{13}C$ and growth in (a) irrigated (b) droughted treatment.

3.10 Carbon isotope composition ($\delta^{13}C$) vs. growth according to ontogenic stage (MA_9)

We divided the dataset according to ontogenic stage. The meta- analysis results showed that the global estimated r value was very weak in adult tress (r= 0.26) than in seedlings (r=0.55) at 95% CI. In the contrary, saplings had no effect on the association between $\delta^{13}C$ and growth. Moreover, from the distributions of data in figure 3.8, we found that about 62% of studies did not represent any trend between $\delta^{13}C$ and growth in sapling stage.

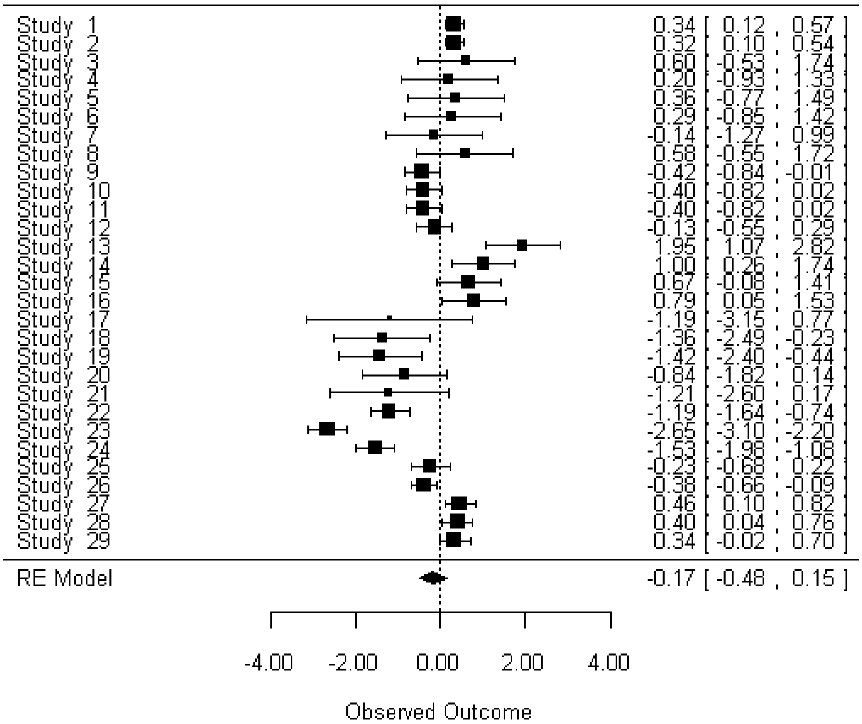

Figure 3.8: Z-transformed effect size and95% confidence intervals (error bars) of individual studies correlating $\delta^{13}C$ and growth in saplings.

CHAPTER FOUR: DISCUSSION

4.1 Intra-specific association between $\delta^{13}C$ and plant growth

Many studies have demonstrated a significant and positive association between $\delta^{13}C$ and height (e.g. Toillon *et al.*, 2013; Pastorino *et.al.*, 2012; Lauteri *et al.*, 2004; Xu *et al.*, 2000; Pennington *et al.*, 1999; Johnsen *et al.*, 1999; Aitken *et al.*, 1995). Our results confirm these associations but the correlation is weak (r= 0.39) suggesting that genetic variation in height is not strongly driven by WUE_i. The weak correlation between $\delta^{13}C$ and height has been also found in several studies included in our meta- analysis (e.g. Marguerit *et al.*, 2014; Corcuera *et.al*, 2012; Monclus *et al.*, 2009; Prasolova *et al.*, 2003; Prasolova *et al.*, 2001; Tognetti *et al.*, 2000; Zhang *et al.*, 1996). However, the weak correlation between $\delta^{13}C$ and height increment may be explained by different adaptive strategies of forest species. Different adaptive mechanisms in different forest species growing in distinct conditions may result in apparently contradictory performances, demonstrating that comparison of $\delta^{13}C$ studies must be carefully approached. It has been shown that the growth versus $\delta^{13}C$ associations in several species may change when plant are tested in different environments (Condon *et al.*, 2004).

According to Euler *et al.*, (1992) diameter is more sensitive to environmental conditions than height is. Most of the studies included in our meta-analysis (i.e. Correia *et al.*, 2008 in *Pinus pinaster* populations) have not found association between $\delta^{13}C$ and diameter. As a result, we did not find a non-significant association between $\delta^{13}C$ and diameter. This result points out that diameter is not affected by the WUEi.

The meta-analysis showed a highly positive association between biomass and $\delta^{13}C$ when compare with alternative growth traits, meaning that the total biomass growth is more strongly driven by WUE_i. The high association between biomass and $\delta^{13}C$ also suggested by Gray *et al.*, (2013), Aranda *et al.*, (2010), Lauteri *et al.*, (2004), Livingston *et al.*, (1999), Zhang *et al.*, (1996) and Sun *et al.*, (1996). Total biomass was estimated on seedling stage. However, we should keep in mind that total biomass included the leaves, stem and roots while other growth traits have just measured height or diameter. As a result total biomass seems to be better indicator of the impact of intra- specific variation in WUE_i on growth than other plant growth traits.

In general, our meta-analysis revealed intra-specific variation in WUE_i on growth traits except diameter, but the strength of the association between growth and WUE_i differed among species. The result indicate that biomass is strongly and height is weakly driven by $WUE_{i,}$ and the associations is controlled more by CO_2 assimilation rate (photosynthetic capacity changes) rather than by stomatal conductance at the intra- specific level. This is in argeement with the fact that biomass production is proportional to the amount of synthesized carbohydrates.

When water is not a major environmental constrain, it seems that an increase in the mesophyll photosynthetic capacity would confer an ecological advantage to the genotypes that show higher WUE, due to a maximization of the carboxylation processes per unit of water lost leading to higher biomass increments per unit time.

The increase mesophyll photosynthetic capacity is also related to soil fertility and crown architecture. Higher concentration of Rubisco and chlorophyll per leaf and optimal crown architecture improve maximum photosynthetic capacity. The above mentioned characteristic would also increase fitness in water limited environments provided there is not a decrease in leaf area. Reductions in leaf area may be a drawback associated to photosynthetic capacity changes.

Leaf size and thickness have a significant effect on WUE_i. Thinner leaves (with a lower ratio of internal volume to leaf surface area) predicted to exhibit lower WUE_i than comparable to thicker leaves (Stanhill, 1986). And increasing photosynthetic capacity of the mesophyll will enhance $WUE_{i.}$ However, increased plants' photosynthetic capacity is often associated with a decrease in leaf size (Bhagsari & Brown, 1986), that could reduces whole plant transpitration and light interception (Bacon, 2004). The decline in leaf area is likely to occur if any increase in photosynthetic capacity results from an increase in the concentration of enzyme associated with the photosynthetic biochemistry. Under such circumstance, enhanced photosnthetic capacity and limited nitrogen resources are optimized, such that specific leaf area declines (i.e. there is an increase in dry matter content of leaves on a leaf area basis). Moreover, when soil water availability is limited leaf expansion rates are commonly observed to decline in line with transpiration by stomatal conductance.

4.2 Association between WUEi and productivity varies across functional types

In our meta- analysis we observed that most abundant species were conifers and they showed very consistent results (I^2= 66.9%) between studies which confirms the reliability of the results obtained in the analysis. Moreover, meta- analysis results showed a positive association between WUE_i and productivity in conifers, but productivity is only weakly controlled by WUE_i. This also has been confirmed by several studies included in the meta-analysis (e.g. Marguerit *et al.*, 2014; Xue *et al.*, 2013; Hawkins *et al.*, 2010; Baltunis *et al.*, 2008; Prasolova *et al.*, 2003; Prasolova *et al.*, 2001). The growth of the conifers could be partially influenced by WUE_i along with other key factors such as high temperature, high and low soil moisture condition, intensity and duration of light, increased CO_2 concentration in atmosphere, poor soil structure, high pH value in soil, low nutrient supply.

Our meta-analysis did not find any significant association between WUE_i and productivity in broadleaves. This could be happen by the influence of the large variability between studies in broadleaves (I^2=96.7%). It was well established the isohydric behavior in many conifers species leading to high WUE_i through stomatal closure. Klein *et al.*, (2013) found that isohydric pine species with high WUE_i shows comparable growth rates than anisohydric oaks with lower WUE_i. Our result were more consistent with the observations of the study. Ferrio, *et al.*(2003) also found that the 1.5‰ higher $\delta^{13}C$ in *P. halepensis* compared to *Q. ilex*.

On the contrary, a significant and highly positive association between $\delta^{13}C$ and growth has been observed in shrubs (e.g. Toillon *et al.*, 2013; Gray *et al.*, 2013; Pennington *et al.*, 1999). The same facts have been obtained in our analysis. A high positive correlations between WUE_i and productivity in shrubs suggests that productivity of shrubs was strongly driven by WUE_i, and the variation of WUE_i among the measured species was controlled by CO_2 assimilation rate than by stomatal conductance. Alternatively, Moreno-Gutiérrez *et al*. (2014) found that *Rhamnus lycioides* shrubs has increase WUE_i as a result of their ability to adjust their stomatal conductance in response to increasing atmospheric CO2 and temperature. However, the adaptive response of this shrub is much weaker when they were submitted in drought-stress.

We have found significantly positive but weak association between WUE_i and productivity in both evergreen and deciduous species due to the variations in assimilation rate. Most of the evergreens were conifer species in our dataset. That's why we didn't found too much difference in global estimated correlation value between conifers and evergreen. The correlation was weak but compared to greater in deciduous than evergreen species. However, most of the broadleaves and shrubs were included in deciduous dataset. As a consequence, combined dataset of shrubs and broadleaves showed higher global estimated correlation value between WUE_i and productivity in deciduous compared to evergreen. Antúnez *et al.,* (2001) also confirmed that the intra-specific variation in WUE_i on growth rate was higher in deciduous species compared to evergreen species.

4.3 Association between WUEi and productivity varies across genetic material

Normally when we select genetic materials for breeding purpose we would expect that there is high variability among population, medium variability among families and low variability among clones. Our result showed positive but weak association between WUE_i and productivity in all type of genetic materials. But comparatively high association between WUE_i and growth has been found among clones, medium among populations and lower among families by our study, and shows that variation in WUE_i is not strongly controlled by assimilation rate in all genetic materials. This fact also has been revealed in studies by Jansen *et al.* (2013) and Zhang *et al.* (1996) among population and other stydies by Xue *et al.*, (2013); Toillon *et al.*, (2013); Hawkins *et al.*, (2010) among clones. Correia *et al.*, (2008) found that the high variation in WUE_i among populations could be related to microenvironmental conditions or to short-term climatic variations than to regional differences in climate. Moreover when we tested growth trait effect within each genetic material we found high positive association between WUE_i and biomass production than height increment among population and families that is strongly controlled by assimilation rate rather than stomatal conductance. Alternatively, high positive association found between WUE_i and height than biomass production among clones. Diameter was always non significant in each type of genetic material.

4.4 Association between WUEi and productivity varies across biome type

There is an argument exists regarding the concept of increasing biomass is strongly driven by increasing WUE_i. Several authors found different types of results. For instance Tang *et al.*, (2014) found a consistent increase in latitudinal trend in WUE_i rising from subtropics to northern high latitudes, resulting to higher vegetation productivity was strongly driven by increase WUE_i for forest in mid- and high latitudes (51° N). Boreal systems poses a cool condition that limit water loss and high incoming radiation in summer to maximize the photosynthetic uptake which helps to increase productivity of trees. Our study found the same pattern that the strength of the association between WUE_i and productivity strongly increase from mediterranean to boreal biome (Figure 3.9). These explain also the behavior of stomatal conductance by the limited water loss due to decrease temperature. Alternatively, Peñuelas *et al.*, (2011) found no changes in tree growth even after increase of 20.5% WUE_i during their 40 years study data among different biomes. Therefore, they concluded that the rate of biomass carbon sequestration in tropical, arid, Mediterranean, wet temperate and boreal ecosystems may not increase with increasing atmospheric CO2 concentrations.

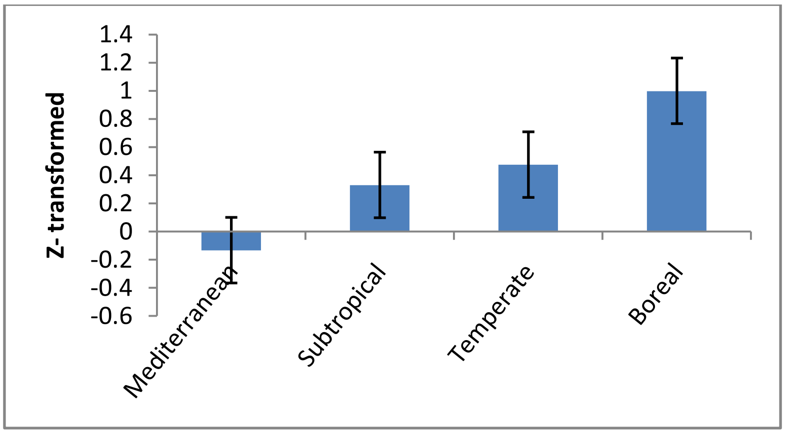

Figure 3.9: Z-transformed effect size and 95% confidence intervals (error bars) for different biomes.

4.5 Association between WUEi and productivity varies across testing condition

Limited water loss due to controlled environment in greenhouse (contrary to field) increases photosynthetic capacity. Therefore, higher productivity is driven by increased WUE_i. Our results also confirm this fact. We found positively strong correlation between WUE_i and productivity in green house than in field. This could be explained as productivity is strongly driven by WUE_i in greenhouse conditions than in field condition, which indicates larger changes in assimilation rate. Moreover, similar results were found in several studies (e.g. Aranda *et al.*, 2010; Lauteri *et al.*, 2004; Pennington *et al.*, 1999;Z hang *et al.*, 1996).

4.6 Association between WUEi and Productivity varies across ontogenic stages

The ontogenic stage effect on $\delta^{13}C$ has been confirmed by several studies. For instance, Marshall & Monserud, (1996) analysed the effect of ontogeny stage (i.e. adult trees versus sapling versus seedlings) of ponderosa pine, western white pine and douglas-fir tree. They found the variation of every tree in $\delta^{13}C$ decrease from seedlings to sapling to adult tress. In the contrary, Duquesnay *et al.*, (1998) conducted their study on *Fagus sylvatica* and observed an increase of $\delta^{13}C$ in seedling stage. This was also confirmed by our meta-analysis indicated that the positive high association between $\delta^{13}C$ and growth in seedling stage.

4.7 Effect of testing environments on relationship between WUE_i and productivity

Flanagan & Johnsen, (1995) conducted the study on families of *Picea mariana* and they found positive association between $\delta^{13}C$ and growth in optimal environment. The meta-analysis results also showed positive but weak association between $\delta^{13}C$ and growth when testing environmental conditions were optimal. On the other hand, meta- analysis showed no significant association between $\delta^{13}C$ and growth in suboptimal environment which could be more emphasized by the experimental treatment effect analysis. Theoretically, WUE_i of plant could either decrease or increase productivity. If stomata close partially, thus limiting photosynthesis will increase WUE_i. Therefore, plants adapted to limited water supply grow more efficiently in water stressed conditions than plants not adapted to limited water supply do (Wright *et al.*, 1993). Drought-adapted species favor carbon CO_2 assimilation under irrigated conditions that leading to higher discrimination against ^{13}C. However, drought adaptation in tree populations is not necessarily reflected in higher WUE_i and lower WUE_i may be related to adaptive mechanisms under genetic control (Hubick & Gibson, 1993). We found a significant difference in the association between $\delta^{13}C$ and growth that was less prominent in the irrigated treatment than in the drought treatment. This leads to the fact that high intra-specific variations in $\delta^{13}C$ on growth in drought treatment are influenced by the change of CO_2 assimilation rate**.** Our findings are in agreement with Sun et al., (1996). He also explained that high $\delta^{13}C$ and also low c_i/c_a can arise because of low g_s or high photosynthetic capacity, both leading to high productivity driven by high WUE_i.

4.8 Limitation of meta- analysis and research gaps

Most of the selected studies were conducted on coniferous species in our meta- analysis. However, some limitations existed. For instance, some papers did not show the correlation statistics or other transformable statistics such as mean value in table or graph. Therefore, we could not include those papers in our meta- analysis [e.g. (Cao *et al.,* 2012; Monclus *et al.*, 2005)] (iii) We focused only on the relationship between $\delta^{13}C$ and above- ground biomass since the height and diameter can easily be measured than below ground part of the trees. Moreover, there was a lack of sufficient studies conducted on hardwood and shrubs species along with studies in boreal biome and nursery condition as compared to their counterpart. If we had equal amount of studies for all the cases, then we could probably get a better result in overall global estimated correlation.

CHAPTER FIVE: CONCLUSION

5.1 Conclusion

Intra- specific genetic variation in WUE_i (measured through $\delta^{13}C$) in relation to productivity is essential to investigate adaptation pattern under climate change scenarios.

1) Our meta-analysis indicated that biomass production was strongly driven by an increase in WUE_i while height increment was weakly driven by that. The biomass production was controlled by CO_2 assimilation rate rather than stomatal conductance. Apart from this the diameter was not driven by WUE_i.
2) In our analysis most of the species were conifers and the association between WUE_i and productivity was weak but highly consistent. Shrubs showed high positive correlation between them. The broadleaves and shrubs showed a more positive association when we combine them in deciduous functional type.
3) Comparatively higher association between WUE_i and productivity was observed among clone, medium among population and low among families. Among populations and families biomass production was strongly driven by WUE_i than height increment did, while among clones height increment was strongly driven by WUE_i than biomass production did.
4) The strength of the association between WUE_i and productivity was increase from Mediterranean to boreal biome.
5) Seedling stage productivity was strongly driven by WUE_i.
6) In green house the plant growth was strongly driven by WUE_i. But in field and nursery productivity was weakly driven by $WUE_{i.}$
7) In optimal environment productivity of plant was not strongly driven by WUE_i while suboptimal condition showed no association between productivity and WUE_i
8) Plant growth was strongly controlled by WUE_i under drought conditions.

After many years of research we have less information on broadleaves and shrubs species. In future, we would have to find more association between WUE_i and productivity if we include more studies on broadleaves and shrubs in our meta-analysis. However, this meta-analysis with existing literature was the first approach to understand the general patterns of the association between WUE_i and productivity at the intra-specific level.

REFERENCES

Aitken, S. N., Kavanagh, K. L., &Yoder, B. J. (1995). Genetic variation in seedling water-use efficiency as estimated by carbon isotope ratios and its relationship to sapling growth in douglas-Fir. *Forest Genetics*, *2*(4), 199–206.

Aletà, N., Vilanova, A., Díaz, R., & Voltas, J. (2009). Genetic variation for carbon isotope composition in Juglans regia L.: relationships with growth, phenology and climate of origin. *Annals of Forest Science*, *66*(4), 413–413. http://doi.org/10.1051/forest/2009021

Antúnez, I., Retamosa, E. C., & Villar, R. (2001). Relative growth rate in phylogenetically related deciduous and evergreen woody species. *Oecologia*, *128*(2), 172–180. http://doi.org/10.1007/s004420100645

Bacon, M. (2004). Water - use efficiency in plant biology. Blackwell publishing, Ltd, UK.

Aranda, I., Alía, R., Ortega, U., Dantas, Â. K., & Majada, J. (2010). Intra-specific variability in biomass partitioning and carbon isotopic discrimination under moderate drought stress in seedlings from four Pinus pinaster populations. *Tree Genetics and Genomes*, *6*(2), 169–178. http://doi.org/10.1007/s11295-009-0238-5

Baltunis, B. S., Martin, T. a., Huber, D. a., & Davis, J. M. (2008). Inheritance of foliar stable carbon isotope discrimination and third-year height in Pinus taeda clones on contrasting sites in Florida and Georgia. *Tree Genetics and Genomes*, *4*(4), 797–807. http://doi.org/10.1007/s11295-008-0152-2

Bhagsari, A. S., & Brown, R. H. (1986). Leaf Photosynthesis and its Correlation with Leaf Area. *Crop Science*, *26*, 127–132. http://doi.org/10.2135/cropsci1986.0011183X002600010030x

Cao, X., Jia, J. B., Li, H., Li, M. C., Luo, J., Liang, Z. S., … Luo, Z. B. (2012). Photosynthesis, water use efficiency and stable carbon isotope composition are associated with anatomical properties of leaf and xylem in six poplar species. *Plant Biology*, *14*(4), 612–620. http://doi.org/10.1111/j.1438-8677.2011.00531.x

Chapin III, F.S., Matson, P.A., Mooney, H.A., (2002). Principles of Terrestrial Ecosystem Ecology. Springer Science, New York.

Condon, a. G., Richards, R. a., Rebetzke, G. J., & Farquhar, G. D. (2004). Breeding for high water-use efficiency. *Journal of Experimental Botany*, *55*(407), 2447–2460. http://doi.org/10.1093/jxb/erh277

Condon, a. G., Richards, R., Rebetzke, G., & Farquhar, G. (2002). Improving intrinsic water use efficiency and crop yield. *Crop Science, 42*, 122–131. http://doi.org/10.2135/cropsci2002.0122

Condon, A., & Richards, R. (1992). Broad sense heritability and genotype × environment interaction for carbon isotope discrimination in field-grown wheat . *Australian Journal of Agricultural Research*, *43*(5), 921. http://doi.org/10.1071/AR9920921

Corcuera, L., Gil-Pelegrín, E., Notivol, E., & Tognetti, R. (2012). Differences in hydraulic architecture between mesic and xeric Pinus pinaster populations at the seedling stage. *Tree Physiology*, *32*(12), 1442–1457. http://doi.org/10.1093/treephys/tps103

Correia, I., Almeida, M. H., Aguiar, A., Alía, R., David, T. S., & Pereira, J. S. (2008). Variations in growth, survival and carbon isotope composition (delta(13)C) among Pinus pinaster populations of different geographic origins. *Tree Physiology*, *28*(10), 1545–1552.

Cregg, B. M., Olivas-García, J. M., & Hennessey, T. C. (2000). Provenance variation in carbon isotope discrimination of mature ponderosa pine trees at two locations in the Great Plains. *Canadian Journal of Forest Research*, *30*(3), 428–439. http://doi.org/10.1139/x99-226

Duquesnay, a., Bréda, N., Stievenard, M., & Dupouey, J. L. (1998). Changes of tree-ring δ13C and water-use efficiency of beech (Fagus sylvatica L.) in north-eastern France during the past century. *Plant, Cell and Environment*, *21*(6), 565–572. http://doi.org/10.1046/j.1365-3040.1998.00304.x

Ehleringer, J. R. (1991). *Carbon Isotope Techniques*. *Carbon Isotope Techniques*. Elsevier. http://doi.org/10.1016/B978-0-12-179730-0.50017-5

Euler, F. von, Baradat, P., & Lemoine, B. (1992). Effects of plantation density and spacing on competitive interactions among half-sib families of maritime pine. *Canadian Journal of Forest Research*, *22*(4), 482–489. http://doi.org/10.1139/x92-063

Farquhar, G. (1989). Carbon Isotope Discrimination And Photosynthesis. *Annual Review of Plant Physiology and Plant Molecular Biology*, *40*(1), 503–537. http://doi.org/10.1146/annurev.arplant.40.1.503

Farquhar, G., & Richards, R. (1984). Isotopic Composition of Plant Carbon Correlates With Water-Use Efficiency of Wheat Genotypes. *Australian Journal of Plant Physiology*, *11*(6), 539. http://doi.org/10.1071/PP9840539

Ferrio, J. P., Florit, a., Vega, a., Serrano, L., & Voltas, J. (2003). ??13C and tree-ring width reflect different drought responses in Quercus ilex and Pinus halepensis. *Oecologia*, *137*(4), 512–518. http://doi.org/10.1007/s00442-003-1372-7

Ferrio, J. P., Voltas, J., & Araus, J. L. (2003). Use of carbon isotope composition in monitoring environmental changes. *Management of Environmental Quality: An International Journal*, *14*(1), 82–98. http://doi.org/10.1108/14777830310460405

Flanagan, L. B., & Johnsen, K. H. (1995). Genetic variation in carbon isotope discrimination and its relationship to growth under field conditions in full-sib families of Piceamariana. *Canadian Journal of Forest Research*, *25*(1), 39–47. http://doi.org/10.1139/x95-005

Grant, O. M., Chaves, M. M., & Jones, H. G. (2006). Optimizing thermal imaging as a technique for detecting stomatal closure induced by drought stress under greenhouse conditions. *Physiologia Plantarum*, *127*(3), 507–518. http://doi.org/10.1111/j.1399-3054.2006.00686.x

Gray, A., Odee, D., Cavers, S., Wilson, J., Telford, A., Grant, F., … Stott, A. (2013). Does geographic origin dictate ecological strategies in Acacia senegal (L.) Willd.? Evidence from carbon and nitrogen stable isotopes. *Plant and Soil*, *369*(1-2), 479–496. http://doi.org/10.1007/s11104-013-1593-4

Gyenge, J., Fernández, M. E., Sarasola, M., & Schlichter, T. (2008). Testing a hypothesis of the relationship between productivity and water use efficiency in Patagonian forests with native and exotic species. *Forest Ecology and Management*, *255*(8-9), 3281–3287. http://doi.org/10.1016/j.foreco.2008.01.078

Hawkins, B. J., Xue, J., Bown, H. E., & Clinton, P. W. (2010). Relating nutritional and physiological characteristics to growth of Pinus radiata clones planted on a range of sites in New Zealand. *Tree Physiology*, *30*(9), 1174–1191. http://doi.org/10.1093/treephys/tpq069

Higgins, J. P. T., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*(11), 1539–1558. http://doi.org/10.1002/sim.1186

Huedo-Medina, T. B., Sánchez-Meca, J., Marín-Martínez, F., & Botella, J. (2006). Assessing heterogeneity in meta-analysis: Q statistic or I2 index? *Psychological Methods*, *11*(2), 193–206. http://doi.org/10.1037/1082-989X.11.2.193

Jansen, K., Sohrt, J., Kohnle, U., Ensminger, I., & Gessler, A. (2013). Tree ring isotopic composition, radial increment and height growth reveal provenance-specific reactions of Douglas-fir towards environmental parameters. *Trees - Structure and Function*, *27*(1), 37–52. http://doi.org/10.1007/s00468-012-0765-9

Johnsen, K. H., Flanagan, L. B., Huber, D. a., & Major, J. E. (1999). Genetic variation in growth, carbon isotope discrimination, and foliar N concentration in *Picea mariana*: analyses from a half-diallel mating design using field-grown trees. *Canadian Journal of Forest Research*, *29*(11), 1727–1735. http://doi.org/10.1139/cjfr-29-11-1727

Johnsen, K. H., & Major, J. E. (1995). Gas exchange of 20-year-old black spruce families displaying a genotype × environment interaction in growth rate. *Canadian Journal of Forest Research*, *25*(3), 430–439. http://doi.org/10.1139/x95-048

Klein, T., Shpringer, I., Fikler, B., Elbaz, G., Cohen, S., & Yakir, D. (2013). Relationships between stomatal regulation, water-use, and water-use efficiency of two coexisting key Mediterranean tree species. *Forest Ecology and Management*, *302*(July 2015), 34–42. http://doi.org/10.1016/j.foreco.2013.03.044

Knapp, A. K., Briggs, J. M., & Koelliker, J. K. (2001). Frequency and Extent of Water Limitation to Primary Production in a Mesic Temperate Grassland. *Ecosystems*, *4*(1), 19–28. http://doi.org/10.2307/3658783

Korner, C. (1991). Some Often Overlooked Plant Characteristics as Determinants of Plant Growth: A Reconsideration. *Functional Ecology*, *5*(2), 162–173 CR – Copyright © 1991 British Ecolog. http://doi.org/10.2307/2389254

Kozlowski, T. T., Kramer, P. J., & Pallardy, S. G. (1991). The Physiological ecology of woody plants. *Academic Press*, San Diego, California, USA.

Kruse, J., Hopmans, P., Rennenberg, H., & Adams, M. (2012). Modern tools to tackle traditional concerns: Evaluation of site productivity and Pinus radiata management via δ13C- and δ18O-analysis of tree-rings. *Forest Ecology and Management*, *285*(2012), 227–238. http://doi.org/10.1016/j.foreco.2012.08.011

Lambers, H., Chapin, F. S. & Pons, T.L. (1998). Plant physiological ecology III. Springer-Verlag New York Berlin Heidelberg.

Lauteri, M., Pliura, a., Monteverdi, M. C., Brugnoli, E., Villani, F., & Eriksson, G. (2004). Genetic variation in carbon isotope discrimination in six European populations of Castanea sativa Mill. originating from contrasting localities. *Journal of Evolutionary Biology*, *17*(6), 1286–1296. http://doi.org/10.1111/j.1420-9101.2004.00765.x

Lauteri, M., Scartazza, A., Guido, M. C., & Brugnoli, E. (1997). Genetic Variation in Photosynthetic Capacity, Carbon Isotope Discrimination and Mesophyll Conductance in Provenances of Castanea sativa Adapted to Different Environments. *Functional Ecology*, *11*(6), 675–683. http://doi.org/10.2307/2390297

Le Roux, D., Le Roux, D., Stock, W. D., Stock, W. D., Bond, W. J., Bond, W. J., … Maphanga, D. (1996). Dry mass allocation, water use efficiency and δ 13 C in clones of Eucalyptus grandis, E. grandis × camaldulensis and E. grandis × nitens grown under two irrigation regimes. *Tree Physiology*, *16*, 497–502. http://doi.org/10.1093/treephys/16.5.497

Livingston, N. J., Guy, R. D., Sun, Z. J., & Ethier, G. J. (1999). The effects of nitrogen stress on the stable carbon isotope composition, productivity and water use efficiency of white spruce (Picea glauca (Moench) Voss) seedlings. *Plant, Cell & Environment*, *22*(3), 281–289.

Marguerit, E., Bouffier, L., Chancerel, E., Costa, P., Lagane, F., Guehl, J.-M., … Brendel, O. (2014). The genetics of water-use efficiency and its relation to growth in maritime pine. *Journal of Experimental Botany*, *65*(17), 1–12. http://doi.org/10.1093/jxb/eru226

Marshall, J. D., & Monserud, R. A. (1996). Homostatic gas exchange parameter inferred from $^{13}C/^{12}C$ in tree ring of conifers. Ecologia, 105, 13–21.

Monclus, R., Monclus, R., Dreyer, E., Dreyer, E., Villar, M., Villar, M., … Brignolas, F. (2005). Impact of drought on productivity and water use ef ciency in 29 genotypes of. *New Phytologist*. http://doi.org/10.1111/j.1469-8137.2005.01630.x

Monclus, R., Villar, M., Barbaroux, C., Bastien, C., Fichot, R., Delmotte, F. M., … Brignolas, F. (2009). Productivity, water-use efficiency and tolerance to moderate water deficit correlate in 33 poplar genotypes from a Populus deltoides × Populus trichocarpa F1 progeny. *Tree Physiology*, *29*(11), 1329–1339. http://doi.org/10.1093/treephys/tpp075

Moreno-Gutiérrez, C., Battipaglia, G., Cherubini, P., Delgado Huertas, A., & Querejeta, J. I. (2014). Pine afforestation decreases the long-term performance of understorey shrubs in a semi-arid Mediterranean ecosystem: A stable isotope approach. *Functional Ecology*, (July 2015). http://doi.org/10.1111/1365-2435.12311

Nguyen-Queyrens, A., Ferhi, A., Loustau, D., & Guehl, J.-M. (1998). Within-ring δ13C spatial variability and interannual variations in wood cellulose of two contrasting provenances of Pinus pinaster. *Canadian Journal of Forest Research*, *28*(5), 766–773. http://doi.org/10.1139/x98-044

Oliver, O.L. & Larson, B. C. (1996). Forest stand dynamics update edition. USA

Pallardy, S. G. (2008). Physiological of woody plants. *Academic Press*, San Diego, California, USA, 3rd edition.

Pastorino, M. J., Aparicio, a. G., Marchelli, P., & Gallo, L. a. (2012). Genetic variation in seedling water-use efficiency of Patagonian Cypress populations from contrasting precipitation regimes assessed through carbon isotope discrimination. *Forest Systems*, *21*(2), 189–198. http://doi.org/10.5424/fs/2012212-02272

Pennington, R. E., Tischler, C. R., Johnson, H. B., & Polley, H. W. (1999). Genetic variation for carbon isotope composition in honey mesquite (Prosopis glandulosa). *Tree Physiology*, *19*(9), 583–589. http://doi.org/none

Peñuelas, J., Canadell, J. G., & Ogaya, R. (2011). Increased water-use efficiency during the 20th century did not translate into enhanced tree growth. *Global Ecology and Biogeography*, *20*(4), 597–608. http://doi.org/10.1111/j.1466-8238.2010.00608.x

Pita, P. (2001). Carbon isotope discrimination and its relationship to drought resistance under field conditions in genotypes of Eucalyptus globulus Labill. *Forest Ecology and Management*, *141*(3), 211–221. http://doi.org/10.1016/S0378-1127(00)00330-3

Prasolova, N. V, Xu, Z., Farquhar, G. D., Saffigna, P. G., & Dieters, M. J. (2001). Canopy carbon and oxygen isotope composition of 9-year-old hoop pine families in relation to seedling carbon isotope composition, growth, field growth performance, and canopy nitrogen concentration. *Canadian Journal of Forest Research*, *31*(4), 673–681. http://doi.org/10.1139/x00-207

Prasolova, N. V, Xu, Z. H., Farquhar, G. D., Saffigna, P. G., & Dieters, M. J. (2000). Variation in branchlet delta13C in relation to branchlet nitrogen concentration and growth in 8-year-old hoop pine families (Araucaria cunninghamii) in subtropical Australia. *Tree Physiology*, *20*(15), 1049–1055.

Prasolova, N. V., Xu, Z. H., Lundkvist, K., Farquhar, G. D., Dieters, M. J., Walker, S., & Saffigna, P. G. (2003). Genetic variation in foliar carbon isotope composition in relation to tree growth and foliar nitrogen concentration in clones of the F1 hybrid between slash pine and Caribbean pine. *Forest Ecology and Management*, *172*(2-3), 145–160. http://doi.org/10.1016/S0378-1127(01)00807-6

Robson, T. M., Sánchez-Gómez, D., Cano, F. J., & Aranda, I. (2012). Variation in functional leaf traits among beech provenances during a Spanish summer reflects the differences in their origin. *Tree Genetics and Genomes*, *8*(5), 1111–1121. http://doi.org/10.1007/s11295-012-0496-5

Rosenthal, R. (1995). Writing Meta-Analytic Reviews, *118*(2), 183–192.

Rowell, D. M., Ades, P. K., Tausz, M., Arndt, S. K., & Adams, M. a. (2009). Lack of genetic variation in tree ring δ13C suggests a uniform, stomatally-driven response to drought stress across Pinus radiata genotypes. *Tree Physiology*, *29*(2), 191–198. http://doi.org/10.1093/treephys/tpn015

Scheidegger, Y., Saurer, M., Bahn, M., & Siegwolf, R. (2000). Linking stable oxygen and carbon isotopes with stomatal conductance and photosynthetic capacity: a conceptual model. *Oecologia*, *125*(3), 350–357. http://doi.org/10.1007/s004420000466

Seibt, U., Rajabi, A., Griffiths, H., & Berry, J. a. (2008). Carbon isotopes and water use efficiency: Sense and sensitivity. *Oecologia*, *155*(3), 441–454. http://doi.org/10.1007/s00442-007-0932-7

Sun, Z. J., Livingston, N. J., Guy, R. D., & Ethier, G. J. (1996). Stable carbon isotopes as indicators of increased water use efficiency and productivity in white spruce (Picea glauca (Moench) Voss) seedlings. *Plant, Cell and Environment*, *19*(7), 887–894. http://doi.org/doi:10.1111/j.1365-3040.1996.tb00425.x

Tang, X., Li, H., Desai, A. R., Nagy, Z., Luo, J., Kolb, T. E., … Ammann, C. (2014). How is water-use efficiency of terrestrial ecosystems distributed and changing on Earth? *Scientific Reports*, 1–11. http://doi.org/10.1038/srep07483

Temme, a. a., Cornwell, W. K., Cornelissen, J. H. C., & Aerts, R. (2013). Meta-analysis reveals profound responses of plant traits to glacial CO2 levels. *Ecology and Evolution*, *3*(13), 4525–4535. http://doi.org/10.1002/ece3.836

Tian, H., Chen, G., Liu, M., Zhang, C., Sun, G., Lu, C., … Chappelka, A. (2010). Model estimates of net primary productivity, evapotranspiration, and water use efficiency in the terrestrial ecosystems of the southern United States during 1895-2007. *Forest Ecology and Management*, *259*(7), 1311–1327. http://doi.org/10.1016/j.foreco.2009.10.009

Tognetti, R., Michelozzi, M., Lauteri, M., Brugnoli, E., & Giannini, R. (2000). Geographic variation in growth, carbon isotope discrimination, and monoterpene composition in Pinus pinaster Ait. provenances. *Canadian Journal of Forest Research*, *30*(11), 1682–1690. http://doi.org/10.1139/cjfr-30-11-1682

Toillon, J., Rollin, B., Dallé, E., Feinard-Duranceau, M., Bastien, J. C., Brignolas, F., & Marron, N. (2013). Variability and plasticity of productivity, water-use efficiency, and nitrogen exportation rate in Salix short rotation coppice. *Biomass and Bioenergy*, *56*(0), 392–404. http://doi.org/10.1016/j.biombioe.2013.05.017

Voltas, J., Chambel, M. R., Prada, M. A., & Ferrio, J. P. (2008). Climate-related variability in carbon and oxygen stable isotopes among populations of Aleppo pine grown in common-garden tests. *Trees - Structure and Function*, *22*(6), 759–769. http://doi.org/10.1007/s00468-008-0236-5

Waring, R.H., Running, S.W., (2007). Forest Ecosystems Analysis at Multiple Scales, 3rd ed. Elsevier Academic Press, Burlington, San Diego, London.

Warren, C. (2007). Corrigendum to: Estimating the internal conductance to CO 2 movement. *Functional Plant Biology*, *34*(1), 82. http://doi.org/10.1071/FP05298_CO

Wright, G. C., Hubick, K. T., Farquhar, G. D., Nageswara, R.C. (1993). Genetic and environmental variation in transpiration efficiency and its correlation with carbon isotope discrimination and specific leaf area in peanut. *Stable isotopes and plant- carbon relations*, 247-267

Xu, Z. H., Saffigna, P. G., Farquhar, G. D., Simpson, J. a., Haines, R. J., Walker, S., … Guinto, D. (2000). Carbon isotope discrimination and oxygen isotope composition in clones of the F(1) hybrid between slash pine and Caribbean pine in relation to tree growth, water-use efficiency and foliar nutrient concentration. *Tree Physiology*, *20*(18), 1209–1217. http://doi.org/S

Xu, Z., Prasolova, N., Lundkvist, K., Beadle, C., & Leaman, T. (2003). Genetic variation in branchlet carbon and nitrogen isotope composition and nutrient concentration of 11-year-old hoop pine families in relation to tree growth in subtropical Australia. *Forest Ecology and Management*, *186*(1-3), 359–371. http://doi.org/10.1016/S0378-1127(03)00304-9

Xue, J., Clinton, P. W., Davis, M. R., Siddiqui, T., Beets, P. N., & Leckie, A. C. (2013). Genotypic variation in foliar nutrient concentrations, ??13C, and chlorophyll fluorescence in relation to tree growth of radiata pine clones in a serpentine soil. *Journal of Plant Nutrition and Soil Science*, *176*(5), 724–733. http://doi.org/10.1002/jpln.201200272

Zhang, J., & Marshall, J. D. (1994). Population differences in water-use efficiency of well-watered and water-stressed western larch seedlings. *Canadian Journal of Forest Research*, *24*(1), 92–99. http://doi.org/10.1139/x94-014

Zhang, J., Marshall, J., & Jaquish, B. (1993). Genetic differentiation in carbon isotope discrimination and gas exchange in Pseudotsuga menziesii. *Oecologia*, *93*(1), 80–87. http://doi.org/10.1007/BF00321195

Zhang, J., Marshall, J. D., & Fins, L. (1996). Correlated population differences in dry matter accumulation, allocation, and water-use efficiency, in three sympatric onifer species. *Forest Science*, *42*(2).

APPENDICES

Appendix 1: Summary of the data for height included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Adult trees	Height	m	ƌ13C	7	-0.32
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Height	cm	ƌ13C	5	0.04
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Height	cm	ƌ13C	5	-0.27
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƌ13C	5	0.224
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƌ13C	5	0.86
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƌ13C	5	-0.173
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƌ13C	5	-0.332
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ƌ13C	50	0.3
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ƌ13C	50	0.32
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ƌ13C	50	0.08
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Sapling	Height	cm	ƌ13C	6	0.54
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Sapling	Height	cm	ƌ13C	6	0.346
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Sapling	Height	cm	ƌ13C	6	-0.14
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Sapling	Height	m	ƌ13C	25	-0.4
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Sapling	Height	m	ƌ13C	25	-0.38
Zhang et. al.	1996	Pinus	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	-0.32
Zhang et. al.	1996	Pinus	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.1
Zhang et. al.	1996	Pseudotsuga	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.11

Zhang et. al.	1996	Pseudotsuga	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.75
Zhang et. al.	1996	Larix	Glasshouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	ƌ13C	42	0.41
Zhang et. al.	1996	Larix	Glasshouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	ƌ13C	42	0.23
Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.03
Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.5
Zhang et. al.	1996	Pinus	Field	Temperate	Populations	17	Leaves	Adult trees	Height	cm	ƌ13C	17	0.14
Zhang et. al.	1996	Larix	Field	Temperate	Populations	16	Leaves	Adult trees	Height	cm	ƌ13C	16	0.51
Xu et. al.	2000	Pinus	Field	Sub tropical	Clone	8	Leaves	Sapling	Height	m	ƌ13C	8	0.96
Baltunis et.al.	2008	Pinus	Field	Sub tropical	Families	61	Leaves	Seedlings	Height	cm	ƌ13C	61	0.42
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƌ13C	122	0.198
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƌ13C	122	0.315
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƌ13C	122	0.363
Pastorino et. al.	2012	Austrocedrus	Field	Temperate	Families	41	Leaves	Seedlings	Height	cm	ƌ13C	41	0.684
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ƌ13C	6	-0.33
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ƌ13C	6	0.327
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ƌ13C	6	0.479
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Seedlings	Height	m	ƌ13C	4	0.84
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Adult trees	Height	m	ƌ13C	4	0.832
Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Adult trees	Height	cm	ƌ13C	18	0.97
Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƌ13C	101	0.368
Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƌ13C	100	0.41
Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Seedlings	Height	m	ƌ13C	113	0.301
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƌ13C	27	0.16
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƌ13C	27	-0.04
Voltas J.	2010	Pinus	Nursery	Mediterranean	Populations	25	Leaves	Seedlings	Height	m	ƌ13C	25	0.46

(Unpublished)													
Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Height	m	ƌ13C	8	-0.58
Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Adult trees	Height	cm	ƌ13C	6	-0.23
Lauteri et. al.	2004	Castanea	Chamber	Temperate	Populations	6	Leaves	Seedlings	Height		ƌ13C	48	0.52
Lauteri et. al.	2004	Castanea	Chamber	Temperate	Populations	6	Leaves	Seedlings	Height		ƌ13C	48	0.85
Lauteri et. al.	2004	Castanea	Chamber	Temperate	Populations	6	Leaves	Seedlings	Height		ƌ13C	48	0.99
Lauteri et. al.	2004	Castanea	Chamber	Temperate	Populations	6	Leaves	Seedlings	Height		ƌ13C	48	0.12
Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Adult trees	Height	m	ƌ13C	5	0.75
Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Height	cm	ƌ13C	22	–0.83
Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Height	cm	ƌ13C	22	–0.91
Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Height	cm	ƌ13C	33	0.33
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	7	Leaves	Seedlings	Height	cm	ƌ13C	7	0.955
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	9	Leaves	Seedlings	Height	cm	ƌ13C	9	0.957
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	15	Leaves	Seedlings	Height	cm	ƌ13C	15	0.035
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	ƌ13C	6	0.87
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	ƌ13C	6	0.95

Appendix 2: Summary of the data for diameter included in the meta- analysis

Study	Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	No of entries	Measurement part	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Diameter	cm	ƌ13C	7	0.008
2	Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Diameter	mm	ƌ13C	5	-0.16
3	Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Diameter	mm	ƌ13C	5	-0.15
4	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	-0.51
5	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.53
6	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.214
7	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.74
8	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	0.26
9	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	0.21
10	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	-0.02
11	Brendel et.al.	2002	Pinus	Field	Mediterranean	Families	63	Woods	Diameter	mm	ƌ13C	63	0.27
12	Xue et. al.	2013	Pinus	Field	Temperate	Clone	20	Leaves	Diameter	mm	ƌ13C	80	0.33
13	Duglas et. al.	2008	Pinus	Field	Temperate	Families	7	Leaves	Diameter	mm	ƌ13C	7	-0.56
14	Duglas et. al.	2008	Pinus	Field	Temperate	Families	8	Leaves	Diameter	mm	ƌ13C	8	-0.19
15	Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Diameter	mm	ƌ13C	6	0.199
16	Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Diameter	mm	ƌ13C	6	0.278
17	Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Diameter	mm	ƌ13C	6	0.526
18	Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Diameter	cm	ƌ13C	25	-0.38
19	Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Diameter	cm	ƌ13C	25	-0.13
20	Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƌ13C	18	-0.7
21	Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƌ13C	18	0.19
22	Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƌ13C	18	0.16

23	Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ᵭ13C	18	0.66
24	Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Diameter	mm	ᵭ13C	42	0.31
25	Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Diameter	mm	ᵭ13C	42	0.25
26	Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Diameter	cm3	ᵭ13C	10	0.763
27	Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Diameter	cm3	ᵭ13C	10	0.582
28	Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Diameter	cm3	ᵭ13C	10	0.657
29	Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Diameter	cm	ᵭ13C	122	0.186
30	Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Diameter	cm	ᵭ13C	122	0.223
31	Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Diameter	cm	ᵭ13C	6	-0.96
32	Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Diameter	cm	ᵭ13C	18	0.64
33	Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Diameter	mm	ᵭ13C	113	0.187
34	Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Diameter	cm	ᵭ13C	27	0.12
35	Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Diameter	cm	ᵭ13C	27	0.38
36	Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Diameter	cm	ᵭ13C	8	-0.58
37	Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Diameter	mm	ᵭ13C	6	-0.27
38	Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	4	Woods	Diameter	cm	ᵭ13C	4	-0.83
39	Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	6	Woods	Diameter	cm	ᵭ13C	6	-0.88
40	Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	7	Woods	Diameter	cm	ᵭ13C	7	-0.89
41	Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	7	Woods	Diameter	m2/ha	ᵭ13C	7	-0.68
42	Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	5	Woods	Diameter	cm	ᵭ13C	5	-0.84
43	Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Diameter	cm	ᵭ13C	5	0.92
44	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Diameter	mm	ᵭ13C	22	–0.99
45	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Diameter	mm	ᵭ13C	22	–0.23
46	Dillen et.al.	2008	Populus	Field	Temperate	Families	50	Leaves	Diameter		ᵭ13C	50	-0.36
47	Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Diameter	mm	ᵭ13C	33	0.38
48	Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Diameter	mm	ᵭ13C	6	0.93

Appendix 3: Summary of the data for biomass included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	No of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Seedlings	Biomass	g	ƌ13C	20	0.69
Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Seedlings	Biomass	g	ƌ13C	20	0.59
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	-0.3
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	-0.26
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.16
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.81
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	ƌ13C	42	0.59
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	ƌ13C	42	0.74
Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.12
Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.62
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.71
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.85
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.58
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.27
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.75
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.7
Gray et.al.	2013	Acacia	Glasshouse	Sub tropical	Populations	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.21
Gray et.al.	2013	Acacia	Glasshouse	Sub tropical	Populations	11	Leaves	Seedlings	Biomass	g	ƌ13C	11	0.67
Lauteri et. al.	2004	Castanea	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.5
Lauteri et. al.	2004	Castanea	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.63
Lauteri et. al.	2004	Castanea	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.86
Lauteri et. al.	2004	Castanea	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.95
Lauteri et. al.	2004	Castanea	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.5
Lauteri et. al.	2004	Castanea	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.65

Lauteri et. al.	2004	Castanea	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.89
Lauteri et. al.	2004	Castanea	Glasshouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.95
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	-0.84
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.32
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.7
Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Biomass	g	ƌ13C	33	0.43
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.93
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.94

Appendix 4: Summary of the data for coniferous included in the meta- analysis

Articles	Year	Species	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Correia et.al.	2008	Coniferous	Pinus	Field	Mediterranean	Populations	7	Leaves	Height	m	ƌ13C	7	-0.3239
Correia et.al.	2008	Coniferous	Pinus	Field	Mediterranean	Populations	7	Leaves	Diameter	cm	ƌ13C	7	0.0083
Corcuera et. al.	2012	Coniferous	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	0.04
Corcuera et. al.	2012	Coniferous	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	-0.27
Corcuera et. al.	2012	Coniferous	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Diameter	mm	ƌ13C	5	-0.16
Corcuera et. al.	2012	Coniferous	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Diameter	mm	ƌ13C	5	-0.15
Tognetti et.al.	2000	Coniferous	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	0.224
Tognetti et.al.	2000	Coniferous	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	-0.506
Tognetti et.al.	2000	Coniferous	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	0.86
Tognetti et.al.	2000	Coniferous	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.53
Tognetti et.al.	2000	Coniferous	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	-0.173
Tognetti et.al.	2000	Coniferous	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.214
Tognetti et.al.	2000	Coniferous	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	-0.332
Tognetti et.al.	2000	Coniferous	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.746
Aranda et. al.	2010	Coniferous	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Biomass	g	ƌ13C	20	0.685

Aranda et. al.	2010	Coniferous	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Biomass	g	ƌ13C	20	0.591
Marguerit et.al.	2014	Coniferous	Pinus	Field	Mediterranean	Families	50	Woods	Height	cm	ƌ13C	50	0.3
Marguerit et.al.	2014	Coniferous	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	0.26
Marguerit et.al.	2014	Coniferous	Pinus	Field	Mediterranean	Families	50	Woods	Height	cm	ƌ13C	50	0.32
Marguerit et.al.	2014	Coniferous	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	0.21
Marguerit et.al.	2014	Coniferous	Pinus	Field	Mediterranean	Families	50	Woods	Height	cm	ƌ13C	50	0.08
Marguerit et.al.	2014	Coniferous	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	-0.02
Brendel et.al.	2002	Coniferous	Pinus	Field	Mediterranean	Families	63	Woods	Diameter	mm	ƌ13C	63	0.27
Xue et. al.	2013	Coniferous	Pinus	Field	Temperate	Clone	20	Leaves	Diameter	mm	ƌ13C	80	0.33
Xue et. al.	2013	Coniferous	Pinus	Field	Temperate	Clone	20	Leaves	Diameter	cm3	ƌ13C	80	0.31
Duglas et. al.	2008	Coniferous	Pinus	Field	Temperate	Families	7	Leaves	Diameter	mm	ƌ13C	7	-0.56
Duglas et. al.	2008	Coniferous	Pinus	Field	Temperate	Families	8	Leaves	Diameter	mm	ƌ13C	8	-0.19
Hawkins et.al.	2010	Coniferous	Pinus	Field	Temperate	Clone	6	Leaves	Height	cm	ƌ13C	6	0.54
Hawkins et.al.	2010	Coniferous	Pinus	Field	Temperate	Clone	6	Leaves	Diameter	mm	ƌ13C	6	0.199
Hawkins et.al.	2010	Coniferous	Pinus	Field	Temperate	Clone	6	Leaves	Height	cm	ƌ13C	6	0.346
Hawkins et.al.	2010	Coniferous	Pinus	Field	Temperate	Clone	6	Leaves	Diameter	mm	ƌ13C	6	0.278
Hawkins et.al.	2010	Coniferous	Pinus	Field	Temperate	Clone	6	Leaves	Height	cm	ƌ13C	6	-0.142
Hawkins et.al.	2010	Coniferous	Pinus	Field	Temperate	Clone	6	Leaves	Diameter	mm	ƌ13C	6	0.526
Voltas et.al.	2008	Coniferous	Pinus	Field	Mediterranean	Populations	25	Woods	Height	m	ƌ13C	25	-0.4
Voltas et.al.	2008	Coniferous	Pinus	Field	Mediterranean	Populations	25	Woods	Diameter	cm	ƌ13C	25	-0.38
Voltas et.al.	2008	Coniferous	Pinus	Field	Mediterranean	Populations	25	Woods	Height	m	ƌ13C	25	-0.38
Voltas et.al.	2008	Coniferous	Pinus	Field	Mediterranean	Populations	25	Woods	Diameter	cm	ƌ13C	25	-0.13
Zhang et. al.	1996	Coniferous	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Height	cm	ƌ13C	18	-0.32
Zhang et. al.	1996	Coniferous	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƌ13C	18	-0.7
Zhang et. al.	1996	Coniferous	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	18	-0.3
Zhang et. al.	1996	Coniferous	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Height	cm	ƌ13C	18	0.1
Zhang et. al.	1996	Coniferous	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƌ13C	18	0.19
Zhang et. al.	1996	Coniferous	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	18	-0.26
Zhang et. al.	1996	Coniferous	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Height	cm	ƌ13C	18	0.11
Zhang et. al.	1996	Coniferous	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƌ13C	18	0.16
Zhang et. al.	1996	Coniferous	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	18	0.16
Zhang et. al.	1996	Coniferous	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Height	cm	ƌ13C	18	0.75

Zhang et. al.	1996	Coniferous	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƌ13C	18	0.66
Zhang et. al.	1996	Coniferous	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	18	0.81
Zhang et. al.	1996	Coniferous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Height	cm	ƌ13C	42	0.41
Zhang et. al.	1996	Coniferous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Diameter	mm	ƌ13C	42	0.31
Zhang et. al.	1996	Coniferous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Biomass	g	ƌ13C	42	0.59
Zhang et. al.	1996	Coniferous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Height	cm	ƌ13C	42	0.23
Zhang et. al.	1996	Coniferous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Diameter	mm	ƌ13C	42	0.25
Zhang et. al.	1996	Coniferous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Biomass	g	ƌ13C	42	0.74
Zhang et. al.	1996	Coniferous	Pinus	Nursery	Temperate	Populations	6	Leaves	Height	cm	ƌ13C	18	0.03
Zhang et. al.	1996	Coniferous	Pinus	Nursery	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	18	0.12
Zhang et. al.	1996	Coniferous	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Height	cm	ƌ13C	18	0.5
Zhang et. al.	1996	Coniferous	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	18	0.62
Zhang et. al.	1996	Coniferous	Pinus	Field	Temperate	Populations	17	Leaves	Height	cm	ƌ13C	17	0.14
Zhang et. al.	1996	Coniferous	Larix	Field	Temperate	Populations	16	Leaves	Height	cm	ƌ13C	16	0.51
Xu et. al.	2000	Coniferous	Pinus	Field	Sub tropical	Clone	8	Leaves	Height	m	ƌ13C	8	0.96
Baltunis et.al.	2008	Coniferous	Pinus	Field	Sub tropical	Families	61	Leaves	Height	cm	ƌ13C	61	0.42
Guy and Holowachuk	2001	Coniferous	Pinus	Field	Temperate	Populations	10	Woods	Diameter	cm3	ƌ13C	10	0.763
Guy and Holowachuk	2001	Coniferous	Pinus	Field	Temperate	Populations	10	Woods	Diameter	cm3	ƌ13C	10	0.582
Guy and Holowachuk	2001	Coniferous	Pinus	Field	Temperate	Populations	10	Woods	Diameter	cm3	ƌ13C	10	0.657
Prasolova et.al.	2003	Coniferous	Pinus	Field	Sub tropical	Clones	122	Leaves	Height	m	ƌ13C	122	0.198
Prasolova et.al.	2003	Coniferous	Pinus	Field	Sub tropical	Clones	122	Leaves	Height	m	ƌ13C	122	0.315
Prasolova et.al.	2003	Coniferous	Pinus	Field	Sub tropical	Clones	122	Leaves	Diameter	cm	ƌ13C	122	0.186
Prasolova et.al.	2003	Coniferous	Pinus	Field	Sub tropical	Clones	122	Leaves	Height	m	ƌ13C	122	0.363
Prasolova et.al.	2003	Coniferous	Pinus	Field	Sub tropical	Clones	122	Leaves	Diameter	cm	ƌ13C	122	0.223
Pastorino et. al.	2012	Coniferous	Austrocedrus	Field	Temperate	Families	41	Leaves	Height	cm	ƌ13C	41	0.684
Jansen et.al.	2013	Coniferous	Pseudotsuga	Field	Temperate	Populations	6	Woods	Diameter	cm	ƌ13C	6	-0.961
Jansen et.al.	2013	Coniferous	Pseudotsuga	Field	Temperate	Populations	6	Woods	Height	m	ƌ13C	6	-0.331
Jansen et.al.	2013	Coniferous	Pseudotsuga	Field	Temperate	Populations	6	Woods	Height	m	ƌ13C	6	0.327
Jansen et.al.	2013	Coniferous	Pseudotsuga	Field	Temperate	Populations	6	Woods	Height	m	ƌ13C	6	0.479

Aitken et.al.	1995	Coniferous	Pseudotsuga	Field	Temperate	Populations	4	Woods	Height	m	ȡ13C	4	0.84
Aitken et.al.	1995	Coniferous	Pseudotsuga	Field	Temperate	Populations	4	Woods	Height	m	ȡ13C	4	0.832
Johnsen et. al.	1999	Coniferous	Picea	Field	Boreal	Families	18	Leaves	Height	cm	ȡ13C	18	0.97
Johnsen et. al.	1999	Coniferous	Picea	Field	Boreal	Families	18	Leaves	Diameter	cm	ȡ13C	18	0.64
Prasolova et.al.	2001	Coniferous	Araucaria	Field	Sub tropical	Families	22	Leaves	Height	m	ȡ13C	101	0.368
Prasolova et.al.	2001	Coniferous	Araucaria	Field	Sub tropical	Families	22	Leaves	Height	m	ȡ13C	100	0.41
Prasolova et.al.	2000	Coniferous	Araucaria	Field	Sub tropical	Families	23	Leaves	Height	m	ȡ13C	113	0.301
Prasolova et.al.	2000	Coniferous	Araucaria	Field	Sub tropical	Families	23	Leaves	Diameter	mm	ȡ13C	113	0.187
Xu et. al.	2003	Coniferous	Araucaria	Field	Sub tropical	Families	31	Branchlets	Height	m	ȡ13C	27	0.16
Xu et. al.	2003	Coniferous	Araucaria	Field	Sub tropical	Families	31	Branchlets	Height	m	ȡ13C	27	-0.04
Xu et. al.	2003	Coniferous	Araucaria	Field	Sub tropical	Families	31	Branchlets	Diameter	cm	ȡ13C	27	0.12
Xu et. al.	2003	Coniferous	Araucaria	Field	Sub tropical	Families	31	Branchlets	Diameter	cm	ȡ13C	27	0.38
Sun et.al.	1996	Coniferous	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	ȡ13C	10	0.714
Sun et.al.	1996	Coniferous	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	ȡ13C	10	0.848
Livingston et.al.	1999	Coniferous	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	ȡ13C	10	0.583
Livingston et.al.	1999	Coniferous	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	ȡ13C	10	0.268
Livingston et.al.	1999	Coniferous	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	ȡ13C	10	0.754
Livingston et.al.	1999	Coniferous	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	ȡ13C	10	0.7
Voltas J. (Unpublished)	2010	Coniferous	Pinus	Nursery	Mediterranean	Populations	25	Leaves	Height	m	ȡ13C	25	0.46
Zhang et.al.	1994	Coniferous	Larix	Field	Temperate	Families	5	Leaves	Height	m	ȡ13C	5	0.75
Zhang et.al.	1994	Coniferous	Larix	Field	Temperate	Families	5	Leaves	Diameter	cm	ȡ13C	5	0.92

Appendix 5: Summary of the data for broadleaves included in the meta- analysis

Study	Articles	Year	Type of Trees	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Robson et.al.	2012	Broadleaves	Fagus	Field	Mediterranean	Populations	6	Leaves	Height	cm	ƌ13C	6	-0.233
2	Robson et.al.	2012	Broadleaves	Fagus	Field	Mediterranean	Populations	6	Leaves	Diameter	mm	ƌ13C	6	-0.266
3	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	48	0.5
4	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	48	0.63
5	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	48	0.86
6	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	48	0.95
7	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	48	0.5
8	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	48	0.65
9	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	48	0.89
10	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	48	0.95
11	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Height		ƌ13C	48	0.52
12	Lauteri et.	200	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Height		ƌ13C	4	0.85

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13	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Height		ƌ13C	48	0.99
14	Lauteri et. al.	2004	Broadleaves	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Height		ƌ13C	48	0.12
15	Pita et. al.	2001	Broadleaves	Eucalyptus	Field	Temperate	Clones	4	Woods	Diameter	cm	ƌ13C	4	-0.831
16	Pita et. al.	2001	Broadleaves	Eucalyptus	Field	Temperate	Clones	6	Woods	Diameter	cm	ƌ13C	6	-0.877
17	Pita et. al.	2001	Broadleaves	Eucalyptus	Field	Temperate	Clones	7	Woods	Diameter	cm	ƌ13C	7	-0.889
18	Pita et. al.	2001	Broadleaves	Eucalyptus	Field	Temperate	Clones	7	Woods	Diameter	m2/ha	ƌ13C	7	-0.684
19	Pita et. al.	2001	Broadleaves	Eucalyptus	Field	Temperate	Clones	5	Woods	Diameter	cm	ƌ13C	5	-0.837
20	Roux et.al.	1996	Broadleaves	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Biomass	g	ƌ13C	6	-0.84
21	Roux et.al.	1996	Broadleaves	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Biomass	g	ƌ13C	18	0.32
22	Roux et.al.	1996	Broadleaves	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Biomass	g	ƌ13C	18	0.7
23	Aleta et. al.	2009	Broadleaves	Juglans	Field	Mediterranean	Families	22	Leaves	Height	cm	ƌ13C	22	-0.83
24	Aleta et. al.	2009	Broadleaves	Juglans	Field	Mediterranean	Families	22	Leaves	Diameter	mm	ƌ13C	22	-0.99
25	Aleta et. al.	2009	Broadleaves	Juglans	Field	Mediterranean	Families	22	Leaves	Height	cm	ƌ13C	22	-0.91
26	Aleta et.	200	Broadleaves	Juglans	Field	Mediterra	Families	22	Leaves	Diameter	mm	ƌ13C	2	-0.23

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27	Dillen et.al.	2008	Broadleaves	Populus	Field	Temperate	Families	50	Leaves	Diameter		δ13C	50	-0.36
28	Monclus et.al.	2009	Broadleaves	Populus	Field	Temperate	Families	33	Leaves	Biomass	g	δ13C	33	0.43
29	Monclus et.al.	2009	Broadleaves	Populus	Field	Temperate	Families	33	Leaves	Diameter	mm	δ13C	33	0.38
30	Monclus et.al.	2009	Broadleaves	Populus	Field	Temperate	Families	33	Leaves	Height	cm	δ13C	33	0.33

Appendix 6: Summary of the data for shrubs included in the meta- analysis

Articles	Year	Species	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Raddad and Luukkanen	2006	Shrubs	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Height	m	δ13C	8	-0.577
Raddad and Luukkanen	2006	Shrubs	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Diameter	cm	δ13C	8	-0.581
Gray et.al.	2013	Shrubs	Acacia	Glasshouse	Sub tropical	Populations	10	Leaves	Seedlings	Biomass	g	δ13C	10	0.208
Gray et.al.	2013	Shrubs	Acacia	Glasshouse	Sub tropical	Populations	11	Leaves	Seedlings	Biomass	g	δ13C	11	0.671
Pennington et.al.	1999	Shrubs	Prosopis	Greenhouse	Sub tropical	Families	7	Leaves	Seedlings	Height	cm	δ13C	7	0.955
Pennington et.al.	1999	Shrubs	Prosopis	Greenhouse	Sub tropical	Families	9	Leaves	Seedlings	Height	cm	δ13C	9	0.957
Pennington et.al.	1999	Shrubs	Prosopis	Greenhouse	Sub tropical	Families	15	Leaves	Seedlings	Height	cm	δ13C	15	0.035
Toillon et.al.	2013	Shrubs	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	δ13C	6	0.87

Toillon et.al.	2013	Shrubs	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	ƌ13C	6	0.95
Toillon et.al.	2013	Shrubs	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Diameter	mm	ƌ13C	6	0.93
Toillon et.al.	2013	Shrubs	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.93
Toillon et.al.	2013	Shrubs	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.94

Appendix 7: Summary of the data for evergreen included in the meta- analysis

Study	Articles	Year	Tree types	Taxonomic genus	Experimental conditions	Biome	Genetic material	No of entries	Measurement part	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Correia et.al.	2008	Evergreen	Pinus	Field	Mediterranean	Populations	7	Leaves	Height	m	ƌ13C	7	-0.32
2	Correia et.al.	2008	Evergreen	Pinus	Field	Mediterranean	Populations	7	Leaves	Diameter	cm	ƌ13C	7	0.008
3	Corcuera et. al.	2012	Evergreen	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	0.04
4	Corcuera et. al.	2012	Evergreen	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	-0.27
5	Corcuera et. al.	2012	Evergreen	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Diameter	mm	ƌ13C	5	-0.16
6	Corcuera et. al.	2012	Evergreen	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Diameter	mm	ƌ13C	5	-0.15
7	Tognetti et.al.	2000	Evergreen	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	0.224
8	Tognetti et.al.	2000	Evergreen	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	-0.51
9	Tognetti et.al.	2000	Evergreen	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	0.86
10	Tognetti et.al.	2000	Evergreen	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.53
11	Tognetti et.al.	2000	Evergreen	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	-0.17
12	Tognetti et.al.	2000	Evergreen	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.214
13	Tognetti et.al.	2000	Evergreen	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	-0.33
14	Tognetti et.al.	2000	Evergreen	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.746
15	Aranda et. al.	2010	Evergreen	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Biomass	g	ƌ13C	20	0.685

16	Aranda et. al.	2010	Evergreen	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Biomass	g	ƌ13C	20	0.591
17	Marguerit et.al.	2014	Evergreen	Pinus	Field	Mediterranean	Families	50	Woods	Height	cm	ƌ13C	50	0.3
18	Marguerit et.al.	2014	Evergreen	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	0.26
19	Marguerit et.al.	2014	Evergreen	Pinus	Field	Mediterranean	Families	50	Woods	Height	cm	ƌ13C	50	0.32
20	Marguerit et.al.	2014	Evergreen	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	0.21
21	Marguerit et.al.	2014	Evergreen	Pinus	Field	Mediterranean	Families	50	Woods	Height	cm	ƌ13C	50	0.08
22	Marguerit et.al.	2014	Evergreen	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	-0.02
23	Brendel et.al.	2002	Evergreen	Pinus	Field	Mediterranean	Families	63	Woods	Diameter	mm	ƌ13C	63	0.27
24	Xue et. al.	2013	Evergreen	Pinus	Field	Temperate	Clone	20	Leaves	Diameter	cm3	ƌ13C	80	0.31
25	Duglas et. al.	2008	Evergreen	Pinus	Field	Temperate	Families	7	Leaves	Diameter	mm	ƌ13C	7	-0.56
26	Hawkinset.al.	2010	Evergreen	Pinus	Field	Temperate	Clone	6	Leaves	Height	cm	ƌ13C	6	0.346
27	Hawkinset.al.	2010	Evergreen	Pinus	Field	Temperate	Clone	6	Leaves	Diameter	mm	ƌ13C	6	0.278
28	Hawkinset.al.	2010	Evergreen	Pinus	Field	Temperate	Clone	6	Leaves	Height	cm	ƌ13C	6	-0.14
29	Hawkinset.al.	2010	Evergreen	Pinus	Field	Temperate	Clone	6	Leaves	Diameter	mm	ƌ13C	6	0.526
30	Voltas et.al.	2008	Evergreen	Pinus	Field	Mediterranean	Populations	25	Woods	Height	m	ƌ13C	25	-0.4
31	Voltas et.al.	2008	Evergreen	Pinus	Field	Mediterranean	Populations	25	Woods	Diameter	cm	ƌ13C	25	-0.38
32	Voltas et.al.	2008	Evergreen	Pinus	Field	Mediterranean	Populations	25	Woods	Height	m	ƌ13C	25	-0.38
33	Voltas et.al.	2008	Evergreen	Pinus	Field	Mediterranean	Populations	25	Woods	Diameter	cm	ƌ13C	25	-0.13
34	Zhang et. al.	1996	Evergreen	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Height	cm	ƌ13C	18	-0.32
35	Zhang et. al.	1996	Evergreen	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƌ13C	18	-0.7
36	Zhang et. al.	1996	Evergreen	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	18	-0.3
37	Zhang et. al.	1996	Evergreen	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Height	cm	ƌ13C	18	0.1
38	Zhang et. al.	1996	Evergreen	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƌ13C	18	0.19
39	Zhang et. al.	1996	Evergreen	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƌ13C	18	-0.26

40	Zhang et. al.	1996	Evergreen	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Height	cm	ƍ13C	18	0.11
41	Zhang et. al.	1996	Evergreen	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƍ13C	18	0.16
42	Zhang et. al.	1996	Evergreen	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƍ13C	18	0.16
43	Zhang et. al.	1996	Evergreen	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Height	cm	ƍ13C	18	0.75
45	Zhang et. al.	1996	Evergreen	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Diameter	mm	ƍ13C	18	0.66
46	Zhang et. al.	1996	Evergreen	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Biomass	g	ƍ13C	18	0.81
47	Zhang et. al.	1996	Evergreen	Pinus	Nursery	Temperate	Populations	6	Leaves	Height	cm	ƍ13C	18	0.03
48	Zhang et. al.	1996	Evergreen	Pinus	Nursery	Temperate	Populations	6	Leaves	Biomass	g	ƍ13C	18	0.12
49	Zhang et. al.	1996	Evergreen	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Height	cm	ƍ13C	18	0.5
50	Zhang et. al.	1996	Evergreen	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Biomass	g	ƍ13C	18	0.62
51	Zhang et. al.	1996	Evergreen	Pinus	Field	Temperate	Populations	17	Leaves	Height	cm	ƍ13C	17	0.14
52	Xu et. al.	2000	Evergreen	Pinus	Field	Sub tropical	Clone	8	Leaves	Height	m	ƍ13C	8	0.96
53	Baltunis et.al.	2008	Evergreen	Pinus	Field	Sub tropical	Families	61	Leaves	Height	cm	ƍ13C	61	0.42
54	Baltunis et.al.	2008	Evergreen	Pinus	Field	Sub tropical	Populations	32	Leaves	Height	cm	ƍ13C	32	0.54
55	Guy and Holowachuk	2001	Evergreen	Pinus	Field	Temperate	Populations	10	Woods	Diameter	cm3	ƍ13C	10	0.763
56	Guy and Holowachuk	2001	Evergreen	Pinus	Field	Temperate	Populations	10	Woods	Diameter	cm3	ƍ13C	10	0.582
57	Guy and Holowachuk	2001	Evergreen	Pinus	Field	Temperate	Populations	10	Woods	Diameter	cm3	ƍ13C	10	0.657
58	Prasolova et.al.	2003	Evergreen	Pinus	Field	Sub tropical	Clones	122	Leaves	Height	m	ƍ13C	122	0.198
59	Prasolova et.al.	2003	Evergreen	Pinus	Field	Sub tropical	Clones	122	Leaves	Height	m	ƍ13C	122	0.315
60	Prasolova et.al.	2003	Evergreen	Pinus	Field	Sub tropical	Clones	122	Leaves	Diameter	cm	ƍ13C	122	0.186
61	Prasolova et.al.	2003	Evergreen	Pinus	Field	Sub tropical	Clones	122	Leaves	Height	m	ƍ13C	122	0.363
62	Prasolova et.al.	2003	Evergreen	Pinus	Field	Sub tropical	Clones	122	Leaves	Diameter	cm	ƍ13C	122	0.223
63	Pastorino et. al.	2012	Evergreen	Austrocedrus	Field	Temperate	Families	41	Leaves	Height	cm	ƍ13C	41	0.684

64	Jansen et.al.	2013	Evergreen	Pseudotsuga	Field	Temperate	Populations	6	Woods	Diameter	cm	δ13C	6	-0.96
65	Jansen et.al.	2013	Evergreen	Pseudotsuga	Field	Temperate	Populations	6	Woods	Height	m	δ13C	6	-0.33
66	Jansen et.al.	2013	Evergreen	Pseudotsuga	Field	Temperate	Populations	6	Woods	Height	m	δ13C	6	0.327
67	Jansen et.al.	2013	Evergreen	Pseudotsuga	Field	Temperate	Populations	6	Woods	Height	m	δ13C	6	0.479
68	Aitken et.al.	1995	Evergreen	Pseudotsuga	Field	Temperate	Populations	4	Woods	Height	m	δ13C	4	0.84
69	Aitken et.al.	1995	Evergreen	Pseudotsuga	Field	Temperate	Populations	4	Woods	Height	m	δ13C	4	0.832
70	Johnsen et. al.	1999	Evergreen	Picea	Field	Boreal	Families	18	Leaves	Height	cm	δ13C	18	0.97
71	Johnsen et. al.	1999	Evergreen	Picea	Field	Boreal	Families	18	Leaves	Diameter	cm	δ13C	18	0.64
72	Prasolova et.al.	2001	Evergreen	Araucaria	Field	Sub tropical	Families	22	Leaves	Height	m	δ13C	101	0.368
73	Prasolova et.al.	2001	Evergreen	Araucaria	Field	Sub tropical	Families	22	Leaves	Height	m	δ13C	100	0.41
74	Prasolova et.al.	2000	Evergreen	Araucaria	Field	Sub tropical	Families	23	Leaves	Height	m	δ13C	113	0.301
75	Prasolova et.al.	2000	Evergreen	Araucaria	Field	Sub tropical	Families	23	Leaves	Diameter	mm	δ13C	113	0.187
76	Xu et. al.	2003	Evergreen	Araucaria	Field	Sub tropical	Families	31	Branchlets	Height	m	δ13C	27	0.16
77	Xu et. al.	2003	Evergreen	Araucaria	Field	Sub tropical	Families	31	Branchlets	Height	m	δ13C	27	-0.04
78	Xu et. al.	2003	Evergreen	Araucaria	Field	Sub tropical	Families	31	Branchlets	Diameter	cm	δ13C	27	0.12
79	Xu et. al.	2003	Evergreen	Araucaria	Field	Sub tropical	Families	31	Branchlets	Diameter	cm	δ13C	27	0.38
80	Sun et.al.	1996	Evergreen	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	δ13C	10	0.714
81	Sun et.al.	1996	Evergreen	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	δ13C	10	0.848
82	Livingston et.al.	1999	Evergreen	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	δ13C	10	0.583
83	Livingston et.al.	1999	Evergreen	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	δ13C	10	0.268
84	Livingston et.al.	1999	Evergreen	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	δ13C	10	0.754
85	Livingston et.al.	1999	Evergreen	Picea	Field	Boreal	Clones	10	Leaves	Biomass	g	δ13C	10	0.7
86	Voltas J. (Unpublished)	2010	Evergreen	Pinus	Nursery	Mediterranean	Populations	25	Leaves	Height	m	δ13C	25	0.46

Appendix 8: Summary of the data for deciduous included in the meta- analysis

Study	Articles	Year	Tree types	Taxonomic genus	Experimental conditions	Biome	Genetic material	No of entries	Measurement part	Growth parameter	WUEi measurement by	n	r
1	Zhang et. al.	1996	Deciduous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Height	δ13C	42	0.41
2	Zhang et. al.	1996	Deciduous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Diameter	δ13C	42	0.31
3	Zhang et. al.	1996	Deciduous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Biomass	δ13C	42	0.59
4	Zhang et. al.	1996	Deciduous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Height	δ13C	42	0.23
5	Zhang et. al.	1996	Deciduous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Diameter	δ13C	42	0.25
6	Zhang et. al.	1996	Deciduous	Larix	Greenhouse	Temperate	Populations	14	Leaves	Biomass	δ13C	42	0.74
7	Zhang et. al.	1996	Deciduous	Larix	Field	Temperate	Populations	16	Leaves	Height	δ13C	16	0.51
8	Raddad and Luukkanen	2006	Deciduous	Acacia	Field	Sub tropical	Populations	8	Leaves	Height	δ13C	8	-0.6
9	Raddad and Luukkanen	2006	Deciduous	Acacia	Field	Sub tropical	Populations	8	Leaves	Diameter	δ13C	8	-0.6
10	Gray et.al.	2013	Deciduous	Acacia	Greenhouse	Sub tropical	Populations	10	Leaves	Biomass	δ13C	10	0.21
11	Gray et.al.	2013	Deciduous	Acacia	Greenhouse	Sub tropical	Populations	11	Leaves	Biomass	δ13C	11	0.67
12	Robson et.al.	2012	Deciduous	Fagus	Field	Mediterranean	Populations	6	Leaves	Height	δ13C	6	-0.2
13	Robson et.al.	2012	Deciduous	Fagus	Field	Mediterranean	Populations	6	Leaves	Diameter	δ13C	6	-0.3
14	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	δ13C	48	0.5
15	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	δ13C	48	0.63
16	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	δ13C	48	0.86
17	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	δ13C	48	0.95
18	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	δ13C	48	0.5
19	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	δ13C	48	0.65

20	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	ƌ13C	48	0.89
21	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Biomass	ƌ13C	48	0.95
22	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Height	ƌ13C	48	0.52
23	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Height	ƌ13C	48	0.85
24	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Height	ƌ13C	48	0.99
25	Lauteri et. al.	2004	Deciduous	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Height	ƌ13C	48	0.12
26	Pita et. al.	2001	Deciduous	Eucalyptus	Field	Temperate	Clones	4	Woods	Diameter	ƌ13C	4	-0.8
27	Pita et. al.	2001	Deciduous	Eucalyptus	Field	Temperate	Clones	6	Woods	Diameter	ƌ13C	6	-0.9
28	Pita et. al.	2001	Deciduous	Eucalyptus	Field	Temperate	Clones	7	Woods	Diameter	ƌ13C	7	-0.9
29	Pita et. al.	2001	Deciduous	Eucalyptus	Field	Temperate	Clones	7	Woods	Diameter	ƌ13C	7	-0.7
30	Pita et. al.	2001	Deciduous	Eucalyptus	Field	Temperate	Clones	5	Woods	Diameter	ƌ13C	5	-0.8
31	Roux et.al.	1996	Deciduous	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Biomass	ƌ13C	6	-0.8
32	Roux et.al.	1996	Deciduous	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Biomass	ƌ13C	18	0.32
33	Roux et.al.	1996	Deciduous	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Biomass	ƌ13C	18	0.7
34	Zhang et.al.	1994	Deciduous	Larix	Field	Temperate	Families	5	Leaves	Height	ƌ13C	5	0.75
35	Zhang et.al.	1994	Deciduous	Larix	Field	Temperate	Families	5	Leaves	Diameter	ƌ13C	5	0.92
36	Aleta et. al.	2009	Deciduous	Juglans	Field	Mediterranean	Families	22	Leaves	Height	ƌ13C	22	–0.83
37	Aleta et. al.	2009	Deciduous	Juglans	Field	Mediterranean	Families	22	Leaves	Diameter	ƌ13C	22	–0.99
38	Aleta et. al.	2009	Deciduous	Juglans	Field	Mediterranean	Families	22	Leaves	Height	ƌ13C	22	–0.91
39	Aleta et. al.	2009	Deciduous	Juglans	Field	Mediterranean	Families	22	Leaves	Diameter	ƌ13C	22	–0.23
40	Dillen et.al.	2008	Deciduous	Populus	Field	Temperate	Families	50	Leaves	Diameter	ƌ13C	50	-0.4
41	Monclus et.al.	2009	Deciduous	Populus	Field	Temperate	Families	33	Leaves	Biomass	ƌ13C	33	0.43
42	Monclus et.al.	2009	Deciduous	Populus	Field	Temperate	Families	33	Leaves	Diameter	ƌ13C	33	0.38
43	Monclus et.al.	2009	Deciduous	Populus	Field	Temperate	Families	33	Leaves	Height	ƌ13C	33	0.33
44	Pennington et.al.	1999	Deciduous	Prosopis	Greenhouse	Sub tropical	Families	7	Leaves	Height	ƌ13C	7	0.96

45	Pennington et.al.	1999	Deciduous	Prosopis	Greenhouse	Sub tropical	Families	9	Leaves	Height	ð13C	9	0.96
46	Pennington et.al.	1999	Deciduous	Prosopis	Greenhouse	Sub tropical	Families	15	Leaves	Height	ð13C	15	0.04
47	Toillon et.al.	2013	Deciduous	Salix	Field	Temperate	Clones	6	Leaves	Height	ð13C	6	0.87
48	Toillon et.al.	2013	Deciduous	Salix	Field	Temperate	Clones	6	Leaves	Height	ð13C	6	0.95
49	Toillon et.al.	2013	Deciduous	Salix	Field	Temperate	Clones	6	Leaves	Diameter	ð13C	6	0.93
50	Toillon et.al.	2013	Deciduous	Salix	Field	Temperate	Clones	6	Leaves	Biomass	ð13C	6	0.93
51	Toillon et.al.	2013	Deciduous	Salix	Field	Temperate	Clones	6	Leaves	Biomass	ð13C	6	0.94

Appendix 9: Summary of the data for populations included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Adult trees	Height	m	ð13C	7	-0.324
Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Adult trees	Diameter	cm	ð13C	7	0.0083
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Height	cm	ð13C	5	0.04
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Height	cm	ð13C	5	-0.27
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Diameter	mm	ð13C	5	-0.16
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Diameter	mm	ð13C	5	-0.15
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ð13C	5	0.224
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ð13C	5	-0.506
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ð13C	5	0.8602
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ð13C	5	0.53
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ð13C	5	-0.173
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ð13C	5	0.214
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ð13C	5	-0.332

Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ծ13C	5	0.746
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Saplings	Height	m	ծ13C	25	-0.4
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Saplings	Diameter	cm	ծ13C	25	-0.38
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Saplings	Height	m	ծ13C	25	-0.38
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Saplings	Diameter	cm	ծ13C	25	-0.13
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ծ13C	18	-0.32
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ծ13C	18	-0.7
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ծ13C	18	-0.3
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ծ13C	18	0.1
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ծ13C	18	0.19
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ծ13C	18	-0.26
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ծ13C	18	0.11
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ծ13C	18	0.16
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ծ13C	18	0.16
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ծ13C	18	0.75
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ծ13C	18	0.66
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ծ13C	18	0.81
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	ծ13C	42	0.41
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Diameter	mm	ծ13C	42	0.31
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	ծ13C	42	0.59
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	ծ13C	42	0.23
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Diameter	mm	ծ13C	42	0.25
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	ծ13C	42	0.74
Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ծ13C	18	0.03
Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ծ13C	18	0.12
Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ծ13C	18	0.5
Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ծ13C	18	0.62

Zhang et. al.	1996	Pinus	Field	Temperate	Populations	17	Leaves	Adult trees	Height	cm	ð13C	17	0.14
Zhang et. al.	1996	Larix	Field	Temperate	Populations	16	Leaves	Adult trees	Height	cm	ð13C	16	0.51
Baltunis et.al.	2008	Pinus	Field	Sub tropical	Populations	32	Leaves	Seedlings	Height	cm	ð13C	32	0.54
Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Saplings	Diameter	cm3	ð13C	10	0.763
Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Saplings	Diameter	cm3	ð13C	10	0.582
Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Saplings	Diameter	cm3	ð13C	10	0.657
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Diameter	cm	ð13C	6	-0.961
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ð13C	6	-0.331
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ð13C	6	0.327
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ð13C	6	0.479
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Seedlings	Height	m	ð13C	4	0.84
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Adult trees	Height	m	ð13C	4	0.832
Voltas J. (Unpublished)	2010	Pinus	Nursery	Mediterranean	Populations	25	Leaves	Seedlings	Height	m	ð13C	25	0.46
Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Height	m	ð13C	8	-0.577
Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Diameter	cm	ð13C	8	-0.581
Gray et.al.	2013	Acacia	Greenhouse	Sub tropical	Populations	10	Leaves	Seedlings	Biomass	g	ð13C	10	0.208
Gray et.al.	2013	Acacia	Greenhouse	Sub tropical	Populations	11	Leaves	Seedlings	Biomass	g	ð13C	11	0.671
Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Adult trees	Height	cm	ð13C	6	-0.233
Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Adult trees	Diameter	mm	ð13C	6	-0.266
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ð13C	48	0.5
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ð13C	48	0.63
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ð13C	48	0.86
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ð13C	48	0.95
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ð13C	48	0.5
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ð13C	48	0.65
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ð13C	48	0.89
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ð13C	48	0.95

Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		ẟ13C	48	0.52
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		ẟ13C	48	0.85
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		ẟ13C	48	0.99
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		ẟ13C	48	0.12

Appendix 10: Summary of the data for families included in the meta- analysis

Study	Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Ontogeny stages	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Seedlings	Biomass	g	ẟ13C	20	0.69
2	Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Seedlings	Biomass	g	ẟ13C	20	0.59
3	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ẟ13C	50	0.3
4	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Diameter	cm	ẟ13C	50	0.26
5	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ẟ13C	50	0.32
6	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Diameter	cm	ẟ13C	50	0.21
7	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ẟ13C	50	0.08
8	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Diameter	cm	ẟ13C	50	-0.02
9	Brendel et.al.	2002	Pinus	Field	Mediterranean	Families	63	Woods	Adult trees	Diameter	mm	ẟ13C	63	0.27
10	Duglas et. al.	2008	Pinus	Field	Temperate	Families	7	Leaves	Adult trees	Diameter	mm	ẟ13C	7	-0.56
11	Duglas et. al.	2008	Pinus	Field	Temperate	Families	8	Leaves	Adult trees	Diameter	mm	ẟ13C	8	-0.19
12	Baltunis et.al.	2008	Pinus	Field	Sub tropical	Families	61	Leaves	Seedlings	Height	cm	ẟ13C	61	0.42
13	Pastorino et. al.	2012	Austrocedrus	Field	Temperate	Families	41	Leaves	Seedlings	Height	cm	ẟ13C	41	0.68
14	Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Adult trees	Height	cm	ẟ13C	18	0.97
15	Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Adult trees	Diameter	cm	ẟ13C	18	0.64

16	Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƌ13C	101	0.37
17	Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƌ13C	100	0.41
18	Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Seedlings	Height	m	ƌ13C	113	0.3
19	Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Seedlings	Diameter	mm	ƌ13C	113	0.19
20	Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƌ13C	27	0.16
21	Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƌ13C	27	-0.04
22	Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Diameter	cm	ƌ13C	27	0.12
23	Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Diameter	cm	ƌ13C	27	0.38
24	Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Adult trees	Height	m	ƌ13C	5	0.75
25	Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Adult trees	Diameter	cm	ƌ13C	5	0.92
26	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Height	cm	ƌ13C	22	–0.83
27	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Diameter	mm	ƌ13C	22	–0.99
28	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Height	cm	ƌ13C	22	–0.91
29	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Diameter	mm	ƌ13C	22	–0.23
30	Dillen et.al.	2008	Populus	Field	Temperate	Families	50	Leaves	Saplings	Diameter		ƌ13C	50	-0.36
31	Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Biomass	g	ƌ13C	33	0.43
32	Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Diameter	mm	ƌ13C	33	0.38
33	Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Height	cm	ƌ13C	33	0.33
34	Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	7	Leaves	Seedlings	Height	cm	ƌ13C	7	0.96
35	Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	9	Leaves	Seedlings	Height	cm	ƌ13C	9	0.96
36	Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	15	Leaves	Seedlings	Height	cm	ƌ13C	15	0.04

Appendix 11: Summary of the data for clones included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUE_i measured by	n	r
Xue et. al.	2013	Pinus	Field	Temperate	Clones	20	Leaves	Saplings	Diameter	mm	ȡ13C	80	0.33
Xue et. al.	2013	Pinus	Field	Temperate	Clones	20	Leaves	Saplings	Diameter	cm3	ȡ13C	80	0.31
Hawkins et.al.	2010	Pinus	Field	Temperate	Clones	6	Leaves	Saplings	Height	cm	ȡ13C	6	0.54
Hawkins et.al.	2010	Pinus	Field	Temperate	Clones	6	Leaves	Saplings	Diameter	mm	ȡ13C	6	0.199
Hawkins et.al.	2010	Pinus	Field	Temperate	Clones	6	Leaves	Saplings	Height	cm	ȡ13C	6	0.346
Hawkins et.al.	2010	Pinus	Field	Temperate	Clones	6	Leaves	Saplings	Diameter	mm	ȡ13C	6	0.278
Hawkins et.al.	2010	Pinus	Field	Temperate	Clones	6	Leaves	Saplings	Height	cm	ȡ13C	6	-0.142
Hawkins et.al.	2010	Pinus	Field	Temperate	Clones	6	Leaves	Saplings	Diameter	mm	ȡ13C	6	0.526
Xu et. al.	2000	Pinus	Field	Sub tropical	Clones	8	Leaves	Saplings	Height	m	ȡ13C	8	0.96
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ȡ13C	122	0.198
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ȡ13C	122	0.315
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Diameter	cm	ȡ13C	122	0.186
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ȡ13C	122	0.363
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Diameter	cm	ȡ13C	122	0.223
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ȡ13C	10	0.714
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ȡ13C	10	0.848
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ȡ13C	10	0.583
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ȡ13C	10	0.268
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ȡ13C	10	0.754
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ȡ13C	10	0.7
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	4	Woods	Saplings	Diameter	cm	ȡ13C	4	-0.831
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	6	Woods	Saplings	Diameter	cm	ȡ13C	6	-0.877
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	7	Woods	Saplings	Diameter	cm	ȡ13C	7	-0.889
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	7	Woods	Saplings	Diameter	m2/ha	ȡ13C	7	-0.684

Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	5	Woods	Saplings	Diameter	cm	ƌ13C	5	-0.837
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	-0.84
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.32
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.7
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	ƌ13C	6	0.87
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	ƌ13C	6	0.95
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Diameter	mm	ƌ13C	6	0.93
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.93
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.94

Appendix 12: Summary of the data for Mediterranean included in the meta- analysis

Study	Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	No of entries	Measurement part	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Height	m	ƌ13C	7	-0.32
2	Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Diameter	cm	ƌ13C	7	0.008
3	Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	-0.83
4	Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Diameter	mm	ƌ13C	5	-0.2
5	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	0.224
6	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	-0.51
7	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	0.86
8	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.53
9	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	-0.17
10	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.214
11	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Height	cm	ƌ13C	5	-0.33

12	Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Diameter	cm	ƌ13C	5	0.746
13	Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Biomass	g	ƌ13C	20	0.685
14	Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Biomass	g	ƌ13C	20	0.591
15	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Height	cm	ƌ13C	50	0.3
16	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	0.26
17	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Height	cm	ƌ13C	50	0.32
18	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	0.21
19	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Height	cm	ƌ13C	50	0.08
20	Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Diameter	cm	ƌ13C	50	-0.02
21	Brendel et.al.	2002	Pinus	Field	Mediterranean	Families	63	Woods	Diameter	mm	ƌ13C	63	0.27
22	Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Height	m	ƌ13C	25	-0.4
23	Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Diameter	cm	ƌ13C	25	-0.38
24	Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Height	m	ƌ13C	25	-0.38
25	Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Diameter	cm	ƌ13C	25	-0.13
26	Voltas J. (Unpublished)	2010	Pinus	Nursery	Mediterranean	Populations	25	Leaves	Height	m	ƌ13C	25	0.46
27	Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Height	cm	ƌ13C	6	-0.23
28	Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Diameter	mm	ƌ13C	6	-0.27
29	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Height	cm	ƌ13C	22	–0.83
30	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Diameter	mm	ƌ13C	22	–0.99
31	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Height	cm	ƌ13C	22	–0.91
32	Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Diameter	mm	ƌ13C	22	–0.23

Appendix 13: Summary of the data for boreal included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	Nor of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Adult trees	Height	cm	ƌ13C	18	0.97
Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Adult trees	Diameter	cm	ƌ13C	18	0.64
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.71
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.85
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.58
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.27
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.75
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.7

Appendix 14: Summary of the data for subtropical included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	No of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Xu et. al.	2000	Pinus	Field	Sub tropical	Clone	8	Leaves	Sapling	Height	m	ƌ13C	8	0.96
Baltunis et.al.	2008	Pinus	Field	Sub tropical	Families	61	Leaves	Seedlings	Height	cm	ƌ13C	61	0.42
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƌ13C	122	0.2
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƌ13C	122	0.32
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Diameter	cm	ƌ13C	122	0.19
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƌ13C	122	0.36
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Diameter	cm	ƌ13C	122	0.22
Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƌ13C	101	0.37
Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƌ13C	100	0.41
Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Seedlings	Height	m	ƌ13C	113	0.3

Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Seedlings	Diameter	mm	ƌ13C	113	0.19
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƌ13C	27	0.16
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƌ13C	27	-0.04
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Diameter	cm	ƌ13C	27	0.12
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Diameter	cm	ƌ13C	27	0.38
Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Height	m	ƌ13C	8	-0.58
Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Diameter	cm	ƌ13C	8	-0.58
Gray et.al.	2013	Acacia	Greenhouse	Sub tropical	Populations	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.21
Gray et.al.	2013	Acacia	Greenhouse	Sub tropical	Populations	11	Leaves	Seedlings	Biomass	g	ƌ13C	11	0.67
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	-0.84
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.32
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.7
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	7	Leaves	Seedlings	Height	cm	ƌ13C	7	0.96
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	9	Leaves	Seedlings	Height	cm	ƌ13C	9	0.96
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	15	Leaves	Seedlings	Height	cm	ƌ13C	15	0.04

Appendix 15: Summary of the data for temperate included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	No of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi mreasured by	n	r
Xue et. al.	2013	Pinus	Field	Temperate	Clone	20	Leaves	Sapling	Diameter	mm	ƌ13C	80	0.33
Xue et. al.	2013	Pinus	Field	Temperate	Clone	20	Leaves	Sapling	Diameter	cm3	ƌ13C	80	0.31
Duglas et. al.	2008	Pinus	Field	Temperate	Families	7	Leaves	Adult trees	Diameter	mm	ƌ13C	7	-0.56
Duglas et. al.	2008	Pinus	Field	Temperate	Families	8	Leaves	Adult trees	Diameter	mm	ƌ13C	8	-0.19
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Sapling	Height	cm	ƌ13C	6	0.54
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Sapling	Diameter	mm	ƌ13C	6	0.199
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Sapling	Height	cm	ƌ13C	6	0.346
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Sapling	Diameter	mm	ƌ13C	6	0.278
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Sapling	Height	cm	ƌ13C	6	-0.142
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Sapling	Diameter	mm	ƌ13C	6	0.526
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	-0.32
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ƌ13C	18	-0.7
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	-0.3
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.1
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ƌ13C	18	0.19
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	-0.26
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.11
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ƌ13C	18	0.16
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.16
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.75
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ƌ13C	18	0.66
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.81

Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	δ13C	42	0.41
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Diameter	mm	δ13C	42	0.31
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	δ13C	42	0.59
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	δ13C	42	0.23
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Diameter	mm	δ13C	42	0.25
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	δ13C	42	0.74
Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	δ13C	18	0.03
Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	18	0.12
Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	δ13C	18	0.5
Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	18	0.62
Zhang et. al.	1996	Pinus	Field	Temperate	Populations	17	Leaves	Adult trees	Height	cm	δ13C	17	0.14
Zhang et. al.	1996	Larix	Field	Temperate	Populations	16	Leaves	Adult trees	Height	cm	δ13C	16	0.51
Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Sapling	Diameter	cm3	δ13C	10	0.763
Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Sapling	Diameter	cm3	δ13C	10	0.582
Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Sapling	Diameter	cm3	δ13C	10	0.657
Pastorino et. al.	2012	Austrocedrus	Field	Temperate	Families	41	Leaves	Seedlings	Height	cm	δ13C	41	0.684
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Diameter	cm	δ13C	6	-0.961
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	δ13C	6	-0.331
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	δ13C	6	0.327
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	δ13C	6	0.479
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Seedlings	Height	m	δ13C	4	0.84
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Adult trees	Height	m	δ13C	4	0.832
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.5
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.63
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.86

Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.95
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.5
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.65
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.89
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	48	0.95
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		ƌ13C	48	0.52
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		ƌ13C	48	0.85
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		ƌ13C	48	0.99
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		ƌ13C	48	0.12
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	4	Woods	Saplings	Diameter	cm	ƌ13C	4	-0.831
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	6	Woods	Saplings	Diameter	cm	ƌ13C	6	-0.877
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	7	Woods	Saplings	Diameter	cm	ƌ13C	7	-0.889
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	7	Woods	Saplings	Diameter	m2/ha	ƌ13C	7	-0.684
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	5	Woods	Saplings	Diameter	cm	ƌ13C	5	-0.837
Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Adult trees	Height	m	ƌ13C	5	0.75
Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Adult trees	Diameter	cm	ƌ13C	5	0.92
Dillen et.al.	2008	Populus	Field	Temperate	Families	50	Leaves	Saplings	Diameter		ƌ13C	50	-0.36
Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Biomass	g	ƌ13C	33	0.43
Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Diameter	mm	ƌ13C	33	0.38
Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Height	cm	ƌ13C	33	0.33
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	ƌ13C	6	0.87
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	ƌ13C	6	0.95
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Diameter	mm	ƌ13C	6	0.93
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.93
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.94

Appendix 16: Summary of the data for field included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Adult trees	Height	m	ƍ13C	7	-0.324
Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Adult trees	Diameter	cm	ƍ13C	7	0.0083
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƍ13C	5	0.224
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ƍ13C	5	-0.506
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƍ13C	5	0.86
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ƍ13C	5	0.53
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƍ13C	5	-0.173
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ƍ13C	5	0.214
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƍ13C	5	-0.332
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ƍ13C	5	0.746
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ƍ13C	50	0.3
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Diameter	cm	ƍ13C	50	0.26
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ƍ13C	50	0.32
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Diameter	cm	ƍ13C	50	0.21
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ƍ13C	50	0.08
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Diameter	cm	ƍ13C	50	-0.02
Brendel et.al.	2002	Pinus	Field	Mediterranean	Families	63	Woods	Adult trees	Diameter	mm	ƍ13C	63	0.27
Xue et. al.	2013	Pinus	Field	Temperate	Clone	20	Leaves		Diameter	mm	ƍ13C	80	0.33
Xue et. al.	2013	Pinus	Field	Temperate	Clone	20	Leaves		Diameter	cm3	ƍ13C	80	0.31
Duglas et. al.	2008	Pinus	Field	Temperate	Families	7	Leaves	Adult trees	Diameter	mm	ƍ13C	7	-0.56
Duglas et. al.	2008	Pinus	Field	Temperate	Families	8	Leaves	Adult trees	Diameter	mm	ƍ13C	8	-0.19
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Saplings	Height	cm	ƍ13C	6	0.54
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Saplings	Diameter	mm	ƍ13C	6	0.199
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Saplings	Height	cm	ƍ13C	6	0.346

Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Saplings	Diameter	mm	ƌ13C	6	0.278
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Saplings	Height	cm	ƌ13C	6	-0.142
Hawkins et.al.	2010	Pinus	Field	Temperate	Clone	6	Leaves	Saplings	Diameter	mm	ƌ13C	6	0.526
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Saplings	Height	m	ƌ13C	25	-0.4
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Saplings	Diameter	cm	ƌ13C	25	-0.38
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Saplings	Height	m	ƌ13C	25	-0.38
Voltas et.al.	2008	Pinus	Field	Mediterranean	Populations	25	Woods	Saplings	Diameter	cm	ƌ13C	25	-0.13
Zhang et. al.	1996	Pinus	Field	Temperate	Populations	17	Leaves	Adult trees	Height	cm	ƌ13C	17	0.14
Zhang et. al.	1996	Larix	Field	Temperate	Populations	16	Leaves	Adult trees	Height	cm	ƌ13C	16	0.51
Xu et. al.	2000	Pinus	Field	Sub tropical	Clone	8	Leaves	Saplings	Height	m	ƌ13C	8	0.96
Baltunis et.al.	2008	Pinus	Field	Sub tropical	Families	61	Leaves	Seedlings	Height	cm	ƌ13C	61	0.42
Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Saplings	Diameter	cm3	ƌ13C	10	0.763
Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Saplings	Diameter	cm3	ƌ13C	10	0.582
Guy and Holowachuk	2001	Pinus	Field	Temperate	Populations	10	Woods	Saplings	Diameter	cm3	ƌ13C	10	0.657
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƌ13C	122	0.198
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƌ13C	122	0.315
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Diameter	cm	ƌ13C	122	0.186
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƌ13C	122	0.363
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Diameter	cm	ƌ13C	122	0.223
Pastorino et. al.	2012	Austrocedrus	Field	Temperate	Families	41	Leaves	Seedlings	Height	cm	ƌ13C	41	0.684
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Diameter	cm	ƌ13C	6	-0.961
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ƌ13C	6	-0.331
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ƌ13C	6	0.327
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ƌ13C	6	0.479
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Seedlings	Height	m	ƌ13C	4	0.84
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Adult trees	Height	m	ƌ13C	4	0.832
Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Adult trees	Height	cm	ƌ13C	18	0.97
Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Adult trees	Diameter	cm	ƌ13C	18	0.64

Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƌ13C	101	0.368
Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƌ13C	100	0.41
Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Seedlings	Height	m	ƌ13C	113	0.301
Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Seedlings	Diameter	mm	ƌ13C	113	0.187
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƌ13C	27	0.16
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƌ13C	27	-0.04
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Diameter	cm	ƌ13C	27	0.12
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Diameter	cm	ƌ13C	27	0.38
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.714
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.848
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.583
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.268
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.754
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƌ13C	10	0.7
Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Height	m	ƌ13C	8	-0.577
Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Diameter	cm	ƌ13C	8	-0.581
Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Adult trees	Height	cm	ƌ13C	6	-0.233
Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Adult trees	Diameter	mm	ƌ13C	6	-0.266
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	4	Woods	Saplings	Diameter	cm	ƌ13C	4	-0.831
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	6	Woods	Saplings	Diameter	cm	ƌ13C	6	-0.877
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	7	Woods	Saplings	Diameter	cm	ƌ13C	7	-0.889
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	7	Woods	Saplings	Diameter	m2/ha	ƌ13C	7	-0.684
Pita et. al.	2001	Eucalyptus	Field	Temperate	Clones	5	Woods	Saplings	Diameter	cm	ƌ13C	5	-0.837
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	-0.84
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.32
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.7
Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Adult trees	Height	m	ƌ13C	5	0.75

Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Adult trees	Diameter	cm	ƌ13C	5	0.92
Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Height	cm	ƌ13C	22	–0.83
Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Diameter	mm	ƌ13C	22	–0.99
Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Height	cm	ƌ13C	22	–0.91
Aleta et. al.	2009	Juglans	Field	Mediterranean	Families	22	Leaves	Saplings	Diameter	mm	ƌ13C	22	–0.23
Dillen et.al.	2008	Populus	Field	Temperate	Families	50	Leaves	Saplings	Diameter		ƌ13C	50	0.36
Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Biomass	g	ƌ13C	33	0.43
Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Diameter	mm	ƌ13C	33	0.38
Monclus et.al.	2009	Populus	Field	Temperate	Families	33	Leaves	Saplings	Height	cm	ƌ13C	33	0.33
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	ƌ13C	6	0.87
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	ƌ13C	6	0.95
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Diameter	mm	ƌ13C	6	0.93
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.93
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.94

Appendix 17: Summary of the data for greenhouse included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Height	cm	δ13C	5	0.04
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Height	cm	δ13C	5	-0.3
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Diameter	mm	δ13C	5	-0.2
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Diameter	mm	δ13C	5	-0.2
Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Seedlings	Biomass	g	δ13C	20	0.69
Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Seedlings	Biomass	g	δ13C	20	0.59
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	δ13C	18	-0.3
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	δ13C	18	-0.7
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	18	-0.3
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	δ13C	18	0.1
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	δ13C	18	0.19
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	18	-0.3
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	δ13C	18	0.11
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	δ13C	18	0.16
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	18	0.16
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	δ13C	18	0.75
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	δ13C	18	0.66
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	18	0.81
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	δ13C	42	0.41
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Diameter	mm	δ13C	42	0.31
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	δ13C	42	0.59
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	δ13C	42	0.23
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Diameter	mm	δ13C	42	0.25
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	δ13C	42	0.74

Gray et.al.	2013	Acacia	Greenhouse	Sub tropical	Populations	10	Leaves	Seedlings	Biomass	g	δ13C	10	0.21
Gray et.al.	2013	Acacia	Greenhouse	Sub tropical	Populations	11	Leaves	Seedlings	Biomass	g	δ13C	11	0.67
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.5
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.63
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.86
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.95
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.5
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.65
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.89
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.95
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		δ13C	48	0.52
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		δ13C	48	0.85
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		δ13C	48	0.99
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		δ13C	48	0.12
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	7	Leaves	Seedlings	Height	cm	δ13C	7	0.96
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	9	Leaves	Seedlings	Height	cm	δ13C	9	0.96
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	15	Leaves	Seedlings	Height	cm	δ13C	15	0.04

Appendix 18: Summary of the data for nursery included in the meta- analysis

Study	Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	Number of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0
2	Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.1
3	Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.5
4	Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.6
5	Voltas J. (Unpublished)	2010	Pinus	Nursery	Mediterranean	Populations	25	Leaves	Seedlings	Height	m	ƌ13C	25	0.5

Appendix 19: Summary of the data for optimal environment included in the meta- analysis

Study	Articles	Year	Taxonomic genus	Biome	Genetic material	No of entries	Measurement part	Environment of test site	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Correia et.al.	2008	Pinus	Mediterranean	Populations	7	Leaves	Optimal	Height	m	ƌ13C	7	-0.324
2	Correia et.al.	2008	Pinus	Mediterranean	Populations	7	Leaves	Optimal	Diameter	cm	ƌ13C	7	0.0083
3	Tognetti et.al.	2000	Pinus	Mediterranean	Populations	5	Leaves	Optimal	Height	cm	ƌ13C	5	0.224
4	Tognetti et.al.	2000	Pinus	Mediterranean	Populations	5	Leaves	Optimal	Diameter	cm	ƌ13C	5	-0.506
5	Tognetti et.al.	2000	Pinus	Mediterranean	Populations	5	Leaves	Optimal	Height	cm	ƌ13C	5	0.8602
6	Tognetti et.al.	2000	Pinus	Mediterranean	Populations	5	Leaves	Optimal	Diameter	cm	ƌ13C	5	0.53
7	Tognetti et.al.	2000	Pinus	Mediterranean	Populations	5	Leaves	Optimal	Height	cm	ƌ13C	5	-0.173
8	Tognetti et.al.	2000	Pinus	Mediterranean	Populations	5	Leaves	Optimal	Diameter	cm	ƌ13C	5	0.214
9	Tognetti et.al.	2000	Pinus	Mediterranean	Populations	5	Leaves	Optimal	Height	cm	ƌ13C	5	-0.332
10	Tognetti et.al.	2000	Pinus	Mediterranean	Populations	5	Leaves	Optimal	Diameter	cm	ƌ13C	5	0.746

11	Marguerit et.al.	2014	Pinus	Mediterranean	Families	50	Woods	Optimal	Height	cm	ꝺ13C	50	0.32
12	Marguerit et.al.	2014	Pinus	Mediterranean	Families	50	Woods	Optimal	Diameter	cm	ꝺ13C	50	0.21
13	Marguerit et.al.	2014	Pinus	Mediterranean	Families	50	Woods	Optimal	Height	cm	ꝺ13C	50	0.08
14	Marguerit et.al.	2014	Pinus	Mediterranean	Families	50	Woods	Optimal	Diameter	cm	ꝺ13C	50	-0.02
15	Duglas et. al.	2008	Pinus	Temperate	Families	7	Leaves	Optimal	Diameter	mm	ꝺ13C	7	-0.56
16	Duglas et. al.	2008	Pinus	Temperate	Families	8	Leaves	Optimal	Diameter	mm	ꝺ13C	8	-0.19
17	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Optimal	Height	cm	ꝺ13C	6	0.54
18	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Optimal	Diameter	mm	ꝺ13C	6	0.199
19	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Optimal	Height	cm	ꝺ13C	6	-0.142
20	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Optimal	Diameter	mm	ꝺ13C	6	0.526
21	Voltas et.al.	2008	Pinus	Mediterranean	Populations	25	Woods	Optimal	Height	m	ꝺ13C	25	-0.4
22	Voltas et.al.	2008	Pinus	Mediterranean	Populations	25	Woods	Optimal	Diameter	cm	ꝺ13C	25	-0.38
23	Zhang et. al.	1996	Pinus	Temperate	Populations	17	Leaves	Optimal	Height	cm	ꝺ13C	17	0.14
24	Zhang et. al.	1996	Larix	Temperate	Populations	16	Leaves	Optimal	Height	cm	ꝺ13C	16	0.51
25	Xu et. al.	2000	Pinus	Sub tropical	Clone	8	Leaves	Optimal	Height	m	ꝺ13C	8	0.96
26	Baltunis et.al.	2008	Pinus	Sub tropical	Families	61	Leaves	Optimal	Height	cm	ꝺ13C	61	0.42
27	Baltunis et.al.	2008	Pinus	Sub tropical	Populations	32	Leaves	Optimal	Height	cm	ꝺ13C	32	0.54
28	Guy and Holowachuk	2001	Pinus	Temperate	Populations	10	Woods	Optimal	Diameter	cm3	ꝺ13C	10	0.763
29	Guy and Holowachuk	2001	Pinus	Temperate	Populations	10	Woods	Optimal	Diameter	cm3	ꝺ13C	10	0.582
30	Prasolova et.al.	2003	Pinus	Sub tropical	Clones	122	Leaves	Optimal	Height	m	ꝺ13C	122	0.315
31	Prasolova et.al.	2003	Pinus	Sub tropical	Clones	122	Leaves	Optimal	Diameter	cm	ꝺ13C	122	0.186
32	Prasolova et.al.	2003	Pinus	Sub tropical	Clones	122	Leaves	Optimal	Height	m	ꝺ13C	122	0.363
33	Prasolova et.al.	2003	Pinus	Sub tropical	Clones	122	Leaves	Optimal	Diameter	cm	ꝺ13C	122	0.223
34	Pastorino et. al.	2012	Austrocedrus	Temperate	Families	41	Leaves	Optimal	Height	cm	ꝺ13C	41	0.684
35	Jansen et.al.	2013	Pseudotsuga	Temperate	Populations	6	Woods	Optimal	Height	m	ꝺ13C	6	0.327
36	Jansen et.al.	2013	Pseudotsuga	Temperate	Populations	6	Woods	Optimal	Height	m	ꝺ13C	6	0.479

37	Aitken et.al.	1995	Pseudotsuga	Temperate	Populations	4	Woods	Optimal	Height	m	ƌ13C	4	0.84
38	Aitken et.al.	1995	Pseudotsuga	Temperate	Populations	4	Woods	Optimal	Height	m	ƌ13C	4	0.832
39	Johnsen et. al.	1999	Picea	Boreal	Families	18	Leaves	Optimal	Height	cm	ƌ13C	18	0.97
40	Johnsen et. al.	1999	Picea	Boreal	Families	18	Leaves	Optimal	Diameter	cm	ƌ13C	18	0.64
41	Prasolova et.al.	2000	Araucaria	Sub tropical	Families	23	Leaves	Optimal	Height	m	ƌ13C	113	0.301
42	Prasolova et.al.	2000	Araucaria	Sub tropical	Families	23	Leaves	Optimal	Diameter	mm	ƌ13C	113	0.187
43	Xu et. al.	2003	Araucaria	Sub tropical	Families	31	Branchlets	Optimal	Height	m	ƌ13C	27	0.16
44	Xu et. al.	2003	Araucaria	Sub tropical	Families	31	Branchlets	Optimal	Height	m	ƌ13C	27	-0.04
45	Xu et. al.	2003	Araucaria	Sub tropical	Families	31	Branchlets	Optimal	Diameter	cm	ƌ13C	27	0.12
46	Xu et. al.	2003	Araucaria	Sub tropical	Families	31	Branchlets	Optimal	Diameter	cm	ƌ13C	27	0.38
47	Voltas J. (Unpublished)	2010	Pinus	Mediterranean	Populations	25	Leaves	Optimal	Height	m	ƌ13C	25	0.46
48	Raddad and Luukkanen	2006	Acacia	Sub tropical	Populations	8	Leaves	Optimal	Height	m	ƌ13C	8	-0.577
49	Raddad and Luukkanen	2006	Acacia	Sub tropical	Populations	8	Leaves	Optimal	Diameter	cm	ƌ13C	8	-0.581
50	Gray et.al.	2013	Acacia	Sub tropical	Populations	10	Leaves	Optimal	Biomass	g	ƌ13C	10	0.208
51	Gray et.al.	2013	Acacia	Sub tropical	Populations	11	Leaves	Optimal	Biomass	g	ƌ13C	11	0.671
52	Dillen et.al.	2008	Populus	Temperate	Families	50	Leaves	Optimal	Diameter		ƌ13C	50	-0.36
53	Pennington et.al.	1999	Prosopis	Sub tropical	Families	7	Leaves	Optimal	Height	cm	ƌ13C	7	0.955
54	Pennington et.al.	1999	Prosopis	Sub tropical	Families	9	Leaves	Optimal	Height	cm	ƌ13C	9	0.957
55	Pennington et.al.	1999	Prosopis	Sub tropical	Families	15	Leaves	Optimal	Height	cm	ƌ13C	15	0.035
56	Toillon et.al.	2013	Salix	Temperate	Clones	6	Leaves	Optimal	Height	cm	ƌ13C	6	0.87
57	Toillon et.al.	2013	Salix	Temperate	Clones	6	Leaves	Optimal	Biomass	g	ƌ13C	6	0.94

Appendix 20: Summary of the data for sub optimal environment included in the meta- analysis

Study	Articles	Year	Taxonomic genus	Biome	Genetic material	No of entries	Measurement part	Environment of test site	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Marguerit et.al.	2014	Pinus	Mediterranean	Families	50	Woods	Sub optimal	Height	cm	ƌ13C	50	0.3
2	Marguerit et.al.	2014	Pinus	Mediterranean	Families	50	Woods	Sub optimal	Diameter	cm	ƌ13C	50	0.26
3	Brendel et.al.	2002	Pinus	Mediterranean	Families	63	Woods	Sub optimal	Diameter	mm	ƌ13C	63	0.27
4	Xue et. al.	2013	Pinus	Temperate	Clone	20	Leaves	Sub optimal	Diameter	mm	ƌ13C	80	0.33
5	Xue et. al.	2013	Pinus	Temperate	Clone	20	Leaves	Sub optimal	Diameter	cm3	ƌ13C	80	0.31
6	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Sub optimal	Height	cm	ƌ13C	6	0.346
7	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Sub optimal	Diameter	mm	ƌ13C	6	0.278
8	Voltas et.al.	2008	Pinus	Mediterranean	Populations	25	Woods	Sub optimal	Height	m	ƌ13C	25	-0.38
9	Voltas et.al.	2008	Pinus	Mediterranean	Populations	25	Woods	Sub optimal	Diameter	cm	ƌ13C	25	-0.13
10	Guy and Holowachuk	2001	Pinus	Temperate	Populations	10	Woods	Sub optimal	Diameter	cm3	ƌ13C	10	0.657
11	Prasolova et.al.	2003	Pinus	Sub tropical	Clones	122	Leaves	Sub optimal	Height	m	ƌ13C	122	0.198
12	Jansen et.al.	2013	Pseudotsuga	Temperate	Populations	6	Woods	Sub optimal	Diameter	cm	ƌ13C	6	-0.961
13	Jansen et.al.	2013	Pseudotsuga	Temperate	Populations	6	Woods	Sub optimal	Height	m	ƌ13C	6	-0.331
14	Prasolova et.al.	2001	Araucaria	Sub tropical	Families	22	Leaves	Sub optimal	Height	m	ƌ13C	101	0.368
15	Prasolova et.al.	2001	Araucaria	Sub tropical	Families	22	Leaves	Sub optimal	Height	m	ƌ13C	100	0.41
16	Robson et.al.	2012	Fagus	Mediterranean	Populations	6	Leaves	Sub optimal	Height	cm	ƌ13C	6	-0.233
17	Robson et.al.	2012	Fagus	Mediterranean	Populations	6	Leaves	Sub optimal	Diameter	mm	ƌ13C	6	-0.266
18	Pita et. al.	2001	Eucalyptus	Temperate	Clones	4	Woods	Sub optimal	Diameter	cm	ƌ13C	4	-0.831
19	Pita et. al.	2001	Eucalyptus	Temperate	Clones	6	Woods	Sub optimal	Diameter	cm	ƌ13C	6	-0.877
20	Pita et. al.	2001	Eucalyptus	Temperate	Clones	7	Woods	Sub optimal	Diameter	cm	ƌ13C	7	-0.889
21	Pita et. al.	2001	Eucalyptus	Temperate	Clones	7	Woods	Sub optimal	Diameter	m2/ha	ƌ13C	7	-0.684
22	Pita et. al.	2001	Eucalyptus	Temperate	Clones	5	Woods	Sub optimal	Diameter	cm	ƌ13C	5	-0.837

23	Zhang et.al.	1994	Larix	Temperate	Families	5	Leaves	Sub optimal	Height	m	ƌ13C	5	0.75
24	Zhang et.al.	1994	Larix	Temperate	Families	5	Leaves	Sub optimal	Diameter	cm	ƌ13C	5	0.92
25	Aleta et. al.	2009	Juglans	Mediterranean	Families	22	Leaves	Sub optimal	Height	cm	ƌ13C	22	–0.83
26	Aleta et. al.	2009	Juglans	Mediterranean	Families	22	Leaves	Sub optimal	Diameter	mm	ƌ13C	22	–0.99
27	Aleta et. al.	2009	Juglans	Mediterranean	Families	22	Leaves	Sub optimal	Height	cm	ƌ13C	22	–0.91
28	Aleta et. al.	2009	Juglans	Mediterranean	Families	22	Leaves	Sub optimal	Diameter	mm	ƌ13C	22	–0.23
29	Toillon et.al.	2013	Salix	Temperate	Clones	6	Leaves	Sub optimal	Height	cm	ƌ13C	6	0.95
30	Toillon et.al.	2013	Salix	Temperate	Clones	6	Leaves	Sub optimal	Diameter	mm	ƌ13C	6	0.93
31	Toillon et.al.	2013	Salix	Temperate	Clones	6	Leaves	Sub optimal	Biomass	g	ƌ13C	6	0.93

Appendix 21: Summary of the data for irrigated treatment included in the meta- analysis

Study	Articles	Year	Taxonomic genus	Biome	Genetic material	No of entries	Measurement part	Treatment	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Corcuera et. al.	2012	Pinus	Mediterranean	Populations	5	Leaves	Irrigated	Height	cm	ƌ13C	5	0.04
2	Corcuera et. al.	2012	Pinus	Mediterranean	Populations	5	Leaves	Irrigated	Diameter	mm	ƌ13C	5	-0.16
3	Aranda et. al.	2010	Pinus	Mediterranean	Families	20	Leaves	Irrigated	Biomass	g	ƌ13C	20	0.69
4	Zhang et. al.	1996	Pinus	Temperate	Populations	6	Leaves	Irrigated	Height	cm	ƌ13C	18	-0.32
5	Zhang et. al.	1996	Pinus	Temperate	Populations	6	Leaves	Irrigated	Diameter	mm	ƌ13C	18	-0.7
6	Zhang et. al.	1996	Pinus	Temperate	Populations	6	Leaves	Irrigated	Biomass	g	ƌ13C	18	-0.3
7	Zhang et. al.	1996	Pseudotsuga	Temperate	Populations	6	Leaves	Irrigated	Height	cm	ƌ13C	18	0.11
8	Zhang et. al.	1996	Pseudotsuga	Temperate	Populations	6	Leaves	Irrigated	Diameter	mm	ƌ13C	18	0.16
9	Zhang et. al.	1996	Pseudotsuga	Temperate	Populations	6	Leaves	Irrigated	Biomass	g	ƌ13C	18	0.16
10	Zhang et. al.	1996	Larix	Temperate	Populations	14	Leaves	Irrigated	Height	cm	ƌ13C	42	0.41
11	Zhang et. al.	1996	Larix	Temperate	Populations	14	Leaves	Irrigated	Diameter	mm	ƌ13C	42	0.31

12	Zhang et. al.	1996	Larix	Temperate	Populations	14	Leaves	Irrigated	Biomass	g	ƌ13C	42	0.59
13	Sun et.al.	1996	Picea	Boreal	Clones	10	Leaves	Irrigated	Biomass	g	ƌ13C	10	0.85
14	Livingston et.al.	1999	Picea	Boreal	Clones	10	Leaves	Irrigated	Biomass	g	ƌ13C	10	0.58
15	Livingston et.al.	1999	Picea	Boreal	Clones	10	Leaves	Irrigated	Biomass	g	ƌ13C	10	0.27
16	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Irrigated	Biomass	g	ƌ13C	48	0.5
17	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Irrigated	Biomass	g	ƌ13C	48	0.86
8	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Irrigated	Biomass	g	ƌ13C	48	0.5
19	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Irrigated	Biomass	g	ƌ13C	48	0.89
20	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Irrigated	Height		ƌ13C	48	0.52
21	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Irrigated	Height		ƌ13C	48	0.99
22	Roux et.al.	1996	Eucalyptus	Sub tropical	Clones	6	Leaves	Irrigated	Biomass	g	ƌ13C	18	0.32
23	Monclus et.al.	2009	Populus	Temperate	Families	33	Leaves	Irrigated	Biomass	g	ƌ13C	33	0.43
24	Monclus et.al.	2009	Populus	Temperate	Families	33	Leaves	Irrigated	Diameter	mm	ƌ13C	33	0.38
25	Monclus et.al.	2009	Populus	Temperate	Families	33	Leaves	Irrigated	Height	cm	ƌ13C	33	0.33

Appendix 22: Summary of the data for droughted treatment included in the meta- analysis

Study	Articles	Year	Taxonomic genus	Biome	Genetic material	No of entries	Measurement part	Treatment	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Corcuera et. al.	2012	Pinus	Mediterranean	Populations	5	Leaves	Droughted	Height	cm	ƌ13C	5	-0.3
2	Corcuera et. al.	2012	Pinus	Mediterranean	Populations	5	Leaves	Droughted	Diameter	mm	ƌ13C	5	-0.2
3	Aranda et. al.	2010	Pinus	Mediterranean	Families	20	Leaves	Droughted	Biomass	g	ƌ13C	20	0.59
4	Zhang et. al.	1996	Pinus	Temperate	Populations	6	Leaves	Droughted	Height	cm	ƌ13C	18	0.1
5	Zhang et. al.	1996	Pinus	Temperate	Populations	6	Leaves	Droughted	Diameter	mm	ƌ13C	18	0.19
6	Zhang et. al.	1996	Pinus	Temperate	Populations	6	Leaves	Droughted	Biomass	g	ƌ13C	18	-0.3
7	Zhang et. al.	1996	Pseudotsuga	Temperate	Populations	6	Leaves	Droughted	Height	cm	ƌ13C	18	0.75

8	Zhang et. al.	1996	Pseudotsuga	Temperate	Populations	6	Leaves	Droughted	Diameter	mm	ƌ13C	18	0.66
9	Zhang et. al.	1996	Pseudotsuga	Temperate	Populations	6	Leaves	Droughted	Biomass	g	ƌ13C	18	0.81
10	Zhang et. al.	1996	Larix	Temperate	Populations	14	Leaves	Droughted	Height	cm	ƌ13C	42	0.23
11	Zhang et. al.	1996	Larix	Temperate	Populations	14	Leaves	Droughted	Diameter	mm	ƌ13C	42	0.25
12	Zhang et. al.	1996	Larix	Temperate	Populations	14	Leaves	Droughted	Biomass	g	ƌ13C	42	0.74
13	Zhang et. al.	1996	Pinus	Temperate	Populations	6	Leaves	Droughted	Height	cm	ƌ13C	18	0.03
14	Zhang et. al.	1996	Pinus	Temperate	Populations	6	Leaves	Droughted	Biomass	g	ƌ13C	18	0.12
15	Zhang et. al.	1996	Pseudotsuga	Temperate	Populations	6	Leaves	Droughted	Height	cm	ƌ13C	18	0.5
16	Zhang et. al.	1996	Pseudotsuga	Temperate	Populations	6	Leaves	Droughted	Biomass	g	ƌ13C	18	0.62
17	Sun et.al.	1996	Picea	Boreal	Clones	10	Leaves	Droughted	Biomass	g	ƌ13C	10	0.71
18	Livingston et.al.	1999	Picea	Boreal	Clones	10	Leaves	Droughted	Biomass	g	ƌ13C	10	0.75
19	Livingston et.al.	1999	Picea	Boreal	Clones	10	Leaves	Droughted	Biomass	g	ƌ13C	10	0.7
20	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Droughted	Biomass	g	ƌ13C	48	0.63
21	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Droughted	Biomass	g	ƌ13C	48	0.95
22	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Droughted	Biomass	g	ƌ13C	48	0.65
23	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Droughted	Biomass	g	ƌ13C	48	0.95
24	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Droughted	Height		ƌ13C	48	0.85
25	Lauteri et. al.	2004	Castanea	Temperate	Populations	6	Leaves	Droughted	Height		ƌ13C	48	0.12
26	Roux et.al.	1996	Eucalyptus	Sub tropical	Clones	6	Leaves	Droughted	Biomass	g	ƌ13C	18	0.7

Appendix 23: Summary of the data for seedling stage included in the meta- analysis

Articles	Year	Taxonomic genus	Experimental conditions	Biome	Genetic material	No of entries	Measurement part	Ontogeny stage	Growth parameter	Growth parameter unit	WUEi measured by	n	r
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Height	cm	ƌ13C	5	0.04
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Height	cm	ƌ13C	5	-0.3
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Diameter	mm	ƌ13C	5	-0.2
Corcuera et. al.	2012	Pinus	Greenhouse	Mediterranean	Populations	5	Leaves	Seedlings	Diameter	mm	ƌ13C	5	-0.2
Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Seedlings	Biomass	g	ƌ13C	20	0.69
Aranda et. al.	2010	Pinus	Greenhouse	Mediterranean	Families	20	Leaves	Seedlings	Biomass	g	ƌ13C	20	0.59
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	-0.3
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ƌ13C	18	-0.7
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	-0.3
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.1
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ƌ13C	18	0.19
Zhang et. al.	1996	Pinus	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	-0.3
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.11
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ƌ13C	18	0.16
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.16
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƌ13C	18	0.75
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Diameter	mm	ƌ13C	18	0.66
Zhang et. al.	1996	Pseudotsuga	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƌ13C	18	0.81
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	ƌ13C	42	0.41
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Diameter	mm	ƌ13C	42	0.31
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	ƌ13C	42	0.59
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Height	cm	ƌ13C	42	0.23
Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Diameter	mm	ƌ13C	42	0.25

Zhang et. al.	1996	Larix	Greenhouse	Temperate	Populations	14	Leaves	Seedlings	Biomass	g	ƍ13C	42	0.74
Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƍ13C	18	0.03
Zhang et. al.	1996	Pinus	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƍ13C	18	0.12
Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Height	cm	ƍ13C	18	0.5
Zhang et. al.	1996	Pseudotsuga	Nursery	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	ƍ13C	18	0.62
Baltunis et.al.	2008	Pinus	Field	Sub tropical	Families	61	Leaves	Seedlings	Height	cm	ƍ13C	61	0.42
Baltunis et.al.	2008	Pinus	Field	Sub tropical	Populations	32	Leaves	Seedlings	Height	cm	ƍ13C	32	0.54
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƍ13C	122	0.2
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƍ13C	122	0.32
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Diameter	cm	ƍ13C	122	0.19
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Height	m	ƍ13C	122	0.36
Prasolova et.al.	2003	Pinus	Field	Sub tropical	Clones	122	Leaves	Seedlings	Diameter	cm	ƍ13C	122	0.22
Pastorino et. al.	2012	Austrocedrus	Field	Temperate	Families	41	Leaves	Seedlings	Height	cm	ƍ13C	41	0.68
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Seedlings	Height	m	ƍ13C	4	0.84
Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƍ13C	101	0.37
Prasolova et.al.	2001	Araucaria	Field	Sub tropical	Families	22	Leaves	Seedlings	Height	m	ƍ13C	100	0.41
Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Seedlings	Height	m	ƍ13C	113	0.3
Prasolova et.al.	2000	Araucaria	Field	Sub tropical	Families	23	Leaves	Seedlings	Diameter	mm	ƍ13C	113	0.19
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƍ13C	27	0.16
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Height	m	ƍ13C	27	-0
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Diameter	cm	ƍ13C	27	0.12
Xu et. al.	2003	Araucaria	Field	Sub tropical	Families	31	Branchlets	Seedlings	Diameter	cm	ƍ13C	27	0.38
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƍ13C	10	0.71
Sun et.al.	1996	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƍ13C	10	0.85
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƍ13C	10	0.58
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƍ13C	10	0.27
Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	ƍ13C	10	0.75

Livingston et.al.	1999	Picea	Field	Boreal	Clones	10	Leaves	Seedlings	Biomass	g	δ13C	10	0.7
Voltas J. (Unpublished)	2010	Pinus	Nursery	Mediterranean	Populations	25	Leaves	Seedlings	Height	m	δ13C	25	0.46
Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Height	m	δ13C	8	-0.6
Raddad and Luukkanen	2006	Acacia	Field	Sub tropical	Populations	8	Leaves	Seedlings	Diameter	cm	δ13C	8	-0.6
Gray et.al.	2013	Acacia	Greenhouse	Sub tropical	Populations	10	Leaves	Seedlings	Biomass	g	δ13C	10	0.21
Gray et.al.	2013	Acacia	Greenhouse	Sub tropical	Populations	11	Leaves	Seedlings	Biomass	g	δ13C	11	0.67
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.5
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.63
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.86
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.95
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.5
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.65
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.89
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Biomass	g	δ13C	48	0.95
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		δ13C	48	0.52
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		δ13C	48	0.85
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		δ13C	48	0.99
Lauteri et. al.	2004	Castanea	Greenhouse	Temperate	Populations	6	Leaves	Seedlings	Height		δ13C	48	0.12
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	δ13C	6	-0.8
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	δ13C	18	0.32
Roux et.al.	1996	Eucalyptus	Field	Sub tropical	Clones	6	Leaves	Seedlings	Biomass	g	δ13C	18	0.7
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	7	Leaves	Seedlings	Height	cm	δ13C	7	0.96
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	9	Leaves	Seedlings	Height	cm	δ13C	9	0.96
Pennington et.al.	1999	Prosopis	Greenhouse	Sub tropical	Families	15	Leaves	Seedlings	Height	cm	δ13C	15	0.04
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	δ13C	6	0.87
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Height	cm	δ13C	6	0.95

Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Diameter	mm	ƌ13C	6	0.93
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.93
Toillon et.al.	2013	Salix	Field	Temperate	Clones	6	Leaves	Seedlings	Biomass	g	ƌ13C	6	0.94

Appendix 24: Summary of the data for sapling stage included in the meta- analysis

Study	Articles	Year	Taxonomic genus	Biome	Genetic material	No of entries	Measurement part	Measurement species type	Growth parameter	Growth parameter unit	WUEi measured by	n	r
1	Xue et. al.	2013	Pinus	Temperate	Clone	20	Leaves	Saplings	Diameter	mm	ƌ13C	80	0.33
2	Xue et. al.	2013	Pinus	Temperate	Clone	20	Leaves	Saplings	Diameter	cm3	ƌ13C	80	0.31
3	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Saplings	Height	cm	ƌ13C	6	0.54
4	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Saplings	Diameter	mm	ƌ13C	6	0.199
5	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Saplings	Height	cm	ƌ13C	6	0.346
6	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Saplings	Diameter	mm	ƌ13C	6	0.278
7	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Saplings	Height	cm	ƌ13C	6	-0.14
8	Hawkins et.al.	2010	Pinus	Temperate	Clone	6	Leaves	Saplings	Diameter	mm	ƌ13C	6	0.526
9	Voltas et.al.	2008	Pinus	Mediterranean	Populations	25	Woods	Saplings	Height	m	ƌ13C	25	-0.4
10	Voltas et.al.	2008	Pinus	Mediterranean	Populations	25	Woods	Saplings	Diameter	cm	ƌ13C	25	-0.38
11	Voltas et.al.	2008	Pinus	Mediterranean	Populations	25	Woods	Saplings	Height	m	ƌ13C	25	-0.38
12	Voltas et.al.	2008	Pinus	Mediterranean	Populations	25	Woods	Saplings	Diameter	cm	ƌ13C	25	-0.13
13	Xu et. al.	2000	Pinus	Sub tropical	Clone	8	Leaves	Saplings	Height	m	ƌ13C	8	0.96
14	Guy and Holowachuk	2001	Pinus	Temperate	Populations	10	Woods	Saplings	Diameter	cm3	ƌ13C	10	0.763
15	Guy and Holowachuk	2001	Pinus	Temperate	Populations	10	Woods	Saplings	Diameter	cm3	ƌ13C	10	0.582
16	Guy and Holowachuk	2001	Pinus	Temperate	Populations	10	Woods	Saplings	Diameter	cm3	ƌ13C	10	0.657
17	Pita et. al.	2001	Eucalyptus	Temperate	Clones	4	Woods	Saplings	Diameter	cm	ƌ13C	4	-0.83
18	Pita et. al.	2001	Eucalyptus	Temperate	Clones	6	Woods	Saplings	Diameter	cm	ƌ13C	6	-0.88

19	Pita et. al.	2001	Eucalyptus	Temperate	Clones	7	Woods	Saplings	Diameter	cm	ƌ13C	7	-0.89
20	Pita et. al.	2001	Eucalyptus	Temperate	Clones	7	Woods	Saplings	Diameter	m2/ha	ƌ13C	7	-0.68
21	Pita et. al.	2001	Eucalyptus	Temperate	Clones	5	Woods	Saplings	Diameter	cm	ƌ13C	5	-0.84
22	Aleta et. al.	2009	Juglans	Mediterranean	Families	22	Leaves	Saplings	Height	cm	ƌ13C	22	–0.83
23	Aleta et. al.	2009	Juglans	Mediterranean	Families	22	Leaves	Saplings	Diameter	mm	ƌ13C	22	–0.99
24	Aleta et. al.	2009	Juglans	Mediterranean	Families	22	Leaves	Saplings	Height	cm	ƌ13C	22	–0.91
25	Aleta et. al.	2009	Juglans	Mediterranean	Families	22	Leaves	Saplings	Diameter	mm	ƌ13C	22	–0.23
26	Dillen et.al.	2008	Populus	Temperate	Families	50	Leaves	Saplings	Diameter		ƌ13C	50	-0.36
27	Monclus et.al.	2009	Populus	Temperate	Families	33	Leaves	Saplings	Biomass	g	ƌ13C	33	0.43
28	Monclus et.al.	2009	Populus	Temperate	Families	33	Leaves	Saplings	Diameter	mm	ƌ13C	33	0.38
29	Monclus et.al.	2009	Populus	Temperate	Families	33	Leaves	Saplings	Height	cm	ƌ13C	33	0.33

Appendix 25: Summary of the data for adult trees included in the meta- analysis

Articles	**Year**	**Taxonomic genus**	**Experimental conditions**	**Biome**	**Genetic material**	**No of entries**	**Measurement part**	**Measurement species type**	**Growth parameter**	**Growth parameter unit**	**WUEi measured by**	**n**	**r**
Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Adult trees	Height	m	ƌ13C	7	-0.32
Correia et.al.	2008	Pinus	Field	Mediterranean	Populations	7	Leaves	Adult trees	Diameter	cm	ƌ13C	7	0.008
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƌ13C	5	0.224
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ƌ13C	5	-0.51
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƌ13C	5	0.86
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ƌ13C	5	0.53
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƌ13C	5	-0.17
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ƌ13C	5	0.214
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Height	cm	ƌ13C	5	-0.33
Tognetti et.al.	2000	Pinus	Field	Mediterranean	Populations	5	Leaves	Adult trees	Diameter	cm	ƌ13C	5	0.746

Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ƍ13C	50	0.3
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Diameter	cm	ƍ13C	50	0.26
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ƍ13C	50	0.32
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Diameter	cm	ƍ13C	50	0.21
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Height	cm	ƍ13C	50	0.08
Marguerit et.al.	2014	Pinus	Field	Mediterranean	Families	50	Woods	Adult trees	Diameter	cm	ƍ13C	50	-0.02
Brendel et.al.	2002	Pinus	Field	Mediterranean	Families	63	Woods	Adult trees	Diameter	mm	ƍ13C	63	0.27
Duglas et. al.	2008	Pinus	Field	Temperate	Families	7	Leaves	Adult trees	Diameter	mm	ƍ13C	7	-0.56
Duglas et. al.	2008	Pinus	Field	Temperate	Families	8	Leaves	Adult trees	Diameter	mm	ƍ13C	8	-0.19
Zhang et. al.	1996	Pinus	Field	Temperate	Populations	17	Leaves	Adult trees	Height	cm	ƍ13C	17	0.14
Zhang et. al.	1996	Larix	Field	Temperate	Populations	16	Leaves	Adult trees	Height	cm	ƍ13C	16	0.51
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Diameter	cm	ƍ13C	6	-0.96
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ƍ13C	6	-0.33
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ƍ13C	6	0.327
Jansen et.al.	2013	Pseudotsuga	Field	Temperate	Populations	6	Woods	Adult trees	Height	m	ƍ13C	6	0.479
Aitken et.al.	1995	Pseudotsuga	Field	Temperate	Populations	4	Woods	Adult trees	Height	m	ƍ13C	4	0.832
Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Adult trees	Height	cm	ƍ13C	18	0.97
Johnsen et. al.	1999	Picea	Field	Boreal	Families	18	Leaves	Adult trees	Diameter	cm	ƍ13C	18	0.64
Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Adult trees	Height	cm	ƍ13C	6	-0.23
Robson et.al.	2012	Fagus	Field	Mediterranean	Populations	6	Leaves	Adult trees	Diameter	mm	ƍ13C	6	-0.27
Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Adult trees	Height	m	ƍ13C	5	0.75
Zhang et.al.	1994	Larix	Field	Temperate	Families	5	Leaves	Adult trees	Diameter	cm	ƍ13C	5	0.92