THE DOMESTICATION OF LEBANESE NATIVE TREE SPECIES

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ABSTRACT

Native flora in Lebanon is threatened by tourist and urban development, urban expansion in the mountainous areas, political instability, over-collection of medicinal and aromatic plants, lack of legislation prohibiting over-collection from the wild, overgrazing and forest fires. Since the end of the civil war, people started to redevelop their home gardens and there has been an increased demand for landscape plants as a result of extensive reconstruction projects across the country. Lebanon’s dry summer climate has created demand for landscape plants with low water requirement. Despite Lebanon’s floristic richness, estimated at 3, 761 vascular plant species, due to its location, topography and Mediterranean climate, most taxa used in landscape are non-native.

In summer 2002, face-to-face interviews were carried across the country with seventeen nursery managers. Production of woody plants from propagation to finished product does not commonly occur, although herbaceous taxa are grown locally. Most frequently, woody taxa are imported from Italian and Spanish nurseries. The nature of the Lebanese nurseries industry is to import plants, re-pot them, and re-sell the stock within a few months. There is no recent statistical database for nursery production or sales, as the government does not collect or require reporting of landscape imports or sales. Nursery managers are not aware of marketing methods for their products; the many challenges they face are plant production and marketing.

Fertilizer and water use studies were carried out on three species native to Lebanon that have ornamental attributes: *Cercis siliquastrum*, *Acer syriacum* and *Malus trilobata*. The fertilizer study aimed at determining the production potential of six sources of *Cercis siliquastrum*, two sources of *Malus trilobata* and one source of *Acer syriacum*, by exploring their growth, N, P, K nutrient uptake efficiency and partitioning under two fertilizer rates. Two-year old seedlings were planted in 11 liters containers in a 3:1 pine bark: compost substrate and half the seedlings within each source were assigned to either 25 or 100 mg N per L from 21-3.1 P- 5.9 K (21-7-7) Peters Water Soluble Fertilizer. Seedlings of all sources of *Cercis siliquastrum* grown under 25 had greater dry weight than those grown at 100 mg N per L. those of *Malus trilobata* grown under the low fertilizer rate were taller than those grown at the high fertilizer rate. Growth of *Acer syriacum* was not affected by fertilizer rates. Nutrient loading occurred in *Cercis* and *Malus* plants under the high fertilizer rate, although total plant N, P, and K content was not affected by fertilizer rate. There were also significant differences in mineral nutrient uptake and nutrient use efficiencies among the seed sources of *Cercis siliquastrum* and *Malus trilobata*. Therefore, it is recommended that performance trial be carried out for individual tree collection in different sites in Lebanon.

Water use of container-grown plants and the impact of fertilization on water use were studied in these species. Water use estimates were made by saturating the containers early in the morning, allowing them to drain for one hour, weighing them and re-weighing approximately five hours later. For all species, seedlings at the low fertilizer rate used more water per cm height than plants grown at the high fertilizer rate. In addition, there were differences in water use among and within seed sources of *Cercis siliquastrum* and *Malus trilobata*. Differences as great as 50 % were seen in

Cercis siliquastrum per cm height per hour and 14 % in *Malus trilobata*. Water use efficient plants were selected from each species and will be asexually propagated to confirm water use efficiency.

One way to preserve these species is by propagation and reintroduction into appropriate habitats. However, this requires an understanding of the species biology and environment. The relationship of nine species to the soil and climatic conditions in eight sites along an altitudinal gradient was studied. Individual species were counted and identified within transects at each site. Climatic data was collected and soil samples were taken and analyzed for soil texture, soil pH, EC, $CaCO_3$, organic matter content and the following nutrients: Ca, Mn, Na, Fe, P, K, Cu, Mg, and Zn. Each ecosystem had a unique environment that could be described using the first two factors (70.3 % of variation) in a Factor Analysis of the six most important variables. Some species' densities were affected by soil conditions (the first factor) while climatic conditions (the second factor) explained the densities of species. Recommendations are made for the in-situ preservation of the nine species and their ecosystems.

This dissertation is dedicated to my fiancé Michael, my sister Lama and my parents Fatme and Ghassan for their faith in me, encouragement, support and love.

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PUBLICATIONS

Research Publication

1. Zahreddine, H.G., Struve, D. K., and Quigley, M. 2004. Growing *Pinus nigra* seedlings in Spinout^{TM}- treated containers reduces root malformation and increases growth after transplanting. Journal of Environmental Horticulture, 22 (4): 176-182.

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FIELDS OF STUDY

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CHAPTER 1

INTRODUCTION

1.1 *Background information about Lebanon*

Lebanon, is located on the eastern shores of the Mediterranean Sea, and is bordered by Syria in the north and east and by Israel (Palestine) in the South. Two mountain ranges (Mount Lebanon which overlooks the narrow coastal plain, and the Anti-Lebanon mountain range) run parallel the length of the country. The coastal plain is characterized by a mild frost free climate where fruits, local and exotic banana varieties, vegetables, and annual and fragrant flowers are produced in greenhouses. The Bekaa valley lies between the two mountain ranges, a plateau of 125 km long and about 1000 m elevation. The valley is heavily cultivated with main crops such as tobacco, cereals, sugar beet, onion and potatoes. Lebanon's climate is classified as Mediterranean with hot dry summers and cool moist winters. Lebanon is densely populated, six million people live in 10, 520 km^2. Four million are Lebanese, and two million Syrian. About sixty percent of the population lives in the capital Beirut and its surrounding suburbs.

Because of the country's topography, many vegetation zones based on altitude gradient occur (Table 1.1).

Lebanon falls within an identified center of plant diversity, the Levantine uplands (Davis *et al*., 1995).The country has an estimated flora of 3,761 vascular plant species, of which 38 are rare and endangered and 92 are endemic (UNEP, 1996). Flora was last assessed 40 years ago by Paul Mouterde (1966) and had not been updated from that time. Since then, the country's biodiversity has been exposed to major threats such as tourist and urban development particularly along the coast. Urban expansion and proliferation of summer resorts in the mountains constitute a real threat to the Lebanese forests. Unchecked expansion is not only destroying the trees but also disturbing the ecological systems. A civil war raged from 1975 until 1990; and seriously degraded many plant communities and habitats. Other biodiversity threats include over collection of the aromatic, wild plants, and medicinal herbs; illegal woodcutting and absence of implementation and compliance to regulations prohibiting woodcutting or plant collection from the wild; overgrazing by sheep, goats and cattle; and forest fires due to the lack of proper forest management (UNEP, 1996).

Until this research project, there were no *ex-situ* programs for conservation of Lebanon's biodiversity. In contrast the country is taking *in-situ* measures such as establishment of natural reserves and protected areas, and on-farm conservation of wild varieties. In addition, the government has set conservation objectives in its national biodiversity strategy and action plan, such as the establishment of botanic gardens and wild animal encounters, increasing the green areas in Beirut, increasing the number of protected areas and encouraging research in many conservation related issues (UNEP, 1996).

A large number of the 3,761 plant species in Lebanon have potential economic value as either ornamental or medicinal plants. There are 236 species of wild and cultivated medicinal plants in Lebanon. Sixteen of these are rare or localized in certain regions and 29 are endangered (UNEP, 1996). A consequence of the species richness and varied environments is the wide range of taxa that can be grown and marketed within Lebanon. The many climatic zones offer a diversity of production environments and Lebanon’s location at the crossroads of three major continents (Asia, Europe and Africa) offers potential markets. However, the concept of using wild plants for ornamental purposes is not well recognized in Lebanon. In contrast, in neighboring countries such as Turkey, several studies are carried out to optimize the cultivation of wild plants with ornamental value (Ertug-Firat and Tan, 1997).

The term “Nursery” in Lebanon refers to any producer, retailer, landscape contractor, garden center or broker of ornamental plants including herbaceous, woody or cut flowers. Despite Lebanon’s floristic richness, most taxa used in landscape are non-native. Woody plant production is limited in Lebanon. Only few nursery managers collect native wild material although there is a great potential for developing a native plant production industry in Lebanon. Woody plants are imported from many countries (Italy, Spain, Syria, Egypt, United States, and others) but Italian imports dominate. Production of woody plants from propagation to finished product does not commonly occur, although herbaceous taxa are grown locally. The common practice for Lebanese nurseries is to re-pot imported stock, and after the root system is re-established (about four to six months), the stock is sold for landscaping projects in Lebanon and other Middle Eastern countries. The Lebanese government does not collect or require reporting of landscape imports or sales, therefore there is no recent statistical database for nursery production or sales.

Since 1990 (the end of the civil war) people in Lebanon began to redevelop their home gardens and only recently have rediscovered public and private landscaping. Because of the extensive reconstruction projects from after the war, the demand for landscape plants has been increasing.

A significant challenge is to identify the native taxa suitable for production. Ornamental trees have been used since the earliest of times. They have many benefits as providing beauty around properties, providing shade, reducing wind speed, and conserving energy and the quality of air. In the ornamental industry, seedling selection is needed, which then tends to be followed by vegetative propagation. Seedlings are selected based on desirable characteristics that include foliage color, growth habit, flower color, growth rate, and ability to grow under certain climatic and soil conditions. Growing plants from seeds offers the ability to evaluate all the phenotypic variability within a species. Hence, nurserymen can select for species varieties and cultivars.

Although the need for landscape plants is increasing in Lebanon, there is a lack in landscape professionals who are knowledgeable about plant materials, the plants assets and problems. This is leading to the selection of plants that in some cases do not suit the climate where they are being planted, and in others, are invasive (Table 1.2).

Starting a landscape industry in Lebanon has many advantages. From an economic perspective, it will provide a source of income for people and an alternative for marketing traditional agricultural crops. Besides, local landscape contractors can buy the plants locally rather than importing them. Not only this is good from an economic perspective but it is also important for environmental sustainability and conservation of rare and threatened species through their propagation and reintroduction into their historical habitats and through domestication. Also, because of the Mediterranean climate in Lebanon, characterized by a dry summer season, the demand for landscaping with plants that require a low water requirement is increasing (Garcia-Navarro *et al.* 2004). Water and nitrogen are considered the most limiting factors for plant survival and growth (Dickmann *et al.* 1992; Wright *et al.* 1983). Here comes the basis of this dissertation which was divided into three broad studies.

1.2 *Objectives of the study*

The first study (Chapter 2) aimed at generating baseline information about the landscape industry in Lebanon. Owners of major Lebanese nurseries, that sell ornamental woody plants, were interviewed in summer 2002 about the nursery location and tenure status, production area, products handled, labor usage, production techniques, marketing systems, product handling and quality indices, problems of the industry based on nursery producers' perspectives, and their perspective on the potential for native Lebanese plant production for landscape use.

The second study was divided into two sections: the first section (Chapters 3 and 4) aimed at determining the potential for the production of six Lebanese native *Cercis siliquastrum* sources, two sources of *Malus trilobata* and one source of *Acer syriacum*, by exploring the growth, dry weight and N, P, and K nutrient uptake efficiencies, and mineral nutrient partitioning during one growing season under two fertilizer rates.

The second section (Chapter 5) aimed at studying the effect of two nitrogen fertilizer rates on the water use of the three species grown in containers during the growing season in Ohio and identifying the water use efficient plants from each species and source.

The aim of the third study (Chapter 6) was to compare the vegetation characteristics of the 8 dominant trees in ecosystems in Lebanon (*Acer syriacum*, *Cercis siliquastrum*, *Malus trilobata*, *Sorbus torminalis*, *Ostrya carpinifolia*, *Styrax officinalis*, *Quercus coccifera*, *Quercus cerris, Juniperus excelsa*) and relate their densities within the habitats to environmental and soil characteristics.

1.3 *Description of the studied plant species*

Cercis siliquastrum L., belongs to the family Cesalpinaceae. It is described as a medium height tree with mature height of 5-10 m. At young stages its trunk is purple then becomes gray-pink with age (Anonymous, 1999). The leaves are bluish green with rounded tips. It flowers from March to April and flowers precede leafing. The flowers are pink, usually borne in clusters of three to six on previous years' growth. It is widely distributed in the Thermomediterranean zone (0-500 m altitude) and can be found up to 800 m altitude where it is associated with pine and oak forests. Its wide distribution range over a range of habitats suggests that *Cercis siliquastrum* provenances may exist. *Cercis siliquastrum*, like other redbud species, is reported to grow well in a variety of soil textures but best in soils where the pH is above 7.5 and the species tends to be tolerant to nutrient deficient sites (USDA, 1990).

Contradictory information was provided on the propagation of this species by seeds.

Young, (1992) and Dirr and Heuser, (1987) reported that no embryo dormancy existed for *Cercis siliquastrum* so scarification is only needed to break seed coat dormancy. Hartman, (1997) reported that scarification must be followed by stratification for 3 months at 2-4 ^{o}C since most of the *Cercis sp.* have an imprevious seed coat and a dormant embryo. Other references state that the seeds of *Cercis siliquastrum* are impermeable and have physiologically dormant embryos placing them under the "combinational dormancy class" which is a combination of "physical dormancy" and "physiological dormancy" (Baskin, 2004). Cold stratification is reported to break the physiological dormancy in *Cercis siliquastrum* seeds (Baskin & Baskin, 2001).

Malus trilobata Schneid, is an erect crab or three lobed apple tree. It belongs to the family Rosaceae. It is an erect tree about 13m tall with linear horizontal branches. Leaves are maple-like and deeply three-lobed. Often the lobes themselves are sharply lobed and toothed, attractively tinted from orange to red to deep purple in autumn. The flowering period is between April and May. It has perfect flowers (http://www.wpsm.net/) and performs dichogamy, meaning that the male and female flowers on the same flower or tree mature at different times. It is pollinated by insects or wind (http://www.wpsm.net/). The flowers are white, and the fruits are yellow.

Hillier and Sons, (1973) report the tree distribution in Eastern Mediterranean Region, and North East Greece adding that the species is comparatively rare and very distinct; However, Mouterde (1966) reported the species as being endemic to Lebanon and rare.

The literature on seed germination protocols for *Malus trilobata* does not exist therefore germination trials were based on the literature gathered about other *Malus species*.

American Society of Official Analysts (1998) and Young (1992) recommend prechilling treatment, then incubation at temperatures of 18-22^{o}C. The prechilling period is reported to vary from 30 to 60 to 120 days according to the species (Young, 1992). *Malus sylvetris and Malus* "bittenfelder" need 8-12 weeks (2-3 months) cold stratification (Mcdonald, 1986).

Acer syriacum Boin and Gaill, syrian maple, belongs to the family Aceraceae. It reaches 8 m height. The leaves are evergreen, glabrous, with three short, acute, or broad lobes. Flowering is between February and March. It produces white to yellow flowers, and has divergent samaras. It gives a nice ornamental Fall color. It is distributed in the following countries: Syria, Lebanon, Cyprus, and Palestine. UNEP, (1996) reported that the species needs to be conserved through reintroduction to the wild.

No information is provided on the propagation of this species. Therefore literature was gathered based on the genera. International Seed Testing Association (1999) and Mcdonald, (1986) recommended prechilling for 2 months at 1-5 ^{o}C after removing the pericarp followed by an incubation at 20-30^{0}C. Seeds of red maple (*A. rubrum*) showed maximum germination after prechilling for 6-8 weeks (45-60 days) and then incubation at 20-30^{o}C. Southern US *Acer species* don’t require prechill (AOSA, 1998; Dirr and Heuser, 1987). *Acer palmatum* requires prechilling for 4 months at 1-5 ^{0}C then incubation at 20 ^{0}C. Mcdonald (1986) reported that *Acer palmatum* requires 8-12 weeks warm stratification followed by 8-12 weeks cold stratification. Hartman (1997) reports that stratification for 90 days at 4 ^{o} C will germinate maple seeds.

Dirr and Heuser, (1987) suggest 1-2 months warm then 3-6 months cold to break dormancy for some *Acer* species.

Sorbus torminalis Crantz belongs to the family Rosaceae. Reported to be rare and isolated in Lebanon, Europe and Mediterranean countries (Anonymous, 1999). In Lebanon, it grows in areas above 1000 m altitude, where cedars grow. It has an upright form with a height of 15-20 m. The plant's leaves have ornamental characteristics, 5-9 lobes with red and purple Fall color. The trunk is red brown, and fissured with noticeable rectangles or squares. It blooms in Lebanon between April and May and is ecologically important for birds, which eat the fruits and disperse seeds, and for the bees use them for nectar. The wood is used in making musical instrument.

No information is provided on the sexual or asexual propagation of this species. According to Hartmann (1997), some *Sorbus* species have double dormancy and require a 3-5 months warm stratification followed by a 3 months cold stratification at 5 ^{o}C for good seed germination (Hartmann, 1997). A related species, *Sorbus aria*, has embryo dormancy and good results were obtained with 3 months of warm stratification followed by 3 months of cold stratification (Dirr and Heuser, 1987). Other species of *Sorbus* require 5 months warm stratification followed by 3 months cold stratification (Dirr and Heuser, 1987). ISTA (1999) and Dirr and Heuser, (1987*)* report that *Sorbus sp*ecies require prechilling for 4 months at 3-5 C, then incubation period at 20-30 C, for a maximum 28 days. Baskin & Baskin, (2001), report that the genus Sorbus has physiological dormancy which is usually broken by 1- 4 months of cold stratification; however, in some cases, some need to receive a period of warm stratification such as *Sorbus aria*.

In addition to the above described species, other species of interest were selected for the third study based on their threat category and the importance of the genera in the international market as landscape ornamental trees.

Quercus coccifera is threatened by continuous harvest for fire wood, overgrazing [which is affecting the species' natural regeneration], fires and the expansion of cultivated areas (UNEP, 1996). *Quercus cerris* is threatened by grazing, pruning branches all year long to use it as fodder for livestock and by habitat loss for construction of residential properties (UNEP, 1996). *Juniperus excelsa* is threatened by grazing and chopping fire wood. Natural regeneration is almost non existent because of very low seed numbers from the cones, and their subsequent difficulty in germination (UNEP, 1996).

Styrax officinalis is an understory tree and is known for its ornamental characteristics because of its bell-shaped white flowers.

Zone	Altitude (m)	Most common woody plant species
Thermomediterranean	0-500	*Ceratonia, Pistacia, Pinus, Myrtus.*
Euromediterranean	500-1000	*Quercus, Pinus,* and *Cupressus.*
Supramediterranean	1000-1500	*Quercus, Ostrya, Malus, Fraxinus,* and *Pinus.*
Mediterranean Mountain	1500-2000	*Cedrus, Abies, Juniperus, Quercus* and *Berberis*.
Oromediterranean	> 2000	*Juniperus, Rhamnus, Prunus, Pyrus, Daphne* and *Cotoneaster*.
Pre-steppe Mediterranean*	900-2400	*Quercus* and *Juniperus.*

Table 1.1. Vegetation zones of Lebanon based on altitude gradient.

*The Pre-steppe Mediterranean zone is located at the east side of Mount-Lebanon and north side of Anti-Lebanon in the Northern part of the country. *Quercus* and *Junipers* grow there on degraded soils, where drought and cold make it hard for phytosociological association to develop easily.

Species	Origin	Use	Threat	Reference
Tipuana tipu	South America	Street tree	Invasive	www.weeds.crc.org.au/documents/wmg_rosewood.pdf
Morus kagayama	Korea and Japan	Garden, street tree	unknown	Hillier and Sons, 1973
Magnolia grandiflora	Southern United States	Garden tree	unknown	http://www.lacity.org/BOSS/streettree/MagnoliaGrandiflora.htm
Delonix regia	Madagascar	Street tree	Threat to foundation and sidewalks	http://selectree.calpoly.edu/treedetail.lasso?rid=486
Grevillia robusta	Eastern Australia	Street tree	possible invasive	www.botany.hawaii.edu/ pabitra/biodiversity/chapter10.pdf
Betula alba	Northern Europe	Garden tree	unknown	http://www.freemancorp.com/veneers/birchburl.html
Abies nordmanniana	Russia, Turkey	Garden tree	unknown	http://www.treehavennursery.com/pictures.html
Berberis thunbergii	Japan	Garden plant	invasive	http://www.ct-botanical-society.org/galleries/berberisthun.html
Acer platanoides	Eurasia	Street tree	low level invasive	http://www.rbg.ca/cbcn/en/projects/invasives/i_tree2.html#Norway%20maple
Ailanthus altissima	China	Garden tree	Invasive	http://www.se-eppc.org/manual/ailanthus.html
Lagerstroemia indica	China	Street tree	unknown	http://www.cityofla.org/BOSS/streettree/LagerstroemiaIndica.htm
Liquidambar styraciflua	US and south US	Garden tree	unknown	http://www.na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/liquidambar/styraciflua.htm

Table 1.2. Some of the landscape plants used in Lebanon, their name, origin, use and threats.

CHAPTER 2

Re-emergence of the Lebanese landscape industries; baseline data from a 2002 survey with recommendations[1]

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2.1 Abstract

Interest in ornamental landscapes rekindled as Lebanon's civil war ended. This study was conducted as the first post-war survey of Lebanon nascent green industry. In summer 2002, face-to-face interviews were carried across the country with seventeen nursery managers. The nature of the Lebanese nurseries industry is to import plants, re-pot them, and re-sell the stock within a few months. There is no recent statistical database for nursery production or sales, as the government does not collect or require reporting of landscape imports or sales. Production of woody plants from propagation to finished product does not commonly occur, although herbaceous taxa are grown locally. Despite Lebanon's floristic richness, most taxa used in landscape are non-native. Most frequently, woody taxa are imported from Italian and Spanish nurseries. Few nursery managers collect native wild material although there is a great potential for developing a native plant production industry in Lebanon. Nursery managers are not aware of marketing methods for their products; the many challenges they face are plant production and marketing. We recommend that the government collect and report data on nursery stock imports and exports and domestic production. We further recommend that quality standards be established for nursery stock, growing substrates, composts and water quality. Finally, as a method for distinguishing the developing Lebanese nursery industry, we advocate the production of indigenous Lebanese taxa for both domestic and export markets.

Keywords: Lebanese nursery industry, woody taxa production, survey, native plants

2.2 Introduction

Lebanon, located on the eastern shores of the Mediterranean Sea, is bordered by Syria in the north and east and by Israel (Palestine) in the South. Two mountain ranges (Mount Lebanon which overlooks the narrow coastal plain, and the Anti-Lebanon mountain range) run parallel the length of the country. Between the two ranges is the Bekaa valley, a plateau 125 km long and about 1000 m elevation. Lebanon's climate is classified as Mediterranean with hot dry summer and cool moist winter.

The distance from the north to the south of the country is 180 km and 50 km from east to west. Although distances in Lebanon are short, travel times are relatively long because of the traffic in urban areas and curving mountain roads in rural areas. Traveling north 85 km to Tripoli requires at least one hour. Traveling south 43 km to Saida, requires 45 min. Traveling to the Bekaa area from Beirut (45 km) requires more than an hour and a half.

Lebanon is densely populated with six million people in 10, 520 km^2. Four million are Lebanese, and two million Syrian. About half of the population lives in Beirut and its surrounding suburbs. The large majority lives near the coast and on the western slopes of the coastal mountain range.

In 1973, the floristic richness of the country was estimated at 2600 plant species (Zohary, 1973), with 311 endemic species. An estimated 212 species in Lebanon have economic value as medicinal or edible crops. Vegetation zones in Lebanon are based on altitude gradient; they range from Thermo-Mediterranean (0-500 m) to Eu-Mediterranean (500-1000m), Supra-Mediterranean (1000-1500 m), Mountainous Mediterranean (1500-2000 m) and Oro-Mediterranean zones (> 2000 m). A consequence of the varied environments is the wide range of taxa that can be grown and marketed within Lebanon; thus, a significant challenge is to identify which taxa to produce. The many climatic zones offer a diversity of production environments and markets.

A civil war raged from 1975 until 1990; it seriously degraded many plant communities and habitats. Since 1990 people began to redevelop their home gardens and only recently rediscovered public and private landscaping. Despite Lebanon's floristic richness, most taxa used in landscaping are non-native.

"Nursery" in Lebanon refers to any producer, retailer, landscape contractor, garden center or broker of ornamental plants including herbaceous, woody or cut flowers. Woody plant production is limited in Lebanon. Woody plants are imported from many countries (Italy, Spain, Syria, Egypt, United States, and others) but Italian imports dominate. The common practice for Lebanese nurseries is to re-pot imported stock, and after the root system is re-established (about four to six months), the stock is sold for landscaping projects in Lebanon and other Middle Eastern countries.

The government does not collect statistics for the landscape industry; thus, there is no statistical base for nursery production or sales. To generate baseline information, owners of major Lebanese nurseries, that sell ornamental woody plants, were interviewed in summer 2002.

2.3 Materials and Methods

The Ministry of Agriculture in Lebanon provided us with a list of nurseries: from that list, another list was developed with only those nurseries growing woody plants. Face to face interviews were carried out with seventeen nursery managers or owners in four nursery production areas across the country.

Most of the surveyed nurseries were located in the South (eight), two were in the Bekaa, five were in or near Beirut, and two were in the North. A detailed questionnaire was used (Appendix I); it contained questions about location and tenure status, production area, products handled, labor usage, production techniques, marketing systems, product handling and quality indices, problems of the industry based on nursery producers' perspectives, and their perspective on the potential for native Lebanese plant production for landscape use.

2.4 Results

Nursery location and status

Six of the surveyed nurseries are located in urban areas, eleven in rural areas. Under the Land status category, nine nurseries use leased land, five use private properties and three are on long-term church properties leases.

The nursery owners, who typically are also the nursery managers, are male except for one. Thirteen out of the seventeen nursery managers lacked a university degree; the others had degrees of Bachelor of Science (BS) in agriculture from Lebanese universities; one had a BS. Horticulture degree from Turkey. Salaried personnel are either owners or part of the owner's immediate family. Most employees are seasonal, drawn from either local or migrant (Syrian) labor pools.

Some have other occupations (3/17), such as honey production, stone production, and field cultivation of fruit trees. Greenhouses ranged in size between 750 and 63,000 m^2 (Table 2.1). Until a certain critical size is reached, nursery production is viewed as a supplement to family income. In the United States of America, the critical size for greenhouse production to become the prime income-generating activity is 90,000 m^2 of production area (Brumfield *et al*. 1993).

Production facility

All the interviewed nurseries had greenhouses. Although there is field production of perennial fruit crops, field production of landscape woody plants is not practiced in Lebanon. Production of woody plants from propagation to finished product does not occur in Lebanon, although herbaceous plant production from propagation to finished product does occur.

Owner/ manager responsibilities

Small nursery size prevents managers from specializing in a few aspects of nursery production and it inhibits professional development. Because of relative small size of Lebanese nurseries, managers must balance numerous simultaneous responsibilities, including seed collection and propagation, asexual propagation, nursery production, and retail and export sales, and importation (Fig. 2.1).

Importers refer to persons who import products as well as purchase local seeds and plants. Collectors refer to people who collect seeds of pine (*Pinus pinea*), cedar (*Cedrus libani*), Citrus (*Citrus lemon, Citrus reticulata*, *Citrus sinensis*) and olive tree (*Olea europea*). Nursery owners often have landscape contracting businesses and must negotiate with private and governmental clients. Nursery owners are also responsible for developing production protocols for many taxa, as no nursery is large enough to specialize in production of woody taxa. In addition to woody taxa, nurseries typically managers grow or trade in bulbous and herbaceous taxa. Some examples of non-woody taxa are *Begonia, Cuphea, Lantana, Salvia, Poinsettia, pansy, Petunia, Vinca, Wedelia*.

Some nursery managers (29%) are responsible for collecting seeds of native trees such as *Quercus, Laurus, Cercis, Ceratonia, Spartium, Inula, Crateagus*, and *Cedrus*. Scheduling seedling production varies among nurseries. Some do not have specific collection periods while others collect in late summer or winter. Only one nursery has consistent seed collection period from February until March, when they collect about 200 to 300 seeds of bay laurel, and 50 seeds of carob per year.

Products handled

Plant category.

All nurseries grow containerized stock of the following genera: *Magnolia, Cupressus, Cedrus, Lagerstroemia, Picea, Albizia, Dracaena, Laurus, Populus, Salix, Cotinus, Juniperus, Abies, Pinus, Prunus, Jacaranda, Acer, Eucalyptus, Thuja, Clematis, Citrus, Ceratonia, Quercus, Araucaria, Ficus, Liquidambar, Grevillea, Schinus*, and fruit trees. These plants are considered in high demand by 59% of the interviewed nursery managers. Some genera are container-produced, including *Eucalyptus, Populus, Salix, Albizia,* some fruit trees, *Magnolia, Jacaranda, Brachychiton, Cupressus, Ficus, Cedrus, Pinus, Thuja, Hibiscus,* and *Carissa.*

Only two out of the seventeen surveyed nurseries use field production, and even when used, field production represents a small portion of their total production. Field production is practiced for the following genera: *Thuja, Populus, Salix.* Fruit trees are propagated by field budding (*Malus, Pyrus, Ceratonia)* on to direct sown seedlings. Fruit trees are considered to grow more rapidly in field than in container production. Grafting as a propagation method, is used for a few species (*Persea*, *Mangifera* and *Annona*).

Size of containers

Initial container sizes range from 7.5 cm to 16 cm diameter. Final container sizes are larger than 60 cm. Imported trees are kept in containers ranging from 25 cm to 60 cm in diameter.

Size of trees

Trees are sold by height and caliper. Size of trees when sold varies with species. Tree genera sold at the 1-2 m height are: *Eucalyptus, Malus, Pinus, Abies, Cupressocyparis, Pinus, Thuja,* and fruit trees. *Salix, Populus, Magnolia, Cedrus* and *Jacaranda* are sold at 2-3 m height. *Albizia* and *Araucaria* are sold when their height exceeds 3 m. In the United States, once trees are more than 10 feet tall (3.4m), they are sold by trunk caliper. A recommendation would be for Lebanese nurseries to develop nursery stock standards similar to those for European and American nurseries (Anno., 1996).

Application of pesticides

The most common pesticides applied are the *fungicides* Benlate® and Thiram®, and *insecticides* for aphid control. Only five of the surveyed nurseries (29%) apply *herbicides* for weed control. Among these nurseries, there is a great variation in the frequency of herbicide application; from once every 10 days, to irregular applications with months between applications (Fig. 2.2). No nursery surveyed used integrated pest management (IPM). Research-based pest control methods and products are available but effective delivery methods have not been developed. There is a perceived lack of coordination between the extension sector at the Ministry of Agriculture, the Lebanese research institutions, and the industry.

Use of fertilizers

Fertilizers are applied regularly. The types of fertilizers vary from slow release (53%), to granular (65%) to foliar (35%). Some nurseries use only organic animal manure (goat manure, 18%). Others mix goat manure with horse and cow manures and add carob pods. Slow release fertilizers are commonly applied every 2 months. Application of soluble fertilizers varied from weekly to monthly.

Import and Export Seasons

Half of the nurseries import plants once per year, half twice per year. Palm trees are brought to Lebanon in summer, whereas the deciduous stock is imported between December and February. Most landscape trees are imported in the spring, between March and June (between 20,000 and 30,000 trees total).

Imports are least in August to October. Only one nursery answered that they do export all year around. However, most nurseries export by demand, which is highest between November and April. Plants are exported to Kuwait, Gulf countries and United Arab Emirates. Some of the exported tree species are *Olea sp.*, *Citrus sp.*, all kinds of fruit trees, *Jacaranda sp.*, *Brachychiton sp.*, *Schinus sp.* .

Sources, Clients and Markets

Nurseries do not keep public records about the number of trees they market annually, nor was the ratio of retail to wholesale sales disclosed. However, estimates ranged from 10 % and 80%. The majority of total sales are to local markets (77%), while 23% are sold as exports.

Most of the nurseries do not divide nursery production space between tree and non-tree products. This makes inventory maintenance difficult because trees do not occur in production blocks and they are not separated and categorized by container size, or by species. All the containerized landscape plants of different species are placed one next to the other until sold. Improvement should be made in scheduling production space.

When setting the price per unit tree, nursery managers take into account many factors; the most important are the market demand and labor cost (65%, Fig. 2.3). The cost of water and, by implication, water quantity and quality is not an important consideration, as each nursery has artesian wells to satisfy their nursery water needs.

Lebanese nurseries have long standing relationships with foreign producers. Most nurseries have reestablished pre-civil war relationships. One aspect of these relationships is that the exporting nurseries provide an educational service about the woody taxa they are exporting to Lebanon. Lebanese nursery managers also get information from *catalogs* of European nurseries, from attending *trade shows* and/or by *traveling to* and studying practices at the exporting nurseries.

Woody taxa are imported most frequently from Italian and Spanish nurseries (Fig.4). Sixty-five percent of the nursery managers think that the profit margin has been decreasing through the last 15 years. The major perceived challenge faced by most nursery producers is the lack of demand (77%, Fig. 2.5). This is not considered a major challenge for the big nurseries since they sell their landscape products to affluent clientele who are concerned more with product quality than product cost. Also, landscape designers associated with nurseries design according to their available inventories. Plant materials are transported to the job site by private trucks owned and operated by the nursery; the consumer absorbs transport costs.

According to the survey results, few nursery managers are aware of marketing methods for their products. However, all nursery managers feel that high quality plants are easier to market than low quality plants. All nursery managers surveyed are satisfied with their product quality for the domestic market. However, 47 % feel that higher quality is necessary for export markets, but they are not aware of product quality standards. Another marketing technique identified by the nursery producers is product labeling. Most nurseries do not label their plant material. Television, magazines, and newspaper are used to market nursery stock by only one of the surveyed nursery managers; however, all retailers market by word-of-mouth.

Production protocols

Seed handling and germination practices are not matched with the seed storage and germination requirements. For instance, 46 % of the nursery managers sow seeds immediately upon receipt. Others store them either under refrigeration (temperature 3-5°C) (38%) while others keep them at room temperature in the dark at low relative humidity (15%) for few weeks or months until sowing. For many of the taxa grown, the proper seed storage and handling protocols are not known. Collection of plant materials from the wild is not commonly practiced; a few nurseries do collect seeds from the wild (Fig.1).

Plant substrate

The different types of media used by the nursery managers are listed below. These media are used for propagation and production and for herbaceous and woody taxa. All ratios are on a volume basis:

- 100 % Peatmoss

- 1:1 peatmoss : sand
- 1:2 peatmoss : soil
- 1:1:1 peatmoss : soil: compost
- 1:1 peatmoss : soil
- 1:1:1 peatmoss : sand : soil
- 1:1:1 soil: sand: animal manure (not specified)
- 3:1 soil: animal manure
- 1:1 soil: goat or horse manure
- 100 % Soil
- 100 % Plant compost

During the survey, it was noticed that nursery managers do not know the difference between the effects of using animal manure and other composts. Therefore, an explanation of the advantages and disadvantages of both products seems appropriate. Animal manures are considered less expensive than compost and they typically have higher nitrogen and moisture content. The benefits of organic matter are: increased soil water holding capacity, less erosion, improved soil aeration and beneficial effect on soil microorganisms and plants. On the other hand, animal manures can be problematic because they are less stable, and have high electrical conductivity (EC). They are low on humus, high on microbial activity, and if not composted properly may contain some pathogens and weed seeds. In addition, they cause alkaline pH (> pH 8). Few nursery managers test their compost before use and are unaware of the potential variability between lots or sources of compost. Some managers (12%) perform physical and chemical tests, EC and pH, on their container substrate. Few nursery managers (18 %) sterilize their container substrates before use, and 70 % perform no testing prior to using.

Water source

The majority of Lebanese nurseries have their own artesian wells for irrigation (82%). Few use municipal water (12%), or rely on surface water streams (6%). Water quantity and quality are not limiting factors for nursery production. Water testing is performed by half the nurseries (53%). Water is tested for the EC and pH after the beginning of the growing season. This is a low percentage when we consider the fact that 82% said they are aware of the problems caused by poor water quality. According to the nursery managers, some of these problems are: fungi, high pH induced chlorosis, high EC induced stunting and marginal chlorosis. Concerns about mold suggests that nursery managers are not familiar with the consequences from irrigating with poor water quality. Because water quality significantly affects plant growth, a water quality educational program would be beneficial. Container plants are commonly watered by hand. Many types of containers are used: polyethylene bags, ridged plastic containers and tins.

Nursery managers' opinions on the potential for native plant production

All of the interviewed nurseries answered that they are able to distinguish a native from an exotic tree species. However, consumers cannot distinguish between native and exotic species. Most of these nurseries (14 out of 17) are willing to grow native plants if a market exists. They believe they have production facilities appropriate for native plant production because native plants do not require unique production methods. However, a barrier to native plant production is the lack of propagation protocols and expertise because few Lebanese nurseries do their own propagation. Lebanese nurseries currently rely on foreign propagators. However, the challenge to developing a native plant market is that no one produces native taxa because no one purchases them and no one purchases them because no one grows them.

Most nursery managers (14 out of 17) identified potential native woody taxa that could be grown locally: *Quercus, Laurus, Cedrus, Pinus, Olea, Abies, Pistacia, Juniperus, Spartium, Eucalyptus, Populus, Melia and Cercis*.

2.5 Perceived challenges to nursery managers are:

1. Propagation and production management practices for collected and imported tree taxa have not been developed for Lebanese conditions.
2. Protocols for control of plant diseases and pests need to be developed.
3. Quality standards need to be established for growing substrates, compost and irrigation H_2O quality and amounts.
4. Improved methods for efficient transfer of technical and scientific advice are needed.
5. Nursery managers face Financial/Accounting obstacles. The following things are needed:

- Timely payment systems and billing procedures. Municipalities pay their bills more promptly than do individuals, and municipalities are more credit worthy.
- Check verification systems and return check/insufficient funds policies.
- Credit card (MasterCard and Visa) capability.

6. Increasing competition, weaker demand, and higher production costs are lowering profit margins.

7. Small-scale production, ignorance of domestic and foreign export/import regulations, and the lack of uniform nursery stock standards inhibit export opportunities.
8. Lack of nursery trade organizations.

2.6 Conclusions and Recommendations

1. There is high potential for developing a native plant market in Lebanon although the market does not currently exist.
2. The typical Lebanese nursery import plants both container-grown and bare root field-grown stock, transplant them to containers and maintain them until sold; a maximum period of a year. Few Lebanese nurseries propagate woody plant liners.
3. Nursery managers are not aware of export regulations for nursery stock.
4. Nursery managers are satisfied with their current product quality.
5. Production and marketing systems are not as sophisticated as in those countries from whom they import plants.
6. The government does not currently, but should, collect economic data on Lebanese nurseries production and sales.
7. Additional methods of technology transfer need to be developed to supplement current government programs. Subject areas include: technical advice on fertilization and pest control, propagation techniques, compost and substrate, water quality and irrigation techniques.

8. Because of small size, nursery managers are responsible for all aspects of the nursery business. This does not allow them to focus their efforts in developing domestic and foreign markets or increasing the sophistication of their production techniques.
9. Nursery managers feel the major barriers to expansion are business related, not related to plant biology.
10. Best management practices should be developed for the Lebanese nursery industry.

Nursery number	Greenhouse area (m^2)	Status of land	Number of employees	Number of payable labor
1	44000	Private	Seasonal 16-24	All
2	8900	Rent	Based on demand	All
3	4040	Private	2	All
4	14500	Rent	6	All
5	63000	Private	20	All
6	4650	Church property	2	All
7	22000	Church property	2	All
8	3216	Rent	2	All
9	12000	Rent	3	Two
10	9000	Rent	5-6	All
11	25000	Private	7-10	All
12	6000	Rent	4	All
13	1000	Rent	1	All
14	10960	Rent	3	All
15	750	Rent	3	1
16	10400	Private	5	All
17	10600	Church property	2	All

Table 2.1. Characteristics of Lebanese Nurseries.

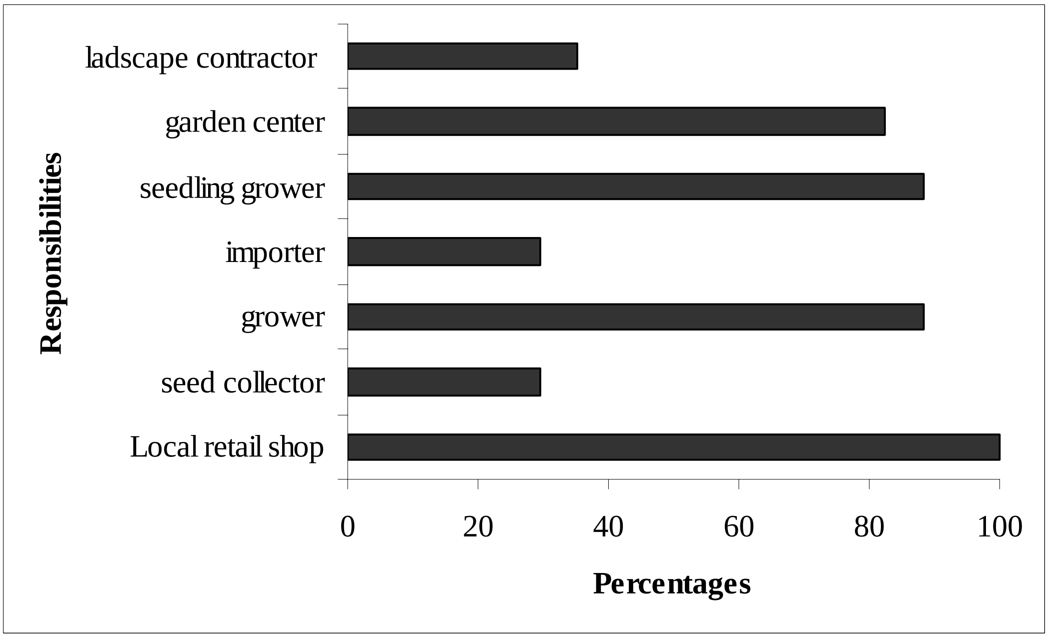

Fig. 2.1. Responsibilities of nursery managers in Lebanon

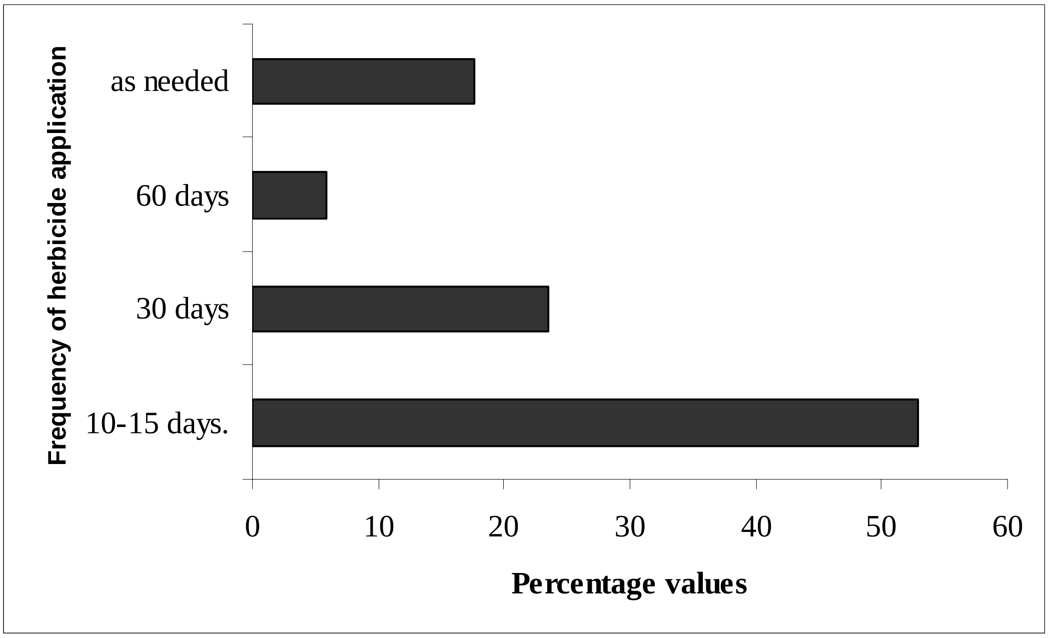

Fig. 2.2. Frequency of herbicide application in some Lebanese nurseries

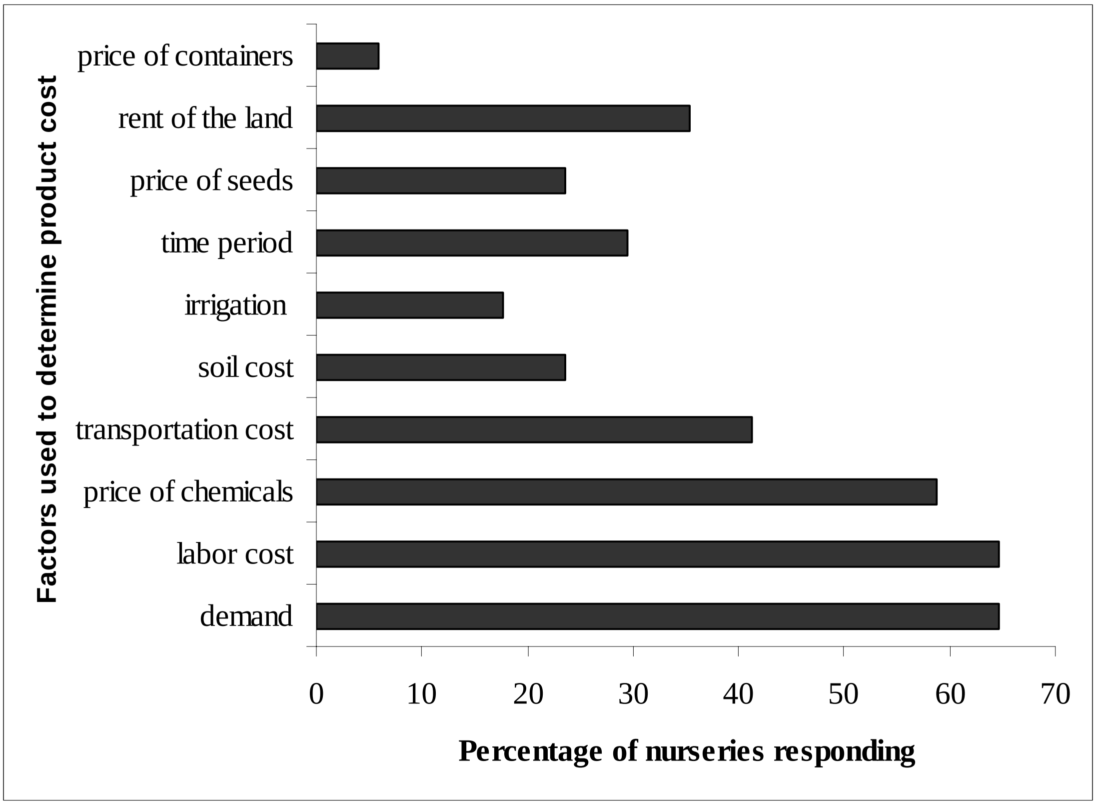

Fig. 2.3. Considerations of Lebanese nursery managers used to establish the price of nursery stock

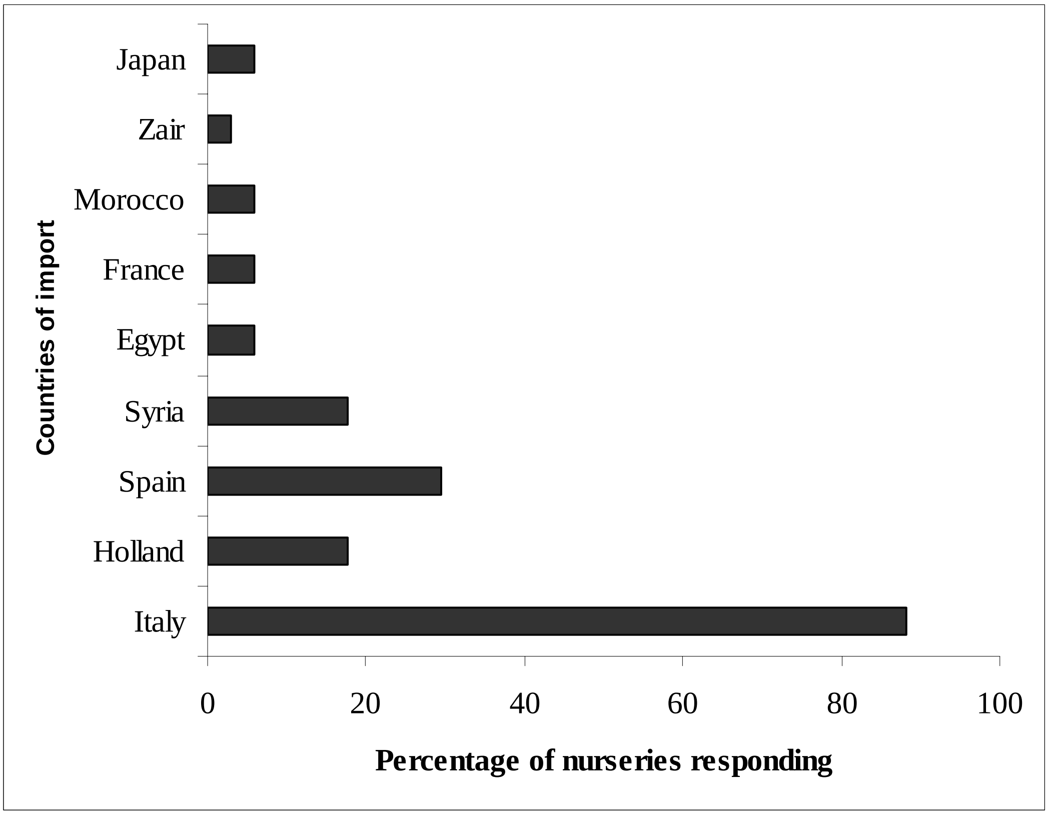

Fig. 2.4. Percent of Lebanese nurseries importing products

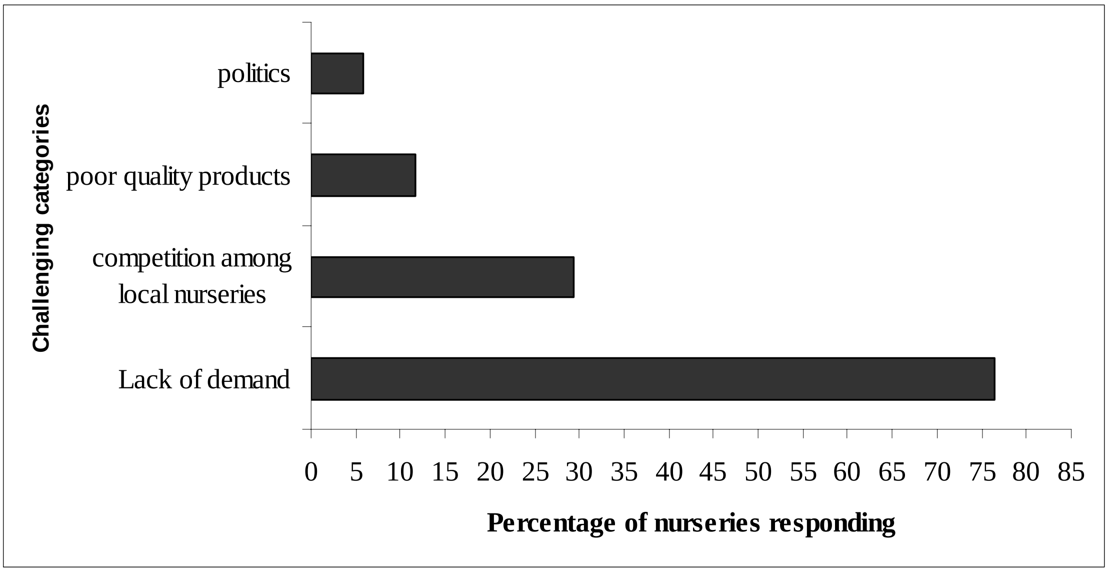

Fig. 2.5. Marketing challenges faced by Lebanese nursery managers

CHAPTER 3

Cercis siliquastrum growth, N, P, K content, concentration, distribution and efficiency as affected by two fertilizer rates[1]

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3.1 Abstract

Native flora in Lebanon is threatened by tourist and urban development, political instability, overcollection of medicinal and aromatic plants, lack of legislation prohibiting overcollection from the wild, overgrazing and forest fires. After the end of the civil war, people started to redevelop their home gardens and the demand for landscape plants has been increasing to meet the extensive reconstruction projects. Despite Lebanon's floristic richness, most taxa used are non-native. This study was done to determine the commercial potential of *Cercis siliquastrum*,a tree native to Lebanon with ornamental attributes, by exploring growth, N, P, K uptake efficiency and partitioning under two fertilizer rates. Seedlings were obtained from six seed sources in Lebanon. Two-year old seedlings were planted in 11 liters containers in a 3:1 pine bark: compost substrate, and half the seedlings within each source were assigned to either 25 or 100 mg N per L from 21-3.1 P- 5.9 K (21-7-7) Peters Water Soluble Fertilizer. Seedlings of all sources grown under 25 had greater dry weight than those grown at 100 mg N per L. Nutrient loading occurred in plants under the high fertilizer rate, although total plant N, P, and K content was not affected by fertilizer rate. There were also significant differences in mineral nutrient uptake and nutrient use efficiencies among the seed sources. Therefore, *Cercis siliquastrum* can be grown commercially and the tree-to-tree variation, (even with the limited genetic variation sampled in this study) suggest that significant gains can be made through mother tree selection.

Index words: Judas tree, Lebanese flora, container production, relative growth rate, Comtil, N-P-K ratios, mineral nutrition, woody ornamentals, nutrient loading.

3.2 Introduction

The Mediterranean region is recognized as a global center of plant diversity (Davis *et al.*, 1995). The Mediterranean climate has favored the evolution of a corresponding unique and extremely variable flora, estimated at 25,000 species (Heywood, 1990). Lebanon falls within the identified center of plant diversity, the Levantine uplands (Davis *et al.*, 1995). Lebanon has an estimated 3,761 vascular plant species (UNEP, 1996). This unique flora is threatened by tourist, urban expansion and proliferation of summer resorts in the mountains, political instability, overcollection of the aromatic and medicinal herbs, illegal woodcutting, overgrazing, and forest fires (UNEP, 1996). Additionally, native flora is endangered by absence of regulations or non-compliance with existing preservation regulations.

The country is taking in-situ measures such as establishment of natural reserves and protected areas, and on-farm conservation of wild varieties (UNEP, 1996). Until now, there were no ex-situ conservation measures taken for biodiversity in Lebanon.

Beginning in 1990, people began to redevelop their home gardens and only recently have rediscovered public and private landscaping. Despite Lebanon's floristic richness, most taxa used in landscaping are non-native. Landscape woody plants are imported from many countries (Italy, Spain, Syria, Egypt, United States) but, Italian imports dominate. The common practice for Lebanese nurseries is to re-pot imported stock, and after the root system is re-established (about four to six months), the stock is sold for landscaping projects in Lebanon and other Middle Eastern countries. A large number of plant species in Lebanon have potential economic value whether for ornamental or medicinal use. The concept of using wild (native) plants for ornamental purposes is not well recognized in Lebanon. In contrast, in neighboring Turkey, studies are being conducted to optimize the domestication of wild plants with ornamental value (Ertug Firat and Tan, 1997). Although there is a great potential for developing native plant production nurseries in Lebanon, few nursery managers collect, propagate and produce native wild material.

Cercis siliquastrum L., "Judas tree", is a tree native to Lebanon with ornamental attributes. It belongs to the family Cesalpinaceae. It is described as a medium height tree with mature height of 5-10 m. At young stages its trunk is purple then becomes gray-pink with age (Anonymous, 1999). The leaves are bluish green with rounded tips. It flowers from March to April and flowers precede leafing. The flowers are pink, usually borne in clusters of three to six on previous years' growth. It is widely distributed in the Thermomediterranean zone (0-500 m altitude) and can be found up to 800 m altitude where it is associated with pine and oak forests. It is indifferent to soil types. In its native range, most (80-90 %) of the annual rainfall (700-1000 mm) occurs between November and March and less than 5 % between May and September. Its wide distribution range over a range of habitats suggests that *Cercis siliquastrum* provenances may exist. *Cercis siliquastrum,* like other redbud species, is reported to grow well in a variety of soil textures but best in soils where the pH is above 7.5 (USDA, 1990). Redbud species tend to be tolerant to nutrient deficient sites (USDA, 1990). They grow best in sunny sites, and withstand hot dry summer as long as the soil moisture is adequate in winter and spring.

The aim of the study was to determine the potential for commercial production of six Lebanese native *Cercis siliquastrum* sources, by exploring the growth, dry weight and N, P, and K nutrient uptake efficiency, and mineral nutrient partitioning during one growing season under two fertilizer rates.

3.3 Materials and Methods

A description of plant material and the numbers of plants per source used in the study are given in Table 3.1. *Cercis siliquastrum* seed pods were picked by hand in mid-August 2001, spread to dry in full sun for a few days before they were manually opened and the seeds extracted.

The seedlings used in this study were raised from seeds germinated in germination studies (data not presented). Germinated seeds were immediately transplanted into 250-XL plastic containers (Nursery Supplies, Fairless Hills, PA) using MetroMix® 360 (Scotts Company, Marysville, OH) substrate and placed in a greenhouse under natural photoperiods. The greenhouse temperatures were set at 22/ 21C (71.5/ 70.6 F D/N). The relative humidity averaged 46.6 ± 2 %. Plants were watered as needed to avoid water stress. When seedlings developed two true leaves, they were fertilized once per week with 100 mg N per L of 20N- 8.3P- 4.6K (20-10-10, Peters water-soluble fertilizer (Scotts Company, Marysville, OH). Plants were overwintered (from November to May) in a minimum heat (> 2 C / 35.6 F) polyhouse.

Twenty-four months after germination, (May, 2004), the plants were removed from the containers, root pruned, transplanted into #3- Spin-Out ®treated containers (1200 Classic, Nursery Supplies, Fairless Hills, PA) and moved to an outdoor gravel pad. The most vigorous shoot was trained into a central leader by tying it to a 2 m bamboo stake. The plants were placed on 45.7 cm (18 inches) within row spacing and 2 m (6 ft) between row spacing. A 3 pine bark:1 Comtil (composted municipal sewage sludge, City of Columbus, by volume) substrate was used.

Half of the plants from each source were randomly assigned to one of two N fertility programs: 25 or 100 mg N per L fertigation from 21 N- 3.1 P - 5.9 K (21-7-7, Peters Water Soluble Fertilizer, Scotts Company, Marysville, OH) applied at 0.5 L volume in each of two daily irrigation cycles (1 L total per day). The fertility treatments were initiated on 1 June and terminated on 20 September. Plants from the mother trees within a fertility treatment were arranged in a randomized complete block design; there were eight replications.

An initial harvest was done on 12 May 2004 and a second harvest on 24 September 2004. At each harvest, height and caliper were measured on all trees, while leaf area was measured on ten randomly selected trees per source and fertilizer treatment with a LI- 3100 Area meter (LI- COR, Inc. Lincoln, Nebraska, USA). Plants were pruned at the root collar, substrate washed from the root systems, plant parts (roots, shoots, and leaves) oven dried at 82C (180F) for 96 hours and dry weights recorded. From the ten plant subsample, three randomly selected individuals from each source and fertilizer rate were selected for nutrient analysis. Leaves, shoots and roots from these plants were ground to pass through a 20 mesh screen and 2 g subsamples from each tissue type were sent to the Service Testing And Research Laboratory (STAR laboratory, OARDC, Wooster, Ohio) for N, P, and K nutrient analysis. Total nutrient content of each tissue type was calculated by multiplying their respective dry weights by their tissue nutrient concentrations. Total plant dry weight or nutrient content was calculated by summing the dry weights or nutrient contents of an individual's stem, roots and leaves.

Leaf, stem and root dry weights, as a percentage of total plant dry weight, were calculated. Relative nutrient contents of leaves, stems and roots were determined similar to the relative dry weights of leaves, stems and roots.

Nitrogen use efficiency (NUE) was calculated by the following equation: NUE = [(TNC $_2$) – (TNC $_1$) / TNA] * 100% where TNC $_2$ and TNC $_1$, are total plant N contents in September and May, respectively, and TNA is the total N applied between May and September. Similarly, K and P use efficiencies were calculated.

From the dry weights and leaf area data, net assimilation rate (NAR), leaf area ratio (LAR) and relative growth rate (RGR) were calculated according to Evans (1972). To calculate NAR, LAR and RGR, plants within the initial and final harvests were sorted by total dry weight and paired by ascending order of total plant dry weight. Total plant assimilation rates (g cm^{-2} day^{-1}) were calculated as: NAR= $(TW_2 - TW_1)$ x (Ln A_2 – Ln A_1) / (($T_2 - T_1$) x ($A_2 - A_1$)); Leaf area ratio (g cm^{-2}) as LAR= ($A_2 - A_1$) / (TW_2 - TW_1); Relative growth rate (g g^{-1} day^{-1}) as RGR= (Ln TW_2 – Ln TW_1)/ ($T_2 - T_1$); where T_1= initial time (12 May), T_2= Final time (24 September), TW_1 and TW_2= total plant dry weight at time 1 and 2 respectively, A_1 and A_2 = leaf area at time 1 and 2 respectively.

For dry weight analyses, ten single plant replications were used; while mineral nutrient analyses used three single plant replications. Data was analyzed using One-way ANOVA and GLM within SPSS (SPSS Institute, Chicago, IL, version 12.0). Equations describing plant height during the season were developed using linear regression within SPSS.

3.4 Results

Growth and Dry weight

The equations describing height of plants within each source during the growing season were significant ($P < 0.05$) for all sources except CS5 and CS6 at the high fertilizer rate (Figs.3.1 A and B).

In September, there were no significant source by nitrogen interactions for any of the parameters measured (Table 3.2) nor did fertilizer rate affect height, caliper, shoot and leaf dry weights, or leaf area (Table 3.2). However, root dry weight was greater at the lower fertilizer rate (98.1 vs 63.9 g) as was total plant dry weight (268.8 g vs 193.8 g) but shoot to root ratio (0.94 vs 1.39) was lower at 25 than at 100 mg N per L, respectively, Table 3.2).

There were no significant differences in height among seed sources (Table 3.2). There were significant differences among seed sources for caliper, root ($P = 0.01$), shoot ($P = 0.02$), and total plant dry weights ($P = 0.02$) and shoot to root ratio ($P = 0.017$, Table 3.2). Source CS2 had the largest root, shoot, and total plant dry weights; CS5 had the smallest (Table 3.2). Source CS5 had the highest and CS6 had the lowest shoot - root ratio (Table 3.2). There were no differences in leaf area among the sources.

For all sources, plants under the low fertilizer rate always had a higher percentage of total plant dry weight in the root systems than those grown under the high fertilizer rate, but the percentage of root dry weight varied among sources, from 35.9 %

to 50.3 % (CS5 vs CS2, respectively, Table 3). There was no significant source by fertilizer rate interaction for percent of total plant dry weight in shoots or leaves (Table 3). Fertilizer rate did affect the percentage of total plant dry weight in roots, shoots and leaves (Table 3). At the higher fertilizer rate, the relative percentage of whole plant dry weight in stem and leaf tissue increased (from 40.0 % to 44.2 %, and from 17.9 % to 22.3 %, respectively) while the percentage of root dry weight decreased (from 42.0 % to 33.5 %, Table 3). The percent leaf dry weight varied significantly among sources; it was highest for CS4 and lowest for sources CS1 and CS2 (Table 3).

There was a significant source by fertilizer interaction for relative growth rate but not for LAR or NAR ($P < 0.01$, Table 3.4). Relative growth rate for all sources was higher under 25 mg N per L than under 100 mg N per L except for CS2, which was higher at 100 mg N per L (Table 3.4). Plants grown at 100 mg N per L had a significantly higher LAR ($P = 0.012$) and lower NAR ($P < 0.001$) than plants grown at 25 mg N per L (21.2 and 25.1 g cm^{-2}, and 0.0011 and 0.0008 g cm^{2} day^{-1}, respectively, Table 3.4). There were significant differences among seed sources for LAR ($P < 0.05$); CS3, CS4, and CS5 had higher LAR than CS1, CS2 and CS6 (Table 3.4).

Tissue N concentration, N content and relative N distribution

There were no significant source by nitrogen interactions for N concentration, or content in leaves, shoots, roots and total plant tissues nor for relative percent N in leaves, shoots or roots (Table 3.5). When averaged over sources, nitrogen concentration regardless of the tissue type, was always higher under 100 mg N per L than under 25 mg N per L (1.68, 1.03, 1.45, and 1.33 vs 2.30, 1.27, 1.91, and 1.73 for leaf, shoot, root and total plant percent N, respectively, Table 3.5). Regardless of fertilizer rate, leaf N concentration was higher than that of stem and root tissue at both fertilizer rates. Leaf tissue N content was significantly higher for those plants at the higher fertilizer rate than at the lower fertilizer rate (0.97 vs 0.68 g, respectively). Relative % N in leaf, shoot and roots was not affected by seed source or fertilizer rate (Table 3.5). Tissue N concentrations and contents were higher in plants grown under both fertilizer levels than in plants harvested at the beginning of the study (Appendix A).

Tissue P concentration, P content and relative P distribution

There was one significant source by fertilizer rate interaction for P nutrient concentration (Table 3.6); it was higher at the higher than at the lower fertilizer rate for all sources except CS2 (Table 3.6). Fertilizer rate affected shoot and total plant P concentrations (Table 3.6). Plants grown at the higher fertilizer rate had higher P concentration in shoot tissue (2562 µg/g) than at the lower fertilizer rate (1951µg/g). There was a significant difference among seed sources in leaf and total plant P concentrations (Table 3.6). CS5 had the lowest CS1 the highest P concentration (3286 vs 6415 µg/g, and 3121 vs 3682.5 µg/g, respectively). In most cases, leaf P concentration was higher than that of stem and root tissue at both fertilizer rates (Table 3.6). Fertilizer rate affected shoot P content, it was higher at 100 than at 25 mg N per L (0.22 g vs 0.17 g, respectively, Table 3.6). There were no significant effects due to source or fertilizer rate for P distribution in leaf, shoot and root tissue except that at the high fertilizer rate, where root tissue contained relatively more P under low than under the high rate (50 vs 40 %, respectively, Table 3.6). The relative % of total plant

P contained in the root tissue was higher than that in leaf and shoot tissues at both fertilizer rates (Table 3.6). Tissue P concentrations and contents were higher in plants grown under both fertilizer levels than in plants harvested at the beginning of the study (Appendix B).

Tissue K concentration, K content and relative K distribution

There were no significant source by fertilizer rate interactions for K concentration, or content in leaf, shoot, root and total plant tissues nor for relative percent K in leaves, shoots, roots or total plant (Table 3.7). Fertilizer rate affected root K content; it was lower at the higher than the lower fertilizer rate (0.97 g vs 1.19 g, respectively, Table 3.7). There was a significant difference among seed sources for leaf K concentration (Table 3.7). It was highest in CS1 (2273 µg/g), lowest in CS5 (15064 µg/g, Table 3.7). Leaf K concentration was higher than that of stem and root tissue at both fertilizer rates (Table 3.7). Fertilizer rate and source did not affect relative distribution of K (Table 3.7). Root tissue contained the greatest percentage of whole plant K, it averaged 43 % (Table 3.7). Tissue K concentrations and contents were higher in plants grown under both fertilizer levels than in plants harvested at the beginning of the study (Appendix C).

Nutrient uptake and nutrient use efficiencies

Comtil supplied more N, P, and K than either rate of water soluble fertilizer (Table 3.8). It supplied between 85 and 58 % of the N, 99 and 95 % of the P and 92 to 75 % of the total K.

There were no significant source or fertilizer rate effects for N, P, and K uptake or mineral use efficiency between May and September 2004 (Table 3.9).

Nitrogen and K use efficiencies were affected by fertilizer rate, it was higher at the low than higher fertilizer rate (13 vs 10 %, and 40 vs 28 %, for N and K respectively, Table 3.9).

N-P-K ratios

Plant tissue contained more N than K and more K than P for all sources and fertilizer rates (Table 3.10). The N content relative to P, ranged from 3.7 (CS1) to 4.2 (CS3) at the low fertilizer rate and from 4.6 (CS6) to 5.7 (CS4) at the high fertilizer rate (Table 3.10). The K content ranged from 3.3 (CS1 and CS3) to 4.1 (CS4) and from 3.2 (CS3) to 4.3 (CS4) at the low and high fertilizer rates, respectively (Table 3.10).

3.5 Discussion

There were few fertilizer rate by source interactions; only RGR, percent of total plant dry weight in the root system, and total plant P nutrient concentration were affected. The interactions were attributed to the seedlings of CS2. In CS2, the high fertilizer rate resulted in higher RGR, total plant dry weight in root system, and higher total plant P concentration.

The first hypothesis, that higher fertilizer rate results in better growth was false. Plants grown at the low fertilizer rate had greater root and total plant dry weight than those grown at the high fertilizer rate. Also, height and caliper were not increased by the higher fertilizer rate. In addition, at the low fertilizer rate, plants of all sources but CS2 grew faster (RGR was of 0.0016 g g^{-1} day^{-1} greater at the lower fertilizer rate). Net assimilation rate, was significantly lower at the high fertilizer than the low fertilizer rate by a difference of 0.0003 g cm^{-2} day^{-1}.

Cercis siliquastrum growth was vigorous at a lower rate than that reported by others (Table 3.11). For example, red maple growth was greatest at 200-400 mg N per L (Gilliam *et al.* 1980; Larimer and Struve, 2002). However, 20 mg N per L was optimal for *Cupressus arizonica* var. glabra "Carolina sapphire" where higher rates did not affect height and stem diameter although N concentration in shoots and leaves increased with increased N rate (Stubbs *et al.* 1997).

Since better growth was obtained with plants grown at the lower fertilizer rate, it is recommended that daily applications of 25 mg N per L be applied from the fertilizer 21 N- 3.1 P - 5.9 K (21-7-7) on *Cercis siliquastrum.* A fertilizer savings of 75

% can be realized without reduced plant growth. Additional testing is needed to determine the optimum fertilizer rate for this species in this production system.

An additional benefit of the 25 mg N per L rate was that a higher percentage of total plant dry weight was in the root system resulting in lower shoot to root ratio. High N production systems increase shoot growth relative to root growth, increasing shoot to root ratio (Harris, 1992). Higher shoot - root ratio lowers plant quality and decreases the mechanical stability of a tree once out planted (Harris, 1992) . *Cercis* sources responded to increased fertilizer rates similarly to red maple (Larimer and Struve, 2002). Growth of red maple was altered in response to differences in nutrient availability (Larimer and Struve, 2002). As fertilizer rate increased, relative dry weight distribution in red maple; *Cercis siliquastrum* was affected similarly. However, in the case of *Cercis* plants, although dry weight distribution was altered, nutrient distribution in the root system remained higher than that of stem or leaf tissues at both fertilizer rates.

A possible benefit of growing plants under high fertilizer rates is nutrient loading. Nutrient loading is defined as an increase in plant tissue nutrient concentration without a significant increase in plant dry weight (Malik and Timmer, 1995). Nutrient loading was observed in the *Cercis* sources grown at the high fertilizer rate (Tables 6, 7, 8). The benefits of nutrient loaded trees are many: nutrient loaded conifer seedlings performed better when out planted in nutrient poor sites than those not nutrient loaded (Xu and Timmer, 1999; Malik and Timmer, 1995). Moreover, for conservation purposes (reforestation or reintroduction of species to their native habitats), nutrient loading increases the competitive ability for resources of species in weed-prone or heavily vegetated sites (Malik and Timmer, 1995). Nutrient loading seedlings in the nursery is more effective than fertilizing trees after out planting. If plants perform better after transplanting, this would allow nursery managers to offer higher quality plants, assuming the benefits of nutrient loading are not offset by decreased plant quality (i.e. smaller caliper, smaller total plant dry weight and higher shoot to root ratio). The possible benefits of nutrient loading to *Cercis siliquastrum* need to be confirmed with transplanting studies.

Mineral nutrient uptake (total plant nutrient content) between May and September was not affected by fertilizer rates (Table 3.9). It may be that nutrients added by Comtil overwhelmed that added by the water soluble fertilizer. Comtil is a composted municipal sewage sludge product where the ammonium-N form predominates (Struve, 2002). In this study, the grams of N, P, and K applied via Comtil were 135, 2031 and 308 % more than that added at the high fertilizer rate from the water soluble fertilizer (Table 3.8). Higher concentrations of P and K than those recommended by Wright and Niemiera (1987), 10 and 25-50 mg per L respectively, were applied through the liquid fertilizer and Comtil (Table 3.8).

Root tissue contained most of the plants' N, P and K indicating that the root system is an important mineral nutrient storage organ in *Cercis siliquastrum*. It is likely that roots can serve a nutrient reserve when outplanted in poor nutrient sites. Transplanting studies are needed to confirm the benefits of high nutrient content of *Cercis siliquastrum* roots.

Nitrogen use efficiency was lower at the higher fertilizer rate among all but one source (Table 3.9). No measurements of the root surface or the volume of substrate leachate were taken in order to find out why NUE was lower as the higher fertilizer rate. Nitrogen use efficiency of a related species, *Cercis canadensis* fertilized at 100 mg N per L from 21-7-7 was 42 % in a study by Stoven (2004).

Phosphorus use efficiency in this study, was low but similar, when averaged over all seed sources at both fertilizer rates (between 2 and 4 %, Table 3.9). Potassium use efficiency was higher than either nitrogen or phosphorus. An explanation for the high K efficiency could be genetic ability of *Cercis siliquastrum* to store K for use as an osmoticum in drought. Deficiency in K has been associated with reduced ability to withstand stress and maintain high transpiration rates (Tisdale *et al.* 1998). Another possible explanation for why K use efficiency was higher than N and P use efficiencies is that K promotes the conversion of inorganic P to nucleic acids and phosphoproteins that would otherwise cause plant toxicity. Toxicity effects due to elevated inorganic phosphates has been reported in *Ilex crenata* when P was applied at higher concentration than 10 ppm (Wright and Niemiera, 1987). The toxicity was offset by a K concentration that was five times higher than P concentration (Wright and Niemiera, 1987).

The fertilizer used in this study had an N-P-K ratio of 6.8-1-1.6 when N and K were expressed relative to P. Comtil had an N-P-K ratio of 0.45-1-0.25. However, whole plant mineral nutrient ratios at the end of the growing season did not match the fertilizer or Comtil N-P-K ratios.

Wright (1987) recommended that the N-P-K ratios in container media should be 10-4-6 (2.5-1-1.5). Suggested N-P-K are 6-1-5 for *Betula*, *Acer*, *Cotoneaster* and *Berberis*; 5-1-3 for *Ilex* and a range of 5-1-3 to 8-1-4 for several other woody genera (Wright and Niemiera, 1987). The recommended N-P-K ratios for blackgum seedlings varied with the type of fertilizer used, from 11.7-1-4.6 in slow release fertilizer to 5.8-1-3.8 in water soluble fertilizer (Struve, 1995). The latter N-P-K ratio is close to the 5-1-4 N-P-K for *Cercis siliquastrum*.

There were differences in growth (root, shoot and total plant dry weights) and mineral nutrient uptake and efficiencies among the six seed sources of *Cercis siliquastrum.* Sources CS1 (Ehden), CS2 (Nahr Damour) and CS6 (Zekrit) had greater caliper and root dry weight, lower shoot - root ratio and greater leaf area compared to the other three sources. CS1 and CS6 grew the fastest among other sources. Plants from Zekrit (CS6) had the greatest leaf area and the lowest shoot to root ratio. Source CS2 (Nahr Damour) produced the tallest plants (Table 3.2). The same source had the largest root, shoot, and total plant dry weights averaged over both fertilizer rates. Although mother trees from Nahr Damour location (CS2, CS3, and CS4) produced taller seedlings than the other sources, plants raised from sources CS3 and CS4 were not as tall as those from CS2. Therefore, there is significant within a source (provenance) variation in height growth.

3.6 Conclusion

Seedlings of *Cercis siliquastrum* under 25 mg per N L from 21-7-7 resulted in taller seedling of similar caliper than those grown under 100 mg N per L. Results in Ohio need to be confirmed in the Mediterranean climate of Lebanon. Nutrient content was not affected by fertilizer rate but nutrient concentration was. Nutrient loading occurred in plants under the high fertilizer rate, but possible benefits need to be confirmed by field trials to determine whether the benefits of nutrient loading outweighs the decrease in plant quality (lower dry weight, higher shoot to root ratios) when plants are transplanted. Seed source affects growth and nutrient content; CS2 seedlings had the highest height, caliper and dry weight. Additional sources need to be tested. There was significant within source variation. Sources CS2, CS3 and CS4 came from the same geographical location, but seedlings of CS2 were significantly taller than those of CS3 and CS4.

Fig. 3.1. Height of container-grown *Cercis siliquastrum* under 25 (Fig. A) or 100 mg N per L (Fig. B) fertigation. Each value is the mean of forty plants per fertigation treatment. Plants were fertilized with 21 N- 3.1 P - 5.9 K (21-7-7, Peters Water Soluble Fertilizer, Scotts Company, Marysville, OH). Plant height of CS1 plants at 25 mg N per L is predicted by the equation: HT= 0.4540 X + 13.7519, R^2 = 0.97, P = 0.002; for CS2: HT= 0.3548 X + 25.2305, R^2 = 0.88, P = 0.041; for CS3 plants: HT= 0.3503 X + 34.9468, R^2 = 0.87, P = 0.043. For CS4 plants: HT =0.4121 X + 19.6183, R^2 = 0.92, P = 0.024; for CS5 plants: HT =0.4135 X + 8.4142, R^2 = 0.89, P = 0.038 for CS6 plants, HT = 0.4695 X - 1.5870, R^2 = 0.93, P = 0.022.

Plant height of CS1 plants at 100 mg N per L is predicted by the equation: HT = 0.3566 X + 28.0456, R^2 = 0.93, P = 0.024; for CS2: HT = 0.2625 X + 43.6709, R^2 = 0.92, P = 0.028; for CS3 plants: HT = 0.2019 X + 48.6320, R^2 = 0.94, P = 0.022. For CS4 plants: HT = 0.1887 X + 46.4554, R^2 = 0.88, P = 0.041; for CS5 plants: HT = 0.2224 X + 42.0756, R^2 = 0.76, P = 0.082; for CS6 plants, HT = 0.3545 X + 14.1113, R^2 = 0.85, P = 0.051; where in all the above equations, HT = Plant height (in cm) and X = time period (in calendar days; 174, 202, 230 and 260 for June, July, August and September, respectively).

Species	Source	Elevation (m)	Latitude (N)	Longitude (E)	Number of plants in study
Cercis siliquastrum	CS1: Ehden	1331	34˚18.974"	035˚58.956"	90
	CS2: Nahr Damour	64	33˚42.023"	035˚29.214"	90
	CS3: Nahr Damour	57	33˚41.922"	035˚28.661"	90
	CS4: Nahr Damour	166	33˚41.858"	035˚29.104"	80
	CS5: Ayn w Zein	1042	33˚40.633"	035˚36.678"	90
	CS6: Zekrit	191	33˚56.407"	035˚38.291"	82

Table 3.1. Description of the habitat source from where seeds of *.C siliquastrum* (CS) were collected in Lebanon and the number of individuals from each species included in the study.

Species	Fertilizer (mg per L)	Height (cm)	Caliper (mm)	Dry weights (g) root	shoot	leaf	total plant	Shoot/root ratio	Leaf area (cm^2)
CS1	25	114.7 [y]	15.5	115.1	118.9	42.2	276.2	1.03	4061
	100	110.0	13.3	68.7	85.8	35.4	189.9	1.25	3582
	Avg.	112.4	14.4	91.9	102.3	38.8	233.0	1.14	3821
CS2	25	108.6	13.7	123.3	95.9	33.4	252.6	0.78	3320
	100	123.5	14.8	76.8	128.6	53.9	259.3	1.67	4505
	Avg.	116.0	14.2	100.0	112.2	43.6	255.9	1.22	3912
CS3	25	115.1	12.5	85.3	82.4	37.0	204.7	0.97	3245
	100	113.2	12.9	66.3	83.4	44.7	194.4	1.26	3821
	Avg.	114.1	12.7	75.8	82.9	40.8	199.5	1.11	3533

Continued

Table 3.2. Height, caliper, root, shoot, leaf and total plant dry weights, shoot/root ratio and leaf area of *C. siliquastrum* sources under low or high (25 or 100 mg N per L) fertilizer treatments.

Table 3.2. continued

CS4	25	128.7	13.7	78.2	86.3	47.6	212.1	1.10	3317
	100	96.5	11.3	45.1	66.5	42.4	154.0	1.47	3713
	Avg.	112.6	12.5	61.6	76.4	45.0	183.0	1.28	3515
CS5	25	107.6	13.0	88.0	87.4	26.8	202.2	0.99	3084
	100	104.2	11.4	42.1	70.5	36.5	149.1	1.67	2742
	Avg.	105.9	12.2	65.0	78.9	31.6	175.6	1.33	2913
CS6	25	109.7	13.8	98.4	76.7	40.7	215.8	0.78	4475
	100	114.6	13.6	84.1	84.0	38.8	206.9	1.00	4107
	Avg.	112.1	13.7	91.2	80.3	39.7	211.3	0.89	4291
ANOVA					P > F - Value				
Source (S)		NS [z]	*	**	*	NS	*	*	NS

Continued

Table 3.2 continued

Fertilizer rate (FR)	NS	NS	**	NS	NS	*	**	NS
S * FR	NS	NS	NS	NS	NS	NS	NS	NS

[Y] Each value is the mean of 10 individual seedlings within each species and fertilizer.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Species	Fertilizer (mg per L)	Dry weight distribution (%) Root	Shoot	Leaf
CS1	25	42.0 [y]	42.0	15.4
	100	38.4	44.1	17.5
	Avg.	40.4	43.0	16.4
CS2	25	50.3	36.6	13.1
	100	29.8	49.9	20.3
	Avg.	40.0	43.2	16.7
CS3	25	41.6	40.7	17.7
	100	34.9	41.7	23.3
	Avg.	38.2	41.2	20.5
CS4	25	36.4	40.7	22.9
	100	29.1	41.5	29.3
	Avg.	32.7	41.1	26.1
CS5	25	35.9	44.9	19.2
	100	28.5	47.4	24.1
	Avg.	32.2	46.1	21.6

Continued

Table 3.3. Distribution of root, shoot, and leaf dry weights for *C. siliquastrum* seedlings grown under low or high (25 or 100 mg N per L) fertilizer treatments.

Table 3.3 continued

CS6	25	45.8	35.3	18.9
	100	40.1	40.4	19.5
	Avg.	42.9	37.8	19.2

ANOVA	P > F - Value		
Source (S)	**[z]	NS	**
Fertilizer rate (FR)	**	*	**
S*FR	*	NS	NS

[y] Each value is the mean of 10 individual seedlings within each species and fertilizer.

[z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Species	Fertilizer (mg per L)	LAR ($g.cm^{-2}$)	NAR ($g.cm^{-2}.day^{-1}$)	RGR ($g.g^{-1}.day^{-1}$)
CS1	25	19.3 ^{y}	0.0012	0.0230
	100	23.3	0.0009	0.0198
	Avg.	21.3	0.0010	0.0214
CS2	25	18.8	0.0011	0.0195
	100	22.1	0.0009	0.0201
	Avg.	20.4	0.0010	0.0198
CS3	25	22.1	0.0010	0.0201
	100	27.2	0.0007	0.0190
	Avg.	24.6	0.0008	0.0195
CS4	25	20.6	0.0012	0.0211
	100	29.3	0.0007	0.0183
	Avg.	24.9	0.0009	0.0197
CS5	25	22.7	0.0010	0.0202
	100	26.5	0.0007	0.0170
	Avg.	24.6	0.0008	0.0186

Continued

Table 3.4. Leaf area ratio, net assimilation rate, and relative growth rate of *Cercis siliquastrum* sources under low or high (25 or 100 mg N per L) fertilizer treatments.

Table 3.4 continued

CS6	25	23.4	0.0010	0.0217
	100	22.3	0.0010	0.0213
	Avg.	22.8	0.0010	0.0215

ANOVA		P > F - Value	
Source (S)	*[z]	NS	**
Fertilizer rate (FR)	**	**	**
S* FR	NS	NS	**

[y] Each value is the mean of 10 individual seedlings within each source and fertilizer.

[z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Source	Fertilizer rate[x] (mg per L)	Nitrogen concentration (%) leaf	shoot	root	total plant	Nitrogen content (g) leaf	shoot	root	total plant	Nitrogen distribution (%) leaf	shoot	root
CS1	25	1.91[y]	0.99	1.49	1.30	0.69	1.03	1.30	3.02	23	34	43
	100	2.69	1.28	1.95	1.83	1.04	1.04	1.56	3.65	29	28	43
	Avg.	2.30	1.13	1.72	1.56	0.86	1.03	1.43	3.33	26	31	43
CS2	25	1.84	0.96	1.36	1.27	0.62	0.98	1.78	3.38	18	27	55
	100	2.11	1.12	1.80	1.55	1.21	1.31	1.51	4.03	30	32	38
	Avg.	1.97	1.04	1.58	1.41	0.91	1.14	1.64	3.70	24	29	46
CS3	25	1.71	1.12	1.45	1.38	0.77	0.95	1.33	3.05	26	32	42
	100	2.40	1.58	1.89	1.85	1.08	1.57	1.51	4.16	27	38	35

Continued

Table 3.5. Nitrogen concentration and content, in leaf, shoot, root, and total plant tissues and nitrogen distribution in leaf, shoot and root tissues as percent of total plant N content of *C. siliquastrum* sources grown under two fertilizer rates.

Table 3.5 continued

	Avg.	2.05	1.35	1.67	1.61	0.92	1.26	1.42	3.6	26	35	38
CS4	25	1.62	0.94	1.36	1.30	0.96	0.67	0.98	2.62	35	26	39
	100	2.38	1.38	2.06	1.92	0.80	0.80	0.73	2.34	35	33	32
	Avg.	2.00	1.16	1.71	1.61	0.88	0.73	0.85	2.48	35	29	35
CS5	25	1.56	1.18	1.56	1.40	0.60	1.18	1.37	3.15	22	36	42
	100	2.05	1.17	1.92	1.64	0.76	1.05	1.13	2.94	26	33	41
	Avg.	1.80	1.17	1.74	1.52	0.68	1.11	1.25	3.04	24	34	41
CS6	25	1.46	1.00	1.49	1.31	0.43	0.60	1.21	2.24	18	27	55
	100	2.19	1.09	1.72	1.57	0.94	0.82	1.53	3.29	29	25	46
	Avg.	1.82	1.04	1.60	1.44	0.68	0.71	1.37	2.76	23	26	50

Continued

Table 3.5 continued

ANOVA	P > F - Value										
Source (S)	**[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer rate (FR)	**	**	**	**	**	NS	NS	NS	NS	NS	NS
S*FR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[X] Plants under the low N treatment (25 mg N per L) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high N treatment (100 mg N per L) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the fertilizer and Comtil compost. Plants were fertilized with 21 N - 3.1 P- 5.9 K between 12 May and 24 September.

[Y] Each value is the mean of three plants for each source and fertilizer rate.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Source	Fertilizer rate[x] (mg per L)	Phosphorus concentration (ug/g) leaf	shoot	root	total plant	Phosphorus content (g) leaf	shoot	root	total plant	Phosphorus distribution (%) leaf	shoot	root
CS1	25	5998[y]	2177	4260	3617	0.21	0.23	0.38	0.82	26	28	46
	100	6832	2702	3379	3748	0.26	0.22	0.27	0.75	35	29	36
	Avg.	6415	2439	3819	3682	0.23	0.2	0.32	0.78	30	28	41
CS2	25	4738	1965	3933	3315	0.17	0.19	0.51	0.87	18	22	60
	100	4266	2207	3745	3192	0.25	0.25	0.33	0.83	30	31	39
	Avg.	4502	2086	3839	3253	0.21	0.22	0.42	0.85	24	26	49
CS3	25	4702	1959	3827	3225	0.22	0.17	0.34	0.73	29	24	47
	100	4268	3169	4290	3769	0.19	0.31	0.33	0.83	23	35	42

Continued

Table 3.6. Phosphorus concentration and content, in leaf, shoot, root, and total plant tissues and P distribution in leaf, shoot and root tissues as percent of total plant P content of *C. siliquastrum* sources grown under two fertilizer rates.

Table 3.6 continued

	Avg.	4485	2564	058	3497	0.20	0.24	0.33	0.78	26	29	44
CS4	25	4183	1823	3453	3218	0.27	0.12	0.25	0.64	37	22	41
	100	3900	2516	4121	3380	0.12	0.15	0.14	0.41	33	32	35
	Avg.	4041	2169	3787	3299	0.19	0.13	0.19	0.39	35	27	38
CS5	25	3083	1872	4087	2981	0.13	0.17	0.37	0.68	19	29	52
	100	3488	2142	4682	3262	0.12	0.19	0.27	0.58	21	31	48
	Avg.	3285	2007	4384	3121	0.12	0.18	0.32	0.63	20	30	50
CS6	25	5129	1910	3701	3305	0.15	0.12	0.32	0.59	25	20	55
	100	5549	2635	3542	3567	0.23	0.20	0.29	0.72	32	28	40
	Avg.	5339	2272	3621	3436	0.19	0.16	0.30	0.65	28	24	47

Continued

Table 3.6 continued

ANOVA	P > F - Value										
Source (S)	** [Z]	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
Fertilizer rate (FR)	NS	**	NS	**	NS	*	NS	NS	NS	NS	**
S*FR	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS

[X] Plants under the low N treatment (25 mg N per L) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high N treatment (100 mg N per L) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the fertilizer and Comtil compost. Plants were fertilized with 21 N - 3.1 P- 5.9 K between 12 May and 24 September.

[Y] Each value is the mean of three plants for each source and fertilizer rate.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Source	Fertilizer rate[x] (mg per L)	Potassium concentration (ug/g) leaf	shoot	root	total plant	Potassium content (g) leaf	shoot	root	total plant	Potassium distribution (%) leaf	shoot	root
CS1	25	25269[y]	7341	13842	11811	0.71	0.76	1.21	2.68	26	28	46
	100	20138	7428	13980	12403	0.76	0.61	1.10	2.47	31	24	45
	Avg.	22703	7384	13911	12107	0.73	0.68	1.15	2.57	28	26	45
CS2	25	17769	10904	10909	9031	0.44	1.20	1.50	3.28	18	32	50
	100	19464	12650	12426	12795	1.12	1.12	1.10	3.35	34	34	32
	Avg.	18616	11777	11667	10913	0.78	1.16	1.30	3.31	26	33	41
CS3	25	17391	7499	11028	10922	0.78	0.64	0.96	2.38	33	27	40

Continued

Table 3.7. Potassium concentration and content, in leaf, shoot, root, and total plant tissues and K distribution in leaf, shoot and root tissues as percent of total plant K content of *C. siliquastrum* sources grown under two fertilizer rates.

Table 3.7 continued

	100	17499	8975	13160	12156	0.79	0.87	0.99	2.66	29	31	40
	Avg.	17445	8237	12094	11539	0.78	0.75	0.97	2.52	31	29	40
CS4	25	17946	7721	14038	13135	1.10	0.53	1.01	2.62	39	21	40
	100	17480	9556	16846	14369	0.59	0.56	0.60	1.75	34	31	35
	Avg.	17713	8638	15442	13752	0.84	0.54	0.80	2.18	36	26	37
CS5	25	15020	7487	15131	11656	0.55	0.72	1.30	2.63	22	29	49
	100	15108	8710	17176	13190	0.54	0.79	1.02	2.35	24	31	45
	Avg.	15064	8098	16153	12423	0.54	0.75	1.16	2.49	23	30	47
CS6	25	18548	7644	14446	12667	0.75	0.47	1.18	2.19	23	22	55
	100	21207	9578	12482	12995	0.90	0.75	1.03	2.67	34	27	39
	Avg.	19877	8611	13464	12831	0.82	0.61	1.10	2.43	28	24	47

Continued

Table 3.7 continued

ANOVA	P > F - Value										
Source (S)	** [z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer rate (FR)	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
S*FR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[x] Plants under the low N treatment (25 mg N per L) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high N treatment (100 mg N per L) received 31.3,41.8, and 13.2 g N, P, and K respectively from fertilizer and Comtil compost. Plants were fertilized with 21 N - 3.1 P- 5.9 K between 12 May and 24 September.

[Y] Each value is the mean of three plants for each source and fertilizer rate.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Fertilizer	Water soluble fertilizer			Comtil			Total		
(mg per L)	N	P	K	N	P	K	N	P	K
25	3.3	0.5	0.8	18.0	39.8	9.9	21.3	40.3	10.8
100	13.3	2.0	3.2	18.0	39.8	9.9	31.3	41.8	13.2

Table 3.8. Grams of N, P and K applied between May and September by 21-3.1 P- 5.9 K (21-7-7) Peters Water Soluble Fertilizer and Comtil.

Source	Fertilizer rate[x] (mg per L)	Whole plant mineral nutrient uptake (g)			Mineral nutrient use efficiency (%)		
		N	P	K	N	P	K
CS1	25	3.02[y]	0.79	1.86	13	3	41
	100	3.45	0.70	1.65	11	3	27
CS2	25	3.38	1.15	2.40	15	4	50
	100	3.84	0.80	2.50	12	3	37
CS3	25	3.05	1.07	1.66	13	3	36
	100	3.99	0.80	1.90	13	3	29
CS4	25	2.62	0.62	1.98	12	3	40
	100	2.19	0.40	1.10	7	2	19

Continued

Table 3.9. Nitrogen, P and K uptake and mineral nutrient use efficiency for *C. siliquastrum* grown under two fertility rates.

Table 3.9 continued

CS5	25	3.15	0.47	1.95	14	3	39
	100	2.73	0.50	1.60	9	2	25
CS6	25	2.24	0.57	1.60	10	2	33
	100	3.13	0.70	2.08	10	3	29

ANOVA			P > F - Value			
Source (S)	NS [z]	NS	NS	NS	NS	NS
Fertilizer rate (FR)	NS	NS	NS	*	NS	**
S* FR	NS	NS	NS	NS	NS	NS

[x] Plants under the low N treatment (25 mg N per L) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May

Continued

Table 3.9 continued

and 24 September, those under the high N treatment (100 mg N per L) received 31.3, 41.8, and 13.2 g N, P, and K respectively from fertilizer and Comtil compost. Plants were fertilized with 21 N - 3.1 P- 5.9 K between 12 May and 24 September.

[Y] Each value is the mean of three plants for each source and fertilizer rate.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Source	Fertilizer rate[y] (mg N per L)	Ratio Relative N	P	K
CS 1	25	3.7 [z]	1	3.3
	100	4.9	1	3.3
CS 2	25	3.9	1	3.8
	100	4.8	1	4.0
CS 3	25	4.2	1	3.3
	100	5.0	1	3.2
CS 4	25	4.1	1	4.1
	100	5.7	1	4.3
CS 5	25	4.6	1	3.9
	100	5.1	1	4.0
CS 6	25	3.8	1	3.7
	100	4.6	1	3.7

Continued

Table 3.10. Whole plant N-P-K tissue contents (expressed relative to P content) of *C. siliquastrum* plants from different sources grown under two fertilizer treatments.

Table 3.10 Continued

[Y] Plants under the low N treatment (25 mg N per L) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high N treatment (100 mg N per L) received 31.3, 41.8, and 13.2 g N, P, and K respectively from fertilizer and Comtil compost. Plants were fertilized with 21 N - 3.1 P- 5.9 K between 12 May and 24 September.

[z.] Each value is the mean of 10 plants per source and fertilizer treatment.

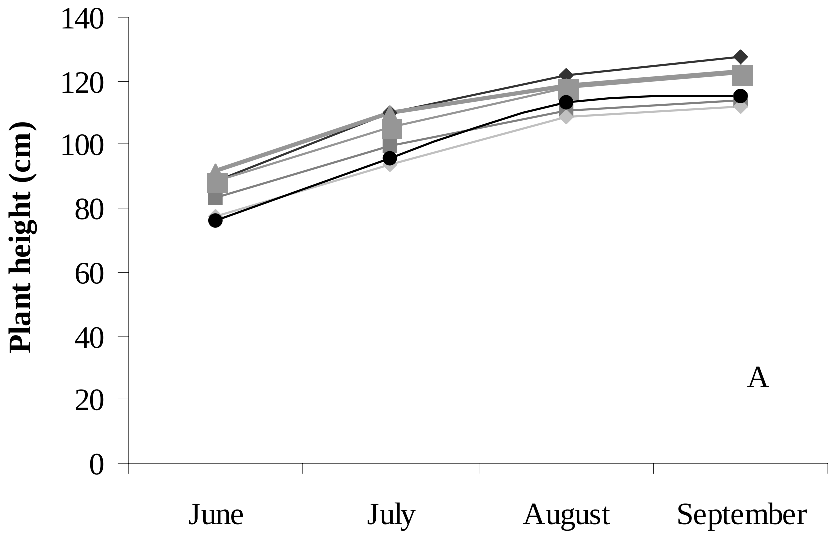
Species	Fertilizer rate (mg per L)	Application time	Medium	Reference
Pyrus calleryana	300	weekly	5:1 pine bark:sandy clay soil	Gilliam *et al.* 1984
Acer rubrum	150, 300	weekly	4:1 pine bark:sand	Gilliam *et al.* 1980
	200-400	daily	3:1:1 pine bark:peat:sand	Larimer and Struve, 2002
Most conifers	100-150	not specified	not specified	Jull et al. 1994
Betula verrucosa	25	not specified	not specified	Ingestad, 1979
Cryptomeria japonica	25	3 times/ week	not specified	Jull *et al.* 1994
Cupressus arizonica var. glabra	20	daily	calcined clay	Stubbs *et al.* 1997

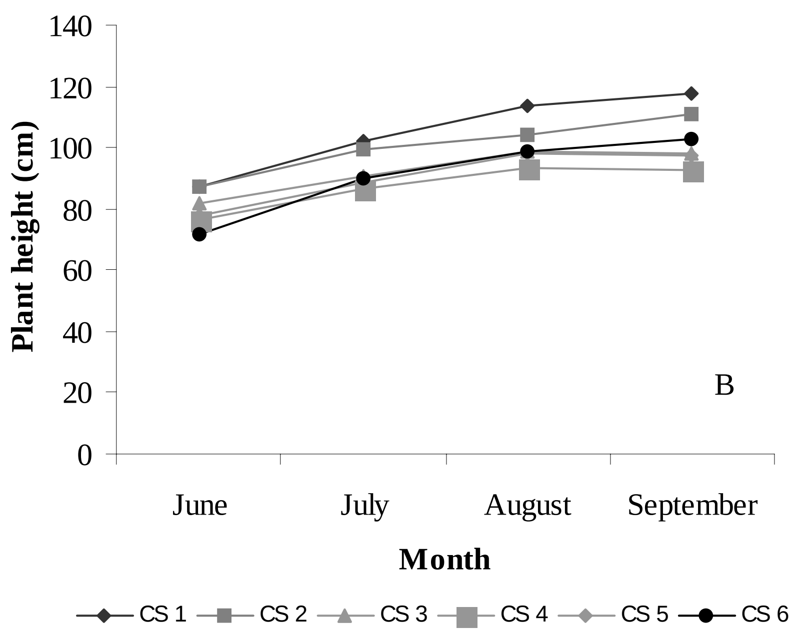
Continued

Table 3.11. Summary of selected recommended N fertilizer rates for some woody ornamentals grown in container production systems.

Table 3.11 continued

Tilia cordata	100	daily	2:1 calcined clay:peat	Wright and Niemiera, 1987
Acer platanoides	100	daily	2:1 calcined clay:peat	Wright and Niemiera, 1987
Ilex crenata	75	daily	sand culture	Wright and Niemiera, 1987
Pyracantha coccinea	50	daily	sand culture	Wright and Niemiera, 1987
Cotoneaster dammeri	50	daily	sand culture	Wright and Niemiera, 1987
Weigela florida	50	daily	sand culture	Wright and Niemiera, 1987
Acer, Pyrus species	300	weekly	mostly pine bark	Wright and Niemiera, 1987
Quercus rubra	400	daily	3:1:1 pine bark:peat:sand	Larimer and Struve, 2002
Thuja occidentalis	200	not specified	not specified	Lumis *et al.* 2000
Buxus sinica var insularis	100-125	daily	Pine bark	Musselwhite *et al.* 2004


140
120
100
80
60
40
20
0
Plant height (cm)
A
June
July
August
September


140
120
100
80
60
40
20
0
Plant height (cm)
B
June
July
August
September
Month
CS 1
CS 2
CS 3
CS 4
CS 5
CS 6

CHAPTER 4

Malus trilobata, Acer syriacum growth, N, P, K content, concentration, distribution and efficiency as affected by two fertilizer rates[1]

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4.1 Abstract

This study was done to determine growth, N, P, K uptake efficiency and partitioning under two fertilizer rates of *Malus trilobata* and *Acer syriacum*, trees native to Lebanon that have ornamental value. *Malus trilobata* seedlings were obtained from seed colleted from two mother trees and *Acer syriacum* seedlings from a single tree in Lebanon. Two-year old seedlings were planted in 11 liters containers in a 3:1 pine bark: compost substrate, with half the seedlings within each source assigned to either 25 or 100 mg N L^{-1} from 21-3.1 P- 5.9 K (21-7-7) water soluble fertilizer. Growth, mineral nutrient uptake or nutrient use efficiency of *Acer syriacum* were not affected by fertilizer rate. Seedlings of *Malus trilobata* sources grown under 25 were taller than those grown at 100 mg N L^{-1}. Nitrogen loading occurred in plants of *Malus trilobata* under the high fertilizer rate, although total plant N, P, and K content was not affected by fertilizer rate. There were significant differences in growth among the two *Malus trilobata* seed sources, but no differences in mineral nutrient uptake or nutrient use efficiency were seen. Hence, *Malus trilobata* and *Acer syriacum* seedlings can be grown commercially in containers at 25 mg N L^{-1}.

Index words: three-lobed apple tree, syrian maple, Lebanese flora, container production, relative growth rate, Comtil, N-P-K ratios, mineral nutrition, woody ornamentals, nutrient loading.

4.2 Introduction

In Lebanon, landscape woody plants are imported from many countries (Italy, Spain, Syria, Egypt, United States) although there is a great potential for developing a native plant production industry. With the end of the civil war, the demand for low maintenance landscape plants has been increasing to meet the extensive reconstruction projects. A large number of plant species in Lebanon have potential economic value whether for ornamental or medicinal use (UNEP, 1996). A previous study showed that *Cercis siliquastrum* sources, native to Lebanon could be grown commercially (Chapter 3). Thus, other native Lebanese plants with great ornamental potential are *Malus trilobata* and *Acer syriacum*.

Malus trilobata Schneid, “erect crab” or “three lobed apple tree”, belongs to the family Rosaceae. It is an erect tree about 13m tall with linear horizontal branches (Anonymous, 1999). Leaves are maple-like and deeply three-lobed. The lobes themselves are sometimes sharply lobed and toothed. The leaves turn from orange to red to deep purple in autumn. The tree blooms from April to May producing white flowers and yellow fruits. Hillier and Sons, (1973) reported the tree is distributed in Eastern Mediterranean Region and North East Greece adding that the species is comparatively rare and very distinct; however, Mouterde (1966) reported the species is endemic to Lebanon and rare. It is found in the Supramediterranean zone in Lebanon, at an altitude of 1000-1500 m along with *Ostrya, Sorbus, Fraxinus,* and *Abies*.

Acer syriacum Boin and Gaill, syrian maple, belongs to the family Aceraceae. It reaches 8 m height. The leaves are evergreen, glabrous, with three short, acute, or broad lobes. The leaves turn yellow and pink in autumn. It grows in the Thremomediterranean zone in Lebanon (0-500 m altitude). White to yellow flowers are produced from February to March. It has divergent samaras. It is reported to be indifferent to soil type, but is mainly found in calcareous soils in Lebanon (Anonymous,1999). It is also native to Syria, Lebanon, Cyprus, and Palestine.

The aim of the study was to determine the commercial potential of two mother trees of *Malus trilobata* and one source of *Acer syriacum*, by exploring the dry weight and mineral nutrient partitioning, mineral nutrient uptake and efficiency under two fertilizer rates.

4.3 Materials and Methods

A description of plant material and the numbers of plants per source used in this study are given in Table 4.1. *Malus trilobata* fruits were collected beginning of October 2001. By first cutting the fruit, seeds were extracted by hand. Samara wings of maple seeds (*Acer syriacum*) were removed by hand.

The seedlings used in this study were raised from seeds germinated in previous studies (data not presented). The procedure from this point forward is similar to the one used for *Cercis siliquastrum* (Chapter 3).

Germinated seeds were transplanted into 250-XL plastic containers (Nursery Supplies, Fairless Hills, PA) using MetroMix® 360 (Scotts Company, Marysville, OH) substrate and placed in a heated greenhouse under natural photoperiods. The greenhouse temperatures were set at 22/ 21C (71.5/ 70.6F D/N). The relative humidity averaged 46.6 ± 2 %. Plants were watered as needed to avoid water stress. When seedlings developed two true leaves, they were fertilized once per week with 100 mg N L^{-1} of 20N- 8.3P- 4.6K

(20-10-10, Peters water-soluble fertilizer O.M. Scotts Company, Marysville, OH). Plants were overwintered (from November to May) in a minimum heat (> 2 C / 35.6 F) polyhouse.

Twenty-four months later, (May, 2004), the plants were removed from the containers, root pruned, transplanted into #3-gallon Spin-Out ®treated containers (1200 Classic, Nursery Supplies, Fairless Hills, PA) and moved to an outdoor gravel pad. The most vigorous shoot was trained into a central leader by tying it to a 2 m bamboo stake. The plants were placed on 45.7 cm (18 inches) within row spacing and 2 m (6 ft) between row spacing. A 3 pine bark:1 Comtil (composted municipal sewage sludge, City of Columbus, by volume) substrate was used.

Half of the plants from each mother tree were randomly assigned to one of two N fertility programs: 25 mg per L or 100 mg per L N fertigation from 21 N- 3.1 P - 5.9 K (21-7-7, Peters Water Soluble Fertilizer O.M. Scotts Company, Marysville, OH) applied at 0.5 L in each of two daily irrigation cycles (1 L total per day). The fertility treatments were initiated on 1 June and terminated on 20 September. Plants within a fertility treatment were arranged in a randomized complete block design with eight replications.

An initial harvest was done on 12 May 2004 and a second harvest on 24 September 2004. At each harvest, height and caliper were measured on all trees, while leaf area was measured on ten randomly selected trees per source and fertilizer treatment with a LI- 3100 Area meter (LI- COR, Inc. Lincoln, Nebraska, USA). Plants were pruned at the root collar, substrate washed from the root systems, plant parts (roots, shoots, and leaves) oven dried at 82C (180F) for 96 hours and dry weights recorded. From the ten plant subsample, three randomly selected individuals from each source and fertilizer rate were selected for nutrient analysis. Leaves, shoots and roots from these plants were ground to pass through a 20 mesh screen and 2 g subsamples from each tissue type was sent to the Service Testing And Research Laboratory (STAR laboratory, OARDC, Wooster, Ohio) for N-P-K nutrient analysis. Total nutrient content of each tissue type was calculated by multiplying their respective dry weights by their tissue nutrient concentrations. Total plant dry weight or nutrient content was calculated by summing the dry weights or nutrient contents of an individual's stem, roots and leaves.

Leaf, stem and root dry weights as a percentage of total plant dry weight were calculated. Relative nutrient contents of leaves, stems and roots were determined similar to the relative dry weights of leaves, stems and roots.

Nitrogen use efficiency was calculated by the following equation: $= [(TNC_2) – (TNC_1) / TNA] \times 100\%$ where TNC_2 and TNC_1, are total plant N contents in September and May, respectively, and TNA is the total N applied between May and September. Similarly, P and K use efficiencies were calculated.

From the dry weights and leaf area data, net assimilation rate (NAR), leaf area ratio (LAR) and relative growth rate (RGR) were calculated according to Evans (1972). To calculate NAR, LAR and RGR, plants within the initial and final harvests were sorted by total dry weight and paired by ascending order of total plant dry weight. Total plant assimilation rates (g cm^{-2} day^{-1}) were calculated as: $NAR = (TW_2 - TW_1) \times (\ln A_2 – \ln A_1) / ((T_2 - T_1) \times (A_2 - A_1))$, leaf area ratio (g cm^{-2}) as: $LAR = (A_2 - A_1) / (TW_2 - TW_1)$ and relative growth rate (g g^{-1} day^{-1}) as $RGR = (\ln TW_2 – \ln TW_1) / (T_2-T_1)$;

where T_1 = initial time (12 May), T_2 = final time (24 September), TW_1 and TW_2 are total plant dry weight at time 1 and 2 respectively, A_1 and A_2 = leaf area at time 1 and 2 respectively.

For dry weight analyses, ten single plant replications were used; while mineral nutrient analyses used three single plant replications. Data was analyzed using One-way ANOVA and GLM within SPSS (SPSS Institute, Chicago, IL, version 12.0). Equations describing plant height during the season were developed using non linear regression within SigmaPlot (Version 9.0).

4.4 Results

Growth and Dry weight

Quadratic equations describing *Malus trilobata* and *Acer syriacum* height under both fertilizer rates during the season were significant with R^2 > 0.93 (Figs.1 and 2).

The source by fertilizer rate interaction was significant only for *Malus trilobata* leaf area (P = 0.043, Table 4.2). Fertilizer rate did not affect any of the parameters measured for *Acer syriacum* (Table 4.2). Fertilizer rate affected only plant height of *Malus trilobata* which were significantly taller at the low fertilizer rate (168.4 cm) than at the high fertilizer rate (130.9 cm, Table 4.2). There were significant differences in root and total plant dry weights between the two sources of *Malus trilobata*. *Malus trilobata* plants from source 2 (MT2) had significantly higher root and total plant dry weights than those from MT3 at both fertilizer rates (P = 0.012 and P = 0.027, respectively; Table 4.2). Root and total plant dry weights were 60.2 g and 199.6 g, respectively, for MT2 and 34.9 g and 145.8 g, respectively for MT3 (Table 4.2).

There were no significant source by fertilizer rate interaction for relative root, shoot or leaf dry weight distribution in *Malus trilobata* plants (Table 4.3). Fertilizer rates affected only leaf dry weight distribution for *Malus trilobata;* it was higher at the high fertilizer rate (14.1 % vs 11.6 %). Fertilizer rate did not affect root, shoot and leaf dry weight distribution in *Acer syriacum* plants (Table 4.3). There were no significant differences between the two *Malus trilobata* seed sources in root, shoot and leaf dry weight distribution (Table 4.3). Both *Malus trilobata* sources and in *Acer syriacum,* relative shoot dry weight was higher than either leaf or root dry weights at both fertilizer rates. For *Acer syriacum* it averaged 4 % and for *Malus trilobata* it was 59 % (Table 4.3).

There was a significant source by fertilizer rate interaction in RGR for *Malus trilobata* plants (P = 0.025, Table 4.4). For both sources, RGR was higher at the low fertilizer rate, but for MT3 plants the difference was greater than for MT2 plants (0.0049 g g^{-1} day^{-1} vs 0.0022 g g^{-1} day^{-1}, respectively). Fertilizer rate did not affect LAR, NAR and RGR of *Acer syriacum* plants but it did in *Malus trilobata* (Table 4.4). *Malus trilobata* plants grown at the high fertilizer rate had significantly higher LAR and lower NAR (Avg = 9.8 g cm^{-2} and 0.0020 g cm^{2} day^{-1}, respectively) than those grown at the low fertilizer rate (Avg = 7.9 g cm^{-2} and 0.0030 g cm^{2} day^{-1}, respectively).

Tissue N concentration, N content and relative N distribution

There were no significant source by fertilizer rate interactions for N concentration, content or relative distribution in leaf, shoot, root and total plant tissues of *Malus trilobata* (Table 4.5). Fertilizer rate affected root and total plant N concentrations; it was higher at 100 mg N L^{-1} than at 25 mg N L^{-1} for both sources (1.49 vs 1.00 and 1.35 vs 1.12 for

MT2 and MT3, respectively, Table 4.5). Regardless of the tissue type in *Malus trilobata*, nitrogen concentration was higher at the high fertilizer rate than the low fertilizer rate (Table 4.5). Regardless of fertilizer rate, leaf N concentration was higher than that of stem and root tissue in *Malus trilobata*. Grams of N in leaf and stem tissue were higher at the high fertilizer rate than at the low fertilizer rate in *Malus trilobata,* but the opposite was true for *Acer syriacum* plants (Table 4.5). Relative N distribution in leaf, shoot and root tissues was not affected by seed source or fertilizer rate in *Malus trilobata* and *Acer syriacum.* In *Malus trilobata* it was highest in shoot tissue; while in *Acer syriacum*, it was higher in shoot tissue at the low fertilizer rate and higher in leaf tissue at high fertilizer rate (Table 4.5). Tissue N concentrations and contents were higher in plants grown under both fertilizer levels than in plants harvested at the beginning of the study (Appendix D).

Tissue P concentration, P content and relative P distribution

Fertilizer rate or source had no effect on P concentration or content and on its relative distribution in leaf, shoot and root tissues in *Malus trilobata* (Table 4.6). In *Acer syriacum,* plants under the high fertilizer rate had greater percent of whole plant P in shoot tissues (44 %), while at high fertilizer rate, roots contained the greatest percent of P (53 %). In most cases, root P concentration was higher than that of stem and root tissue at both fertilizer rates in *Malus trilobata* and *Acer syriacum* (Table 4.6). Tissue P concentrations and contents were higher in plants grown under both fertilizer levels than in plants harvested at the beginning of the study (Appendix E).

Tissue K concentration, K content and relative K distribution

Fertilizer rate or source had no effect on K concentration or content and on its relative distribution in leaf, shoot and root tissues of *Malus trilobata* and *Acer syriacum* (Table 4.7). Tissue K concentrations and contents were higher in plants grown under both fertilizer levels than in plants harvested at the beginning of the study (Appendix F).

Nutrient uptake and nutrient use efficiencies

Comtil supplied more N, P, and K than either rate of water soluble fertilizer (Table 4.8). It supplied between 85 and 58 % of the N, 99 and 95 % of the P and 92 to 75 % of the total K. There was no significant source by fertilizer rate interaction for N, P, and K uptake between May and September 2004 and mineral nutrient use efficiencies in *Malus trilobata* and *Acer syriacum* (Table 4.9). Fertilizer rates affected K use efficiency in *Malus trilobata.* Potassium use efficiency was higher at the low (41.4 %) than at the high fertilizer rate (22.7 %). Fertilizer rates did not affect N, P or K use efficiencies in *Acer syriacum.* There were no significant differences among seed sources of *Malus trilobata* for N, P, and K uptake and use efficiencies (Table 4.9).

N-P-K ratios

At the high fertilizer rate, the ratio of N in whole plant tissue was greatest and P was always the least; on the other hand, at the low fertilizer rate, the relative K content was greatest and P was always the least (Table 4.10). The ratio of N-P-K in whole plant tissues (relative to P) of MT2 plants was 5.7-1-6.8 at the low fertilizer rate and 7.7-1-5.5 at the high fertilizer rate (Table 4.10). In plants from MT3, the ratio of N to K was lower at the low fertilizer rate, and nearly equal at the high fertilizer rate. In *Acer syriacum*, the ratio of N to K was lower at both fertilizer rates (Table 4.10).

4.5 Discussion

There were few significant species by fertilizer rate interactions in *Malus trilobata*; They were leaf area and RGR. As the fertilizer rate increased, leaf area of MT2 plants increased by 377 cm^2 while leaf area of MT3 plants decreased by 543 cm^2. Also, at the high fertilizer rate, RGR of MT3 plants decreased by 0.0049 g g^{-1} day^{-1} whereas that of MT2 decreased by 0.0022 g g^{-1} day^{-1}. Species by fertilizer rate interactions were also significant for RGR of *Cercis siliquastrum* sources from Lebanon (Chapter 3). There were no species by fertilizer interactions in *Acer syriacum* since only one source was included in the study.

The first hypothesis, that higher fertilizer rate results in better growth was false. A higher fertilizer rate did not lead to increased growth in *Malus trilobata* and *Acer syriacum* seedlings. *Malus trilobata* plants grown at the low fertilizer rate were taller than those at the high fertilizer rate. Also, caliper, dry weights of shoot, root and leaf, and leaf area were not increased at the high fertilizer rate. Higher fertilizer rates increased LAR but decreased NAR in both *Malus trilobata* sources. Similar results were found for *Cercis siliquastrum* (Chapter 3). In contrast, *Acer syriacum* growth was not affected by fertilizer rates. *Malus trilobata* growth was more vigorous at a lower rate than that reported by others (Table 4.11).

Since greater growth was obtained at the lower fertilizer rate, we recommended that daily applications of 25 mg N L^{-1} be applied from the fertilizer 21 N- 3.1 P - 5.9 K (21-7-7) on *Malus trilobata.* A fertilizer savings of 75 % can be realized without reducing plant growth. Additional testing is needed to determine the optimum fertilizer rate for these species in this production system.

The relative distribution of total plant dry weight of *Malus trilobata* was altered by fertilizer rate; at high fertilizer rate more dry weight was in leaves and roots and less in shoots. Interestingly, the opposite effect occurred when *Cercis siliquastrum* and red maple were grown at the high fertilizer rate (Chapter 3; Larimer and Struve, 2002). These plants increased the percent of whole plant dry weight in the shoot system. *Malus trilobata* and *Acer syriacum* had the highest percent of total plant dry weight in the shoot system when grown under both fertilizer rates, whereas this was true for *Cercis siliquastrum* only under the high fertilizer rate (Chapter 3) .

Unlike *Cercis siliquastrum*, red maple and *Malus trilobata,* growth of *Acer syriacum* was not altered in response to differences in nutrient availability (Tables 2 and 3; Chapter 3; Larimer and Struve, 2002).

A possible benefit of growing plants under high fertilizer rates is nutrient loading. Nutrient loading is defined as an increase in plant tissue nutrient concentration without a significant increase in plant dry weight (Malik and Timmer, 1995). Nitrogen loading was observed in the *Malus trilobata* sources grown at the high fertilizer rate (Table 4.6). The potential benefits of nutrient loaded trees are many: nutrient loaded conifer seedlings performed better when out planted in nutrient poor sites than those not nutrient loaded (Xu and Timmer, 1999; Malik and Timmer, 1995). Moreover, for conservation purposes (reforestation or reintroduction of species to their native habitats), nutrient loading increases the competitive ability for resources of species in weed-prone or heavily vegetated sites (Malik and Timmer, 1995). Nutrient loading seedlings in the nursery is more effective than fertilizing trees after out planting. If plants perform better after transplanting, this would allow nursery managers to offer higher quality plants, assuming the benefits of nutrient loading are not offset by decreased plant quality (i.e. smaller plants). The possible benefits of nitrogen loading to *Malus trilobata* need to be confirmed with transplanting studies.

Similar to *Cercis siliquastrum,* mineral nutrient uptake (total plant nutrient content) between May and September in *Malus trilobata* and *Acer* s*yriacum* was not affected by fertilizer rates (Chapter 3, Table 4.9). It is likely that nutrients added by Comtil overwhelmed that added by the water soluble fertilizer. Comtil is a composted municipal sewage sludge product where the ammonium-N form predominates (Struve, 2002). In this study, the grams of N, P, and K applied via Comtil were 135, 2031 and 308 % more than that added at the high fertilizer rate from the water soluble fertilizer (Table 4.8). Also, higher concentrations of P and K than those recommended by Wright and Niemiera (1987), 10 and 25-50 mg per L respectively, were applied through the liquid fertilizer and Comtil (Table 4.8).

Phosphorus and K concentrations, contents and distributions, were not affected by fertilizer rates in *Malus trilobata* and *Acer syriacum* unlike *Cercis siliquastrum* (Chapter 3), with the exception of the increased percent of total P content in the root system of *Acer syriacum* and decreased percent of total P content in the shoot system as the fertilizer rate increased (Table 4.6). However, similarly to *Cercis siliquastrum*, leaf N and K concentrations were always higher than that of stem or root under both fertilizer rates in *Malus trilobata* sources (Chapter 3).

Nitrogen use efficiency was lower at the higher fertilizer rate among sources of *Malus trilobata* and in *Acer syriacum* (Table 4.9). A similar finding was observed with *Cercis siliquastrum* (Chapter 3). Nitrogen use efficiency ranged between 7 and 11 % in *Malus*, and 3 and 5 % in *Acer* compared to a range of 7 to15 % in *Cercis siliquastrum* (Chapter 3). Also similar to *Cercis siliquastrum*, P use efficiency in *Malus trilobata* and *Acer syriacum* was lower than N and K use efficiencies. Phosphorus use efficiency at both fertilizer rates ranged between 1 and 2 % in *Malus trilobata*, and was equal to 1 % in *Acer syriacum* compared to a range of 2 to 4 % in *Cercis siliquastrum* (Chapter 3). Furthermore, K use efficiency in *Malus trilobata* was lower at the high fertilizer rate than at the low fertilizer rate and was higher than either nitrogen or phosphorus similarly to *Cercis siliquastrum* (Chapter 3). An explanation for the high K efficiency could be genetic ability of *Malus trilobata* to store K for use as an osmoticum in drought. Deficiency in K has been associated with reduced ability to withstand stress and maintain high transpiration rates (Tisdale *et al.* 1998). Another possible explanation for why K use efficiency was higher than N and P use efficiencies is that K promotes the conversion of inorganic P to nucleic acids and phosphoproteins that would otherwise cause plant toxicity. Toxicity effects due to elevated inorganic phosphates has been reported in *Ilex crenata* when P was applied at higher concentration than 10 ppm (Wright and Niemiera, 1987). The toxicity was offset by a K concentration that was five times higher than P concentration (Wright and Niemiera, 1987).

The fertilizer used in this study had an N-P-K ratio of 6.8-1-1.6 when N and K were expressed relative to P. Comtil had an N-P-K ratio of 0.45-1-0.25. However, whole plant mineral nutrient ratios at the end of the growing season did not match the fertilizer or Comtil N-P-K ratios. Whole Plant tissue contained more N than P and K under the high fertilizer rate but more K than N and P under the lower fertilizer rate in *Malus trilobata* and *Acer syriacum*. Wright (1987) reported that the recommended N-P-K ratios in the container medium is 10-4-6 (2.5-1-1.5). Suggested N-P-K are 6-1-5 for *Betula*, *Acer*, *Cotoneaster* and *Berberis*; 5-1-3 for *Ilex* and a range of 5-1-3 to 8-1-4 for several other woody genera (Wright and Niemiera, 1987). In this study, there was a small difference between N and K content relative to P at both fertilizer rates for *Acer syriacum* and *Malus trilobata*. *Malus trilobata* whole plant N-P-K averaged over fertilizer rates was 7.1-1-7.1 while that of *Acer syriacum* was 4.8-1-5.5. These N-P-K ratios do not match the recommended N-P-K ratios for blackgum seedlings which varied with the type of fertilizer used, from 11.7-1-4.6 in slow release fertilizer to 5.8-1-3.8 in water soluble fertilizer (Struve, 1995). The latter N-P-K ratio was found to be close to the 5-1-4 N-P-K for *Cercis siliquastrum* (Chapter 3). One way to increase the efficiency of the fertilizer applied is to match the fertilizer ratio with the whole plant N-P-K ratios.

There were differences in growth between the two *Malus trilobata* sources, as there were differences in *Cercis siliquastrum* sources (Chapter 3). *Malus trilobata* like other apple trees is reported to be cross pollinated by insects (http://www.ibiblio.org/pfaf/cgi-bin/arr_html?Malus+trilobata&CAN=LATIND). Although both mother trees of *Malus trilobata* came from the same location in Lebanon, MT2 plants had higher root and total plant dry weights than MT3 plants. Plants from MT2 had higher RGR than MT3 plants and higher NAR at both fertilizer rates (Table 4.4).

On the other hand, there were no differences among sources of *Malus trilobata* in mineral nutrient uptake efficiency, and mineral nutrient partitioning whereas there were significant differences among sources of *Cercis siliquastrum* in N, P, K concentrations and contents (Chapter 3). Interestingly, whole plant tissue from MT3 contained more N and K than MT2 at both fertilizer rates. The N-P-K ratio of MT3 was 7.6-1-8.25 compared to that of MT2 which was equal to 6.7-1-6.15.

4.6 Conclusions

Seedlings of *Acer syriacum* grown at 25 mg N L^{-1} had similar growth to those grown at 100 mg per L N. Seedlings of *Malus trilobata* grown under 25 mg N L^{-1} from 21-7-7 resulted in taller seedlings of similar caliper than those grown under 100 mg N L^{-1}. Results in Ohio need to be confirmed in the Mediterranean climate of Lebanon. Different fertilizer rates (0, 10, 15, 25, 35, 50, 75 and 100 mg per L) need to be tested to determine the optimal rate for *Malus trilobata* and *Acer syriacum*. Nutrient uptake was not affected by fertilizer rates in *Malus trilobata* and *Acer syriacum* but N concentration was in *Malus trilobata*. Nitrogen loading occurred in *Malus trilobata* plants grown under the high fertilizer rate, but possible benefits need to be confirmed by field trials to determine whether the benefits of nutrient loading outweighs the decrease in plant quality (smaller plants and lower dry weights) when plants are transplanted. Tree- tree variation occurred in *Malus*: MT2 gave better growth and higher quality plants than MT3 plants even though they both came from the same geographical location in Lebanon. Therefore, it is suggested that performance trial be carried out for individual tree collection in different sites in Lebanon.

Fig. 4.1. Height of container-grown *Acer syriacum* under 25 or 100 mg N L^{-1} fertilizer. Each value is the mean of twenty-five plants per fertilizer rate. Plants were fertilized with 21-7-7 Peters Water Soluble Fertilizer. Plant height at 25 mg N L^{-1} is predicted by the equation: HT= - 101.75 + 1.38 X - 0.0025 X^2, R^2 = 0.962, P < 0.0001; whereas plant height at 100 mg per L N is predicted by the equation: HT = - 37.07 + 0.74 X - 0.0013 X^2, R^2 = 0.952, P = 0.038, where HT = Plant height (in cm) and X = Julian day between 174 and 260.

Fig.4.2. Height of container-grown *Malus trilobata* (MT2 and MT3) under 25 (Fig. A) or 100 mg N L^{-1} (Fig. B) fertilizer. Each value is the mean of twenty-five plants per fertigation treatment. Plants were fertilized with 21-7-7 Peters Water Soluble Fertilizer. Plant height at 25 mg N per L is predicted by the equation: HT for MT2 plants = - 289.48 + 3.07 X - 0.0053 X^2, R^2 = 0.944, P = 0.045. HT for MT3 plants = - 490.15 + 4.74 X - 0.0087 X^2, R^2 = 0.933, P < 0.0001.

Plant height at 100 mg N L^{-1} is predicted by the equation: HT for MT2 plants = - 343.96 + 3.58 X - 0.0067 X^2, R^2 = 0.939, P = 0.028. HT for MT3 plants = - 238.62 + 2.41 X - 0.0038 X^2, R^2 = 0.928, P < 0.0001; where HT = Plant height (in cm) and X = Julian day between 174 and 260.

Species	Source	Elevation (m)	Latitude (N)	Longitude (E)	Number of plants in study
Malus trilobata	MT2 : Ehden	1499	34˚18.776"	035˚59.320"	80
	MT3 : Ehden	1457	34˚18.813"	035˚59.147"	80
Acer syriacum	AS2 : Nahr Damour	43	33˚41.942"	035˚29.052"	80

Table 4.1. Description of the habitat source from where seeds of *Malus trilobata* (MT) and *Acer syriacum* (AS) were collected in Lebanon and the number of individuals from each species included in the study.

Species	Fertilizer (mg per L)	Height (cm)	Caliper (mm)	Dry weights(g)				Shoot/root ratio	Leaf area (cm^2)
				root	shoot	leaf	total plant		
MT2	25	167.4 [y]	12.9	61.6	125.8	21.4	208.9	2.04	1316
	100	140.3	12.2	58.8	106.2	25.4	190.4	1.80	1693
	Avg.	153.8	12.6	60.2	116.0	23.4	199.6	1.92	1504
MT3	25	169.5	12.5	36.7	110.0	21.2	167.9	3.00	1459

Continued

Table 4.2. Height, caliper, root, shoot, leaf and total plant dry weights, shoot/root ratio and leaf area of *Malus trilobata* sources and *Acer syriacum* under low or high (25 or 100 mg N L^{-1}) fertilizer treatments.

Table 4.2 continued

	100	121.5	11.5	33.2	72.1	18.5	123.8	2.17	916
	Avg.	145.5	12.0	34.9	91.0	19.8	145.8	2.58	1187
AS2	25	76.1	11.4	37.7	50.5	32.6	120.7	1.34	2843
	100	77.6	11.0	33.7	55.1	35.1	123.9	1.63	3021
	Avg.	76.8	11.2	35.7	52.8	33.8	122.3	1.48	2932
ANOVA					P > F - Value				

Continued

Table 4.2 continued

Malus trilobata								
Source (S)	NS[z]	NS	*	NS	NS	*	NS	NS
Fertilizer rate (FR)	**	NS	NS	NS	NS	NS	NS	NS
S* FR	NS	NS	NS	NS	NS	NS	NS	*

Continued

Table 4.2 continued

Acer syriacum								
Fertilizer rate (FR)	NS	NS	NS	NS	NS	NS	NS	NS

[y] Each value is the mean of 10 individual seedlings within each species and fertilizer.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Species	Fertilizer	Dry weights distribution (%)		
	(mg per L)	Root	Shoot	Leaf
MT2	25	29.5y	60.2	10.6
	100	30.9	55.8	13.3
	Avg.	30.2	58.0	11.9
MT3	25	21.9	65.5	12.6
	100	26.8	58.2	14.9
	Avg.	24.3	61.8	13.7
AS2	25	31.2	41.8	27.0
	100	27.2	44.5	28.3
	Avg.	29.2	43.1	27.6
ANOVA		P > F - Value		

Continued

Table 4.3. Distribution of root, shoot, and leaf dry weights for *Malus trilobata* sources and *Acer syriacum* seedlings grown under low or high (25 or 100 mg N L^{-1}) fertilizer treatments.

Table 4.3 continued

Malus trilobata			
Source (S)	NS[Z]	NS	NS
Fertilizer rate (FR)	NS	NS	*
S*FR	NS	NS	NS
Acer syriacum			
Fertilizer rate (FR)	NS	NS	NS

[y] Each value is the mean of 10 individual seedlings within each species and fertilizer.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Species	Fertilizer (mg per L)	LAR (g cm^{-2})	NAR (g cm^{-2} day^{-1} x 10^{-3})	RGR (g g^{-1} day^{-1} x 10^{-3})
MT2	25	7.2 [y]	3.7	25.7
	100	10.5	2.5	23.5
	Avg.	8.8	3.1	24.6
MT3	25	8.6	2.2	17.4
	100	9.7	1.4	12.5
	Avg.	9.1	1.8	14.9

Continued

Table 4.4. Leaf area ratio, net assimilation rate, and relative growth rate of *Malus trilobata* sources and *Acer syriacum* seedlings grown under low or high (25 or 100 mg N L^{-1}) fertilizer treatments.

Table 4.4 continued

AS2	25	25.7	0.8	20.3
	100	27.7	0.7	19.0
	Avg.	26.7	0.7	19.6

ANOVA		P > F - Value	
Malus trilobata			
Source (S)	NS [z]	**	**
Fertilizer rate (FR)	*	**	**
S* FR	NS	NS	*
Acer syriacum			
Fertilizer rate (FR)	NS	NS	NS

[y] Each value is the mean of 10 individual seedlings within each source and fertilizer.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Source	Fertilizer rate[x] (mg per L)	Nitrogen concentration (%) leaf	shoot	root	total plant	Nitrogen content (g) leaf	shoot	root	total plant	Nitrogen distribution (%) leaf	shoot	root
MT 2	25	2.16[y]	0.71	1.09	0.98	0.45	1.00	0.94	2.40	19	42	39
	100	2.32	1.13	1.49	1.41	0.51	1.06	0.75	2.32	22	46	32
MT 3	25	2.05	0.73	1.16	1.02	0.57	0.92	0.57	2.06	28	45	27
	100	2.27	0.90	1.49	1.26	0.80	1.10	0.63	2.53	32	43	25

Continued

Table 4.5. Nitrogen concentration and content, in leaf, shoot, root, and total plant tissues and nitrogen distribution in leaf, shoot and root tissues as percent of total plant N content of *Malus trilobata* and *Acer syriacum* grown under two fertilizer rates.

Table 4.5 continued

AS 2	25	1.29	0.83	1.39	1.09	0.46	0.50	0.38	1.35	34	37	28
	100	1.68	0.83	1.30	1.22	0.38	0.26	0.35	1.00	38	27	35
ANOVA						P > F - Value						
Malus trilobata												
Source (S)		NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer rate (FR)		NS	NS	*	*	NS	NS	NS	NS	NS	NS	NS
S* FR		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Continued

Table 4.5 continued

Acer syriacum

Fertilizer rate (FR)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[x] Plants under the low fertilizer rate (25 mg N L^{-1}) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high fertilizer rate (100 mg N L^{-1}) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the water soluble fertilizer and Comtil. Plants were fertilized with 21 N - 3.1 P- 5.1 K between 12 May and 24 September.

[Y] Each value is the mean of three plants for each source and fertilizer rate.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \le 0.05$ and $\alpha \le 0.01$ level, respectively.

Source	Fertilizer rate[x] (mg per L)	Phosphorus concentration (ug/g) leaf	shoot	root	total plant	Phosphorus content (g) leaf	shoot	root	total plant	Phosphorus distribution (%) leaf	shoot	root
MT 2	25	2056[y]	964	2341	1634	0.04	0.13	0.25	0.42	9	31	60
	100	2169	1400	2383	1822	0.05	0.13	0.13	0.30	17	42	42
MT 3	25	1894	995	1954	1354	0.05	0.13	0.10	0.28	18	46	36
	100	2175	1178	2511	1639	0.07	0.14	0.11	0.32	22	44	34
AS 2	25	1408	1922	3375	2102	0.05	0.12	0.10	0.26	19	44	37
	100	1829	2002	4403	2740	0.04	0.06	0.12	0.22	18	29	53

Continued

Table 4.6. Phosphorus concentration and content, in leaf, shoot, root, and total plant tissues and P distribution in leaf, shoot and root tissues as percent of total plant P content of *Malus trilobata* and *Acer syriacum* grown under two fertilizer rates.

Table 4.6 continued

ANOVA	P > F - Value										
Malus trilobata											
Source (S)	NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer rate (FR)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S* FR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Acer syriacum											
Fertilizer rate (FR)	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*

Continued

Continued

Table 4.6 continued

[x] Plants under the low fertilizer rate (25 mg N L^{-1}) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high fertilizer rate (100 mg N L^{-1}) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the water soluble fertilizer and Comtil. Plants were fertilized with 21 N - 3.1 P- 5.1 K between 12 May and 24 September.

[Y] Each value is the mean of three plants for each source and fertilizer rate.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \le 0.05$ and $\alpha \le 0.01$ level, respectively.

Source	Fertilizer rate[x] (mg per L)	Potassium concentration (ug/g) leaf	shoot	root	total plant	Potassium content (g) leaf	shoot	root	total plant	Potassium distribution (%) leaf	shoot	root
MT 2	25	17064[y]	11883	9698	12143	0.35	1.66	0.84	2.85	12	58	30
	100	17130	8835	10242	10561	0.37	0.72	0.55	1.64	23	44	33
MT 3	25	15984	1225	9425	12072	0.45	1.56	0.47	2.48	18	63	19
	100	17425	11736	11537	12722	0.57	1.37	0.52	2.47	23	56	21
AS 2	25	10422	13746	15298	13367	0.37	0.84	0.46	1.67	22	50	27
	100	10043	13798	17620	13920	0.22	0.42	0.47	1.11	20	38	42

Continued

Table 4.7. Potassium concentration and content, in leaf, shoot, root, and total plant tissues and K distribution in leaf, shoot and root tissues as percent of total plant K content of *Malus trilobata* and *Acer syriacum* sources grown under two fertilizer rates.

Table 4.7 continued

ANOVA	P > F - Value										
Malus trilobata											
Source (S)	NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer rate (FR)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S* FR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Acer syriacum											
Fertilizer rate (NFR)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[x] Plants under the low fertilizer rate (25 mg N L^{-1}) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high fertilizer rate (100 mg N L^{-1}) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the water soluble fertilizer and Comtil. Plants were fertilized with 21 N - 3.1 P- 5.1 K between 12 May and 24 September.

[Y] Each value is the mean of three plants for each source and fertilizer rate.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

Fertilizer	Water soluble fertilizer			Comtil			Total		
(mg per L)	N	P	K	N	P	K	N	P	K
25	3.3	0.5	0.8	18.0	39.8	9.9	21.3	40.3	10.8
100	13.3	2.0	3.2	18.0	39.8	9.9	31.3	41.8	13.2

Table 4.8. Grams of N, P and K applied between May and September by 21-3.1 P- 5.9 K (21-7-7) Peters Water Soluble Fertilizer and Comtil.

Source	Fertilizer rate[x]	Mineral nutrient uptake (g)			Mineral nutrient use efficiency (%)		
	(mg per L)	N	P	K	N	P	K
MT 2	25	2.24[y]	0.41	2.42	10	2	45
	100	2.17	0.29	1.21	7	1	18
MT 3	25	1.78	0.25	2.20	8	1	38
	100	2.26	0.29	2.19	7	1	27
AS 2	25	1.13	0.24	1.40	5	1	24
	100	0.77	0.20	0.84	2	1	11

Continued

Table 4.9. Nitrogen, P and K uptake and mineral nutrient use efficiency for *Malus trilobata* and *Acer syriacum* grown under two fertility rates.

Table 4.9 continued

ANOVA	P > F - Value					
Malus trilobata						
Source (S)	NS[z]	NS	NS	NS	NS	NS
Fertilizer rate (FR)	NS	NS	NS	NS	NS	**
S* FR	NS	NS	NS	NS	NS	NS

Continued

Table 4.9 continued

Acer syriacum						
Fertilizer rate (FR)	NS	NS	NS	NS	NS	NS

[x] Plants under the low fertilizer rate (25 mg N L^{-1}) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high fertilizer rate (100 mg N L^{-1}) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the water soluble fertilizer and Comtil. Plants were fertilized with 21 N - 3.1 P- 5.1 K between 12 May and 24 September.

[Y] Each value is the mean of three plants for each source and fertilizer rate.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ level, respectively.

		Ratio		
Source	Fertilizer rate[y] (mg N L^{-1})	N	P	K
MT 2	25	5.7[z]	1	6.8
	100	7.7	1	5.5
MT 3	25	7.3	1	8.8
	100	7.9	1	7.7
AS 2	25	5.2	1	6.1
	100	4.5	1	5.0

Table 4.10. Whole plant N-P-K ratios (expressed relative to P) of *Malus trilobata and Acer syriacum* plants from different sources grown under two fertilizer treatments.

[y] Plants under the low fertilizer rate (25 mg N L^{-1}) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high fertilizer rate (100 mg N L^{-1}) received 31.3, 41.8, and 13.2 g N, P, and K respectively. Plants were fertilized with 21 N - 3.1 P- 5.1 K between 12 May and 24 September.

[z] Each value is the mean of 10 plants per source and fertilizer treatment.

Species	Fertilizer rate (mg per L)	Application time	Medium	Reference
Pyrus calleryana	300	weekly	5:1 pine bark:sandy clay soil	Gilliam *et al.* 1984
Acer rubrum	150, 300	weekly	4:1 pine bark:sand	Giliam *et al.* 1980
	200-400	daily	3:1:1 pine bark:peat:sand	Larimer and Struve, 2002
Most conifers	100-150	not specified	not specified	Jull et al. 1994
Betula verrucosa	25	not specified	not specified	Ingestad, 1979

Continued

Table 4.11. Summary of selected recommended N fertilizer rates for some woody ornamentals grown in container production systems.

Table 4.11 continued

Cryptomeria japonica	25	3 times/ week	not specified	Jull *et al.* 1994
Cupressus arizonica var. glabra	20	daily	calcined clay	Stubbs *et al.* 1997
Tilia cordata	100	daily	2:1 calcined clay:peat	Wright and Niemiera, 1987
Acer platanoides	100	daily	2:1 calcined clay:peat	Wright and Niemiera, 1987
Ilex crenata	75	daily	sand culture	Wright and Niemiera, 1987
Pyracantha coccinea	50	daily	sand culture	Wright and Niemiera, 1987
Cotoneaster dammeri	50	daily	sand culture	Wright and Niemiera, 1987
Weigela florida	50	daily	sand culture	Wright and Niemiera, 1987

Continued

Table 4.11 continued

Acer, Pyrus species	300	weekly	mostly pine bark	Wright and Niemiera, 1987
Quercus rubra	400	daily	3:1:1 pine bark:peat:sand	Larimer and Struve, 2002
Thuja occidentalis	200	not specified	not specified	Lumis *et al.* 2000
Buxus sinica var insularis	100-125	daily	Pine bark	Musselwhite *et al.* 2004

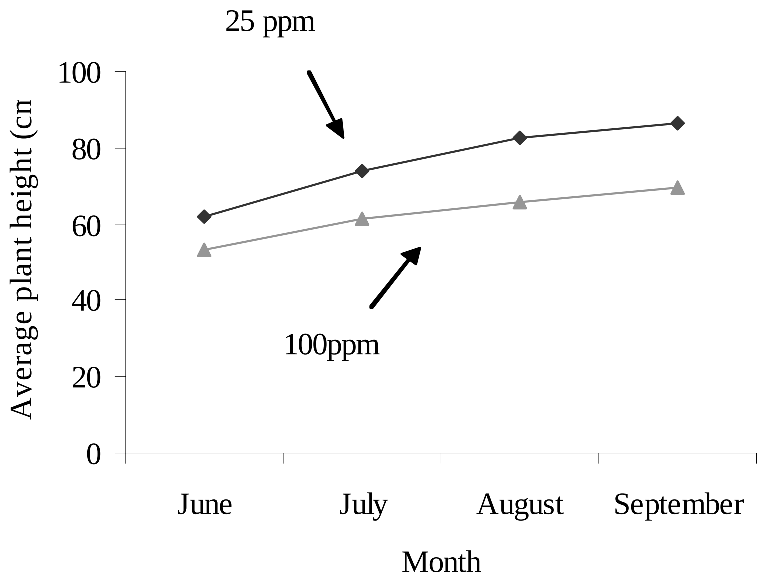

Fig. 4.1. Height of container-grown *Acer syriacum* under 25 or 100 mg N L^{-1} fertilizer.

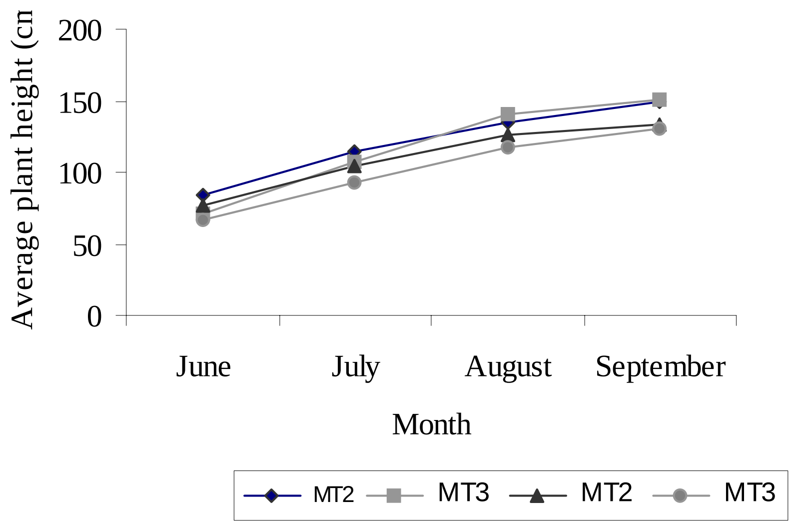

Fig.4.2. Height of container-grown *Malus trilobata* (MT2 and MT3) under 25 (Fig. A) or 100 mg N L^{-1} (Fig. B) fertilizer.

CHAPTER 5

Cercis siliquastrum, *Malus trilobata* and *Acer syriacum* water use as affected by two fertilizer rates[1]

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5.1 Abstract

Since the end of the civil war in Lebanon, there has been an increased demand for landscaping plants as a result of numerous reconstruction projects. Lebanon's Mediterranean dry summer climate has created demand for landscape plants with low water requirement. Thus, we studied water use of container-grown plants and the impact of fertilization on water use in the following native Lebanese species: *Cercis siliquastrum* (L.), *Malus trilobata* (Schneid) and *Acer syriacum* (Boin and Gaill). Two-year old seedlings planted in # 3 containers (11 L) were grown on an outdoor gravel pad and randomly assigned to either 25 or100 mg per L of 21-3.1 P- 5.9 K (21-7-7) Peters Water Soluble Fertilizer. Water use estimates were made by saturating the containers early in the morning, allowing them to drain for one hour, weighing them and re-weighing approximately five hours later. For all species, seedlings at the low fertilizer rate used more water per cm height than plants grown at the high fertilizer rate. In addition, there were differences in water use among and within seed sources of *Cercis siliquastrum* and *Malus trilobata*. Differences as great as 50 % were seen in *Cercis siliquastrum* per cm height per hour and 14 % in *Malus trilobata*. Water use efficient plants were selected from each species and will be asexually propagated to confirm water use efficiency. Water use efficient plants will reduce irrigation cost in nurseries or maintenance costs in a landscape.

Index words: Judas tree, three lobed apple tree, syrian maple, apple tree, Lebanese flora, container production, woody ornamentals, water use efficiency.

5.2 Introduction

Nitrogen and water are considered the most limiting factors for plant survival and growth (Dickmann *et al.* 1992; Wright *et al.* 1983). Drought and urban expansion are causing limitation in the water available to nurseries (Knox, 1989). Using water efficient plants will reduce the production cost for nurserymen and maintenance costs of these plants when used in landscaping projects. To reduce irrigation cost and runoff, irrigation should only supply the amount of water used by the plant. The Mediterranean climate is characterized by a hot, dry summer season and the demand for landscape plants with a low water requirement is increasing (Garcia-Navarro *et al.* 2004). In Lebanon, most (80-90 %) of the annual rainfall occurs between November and March and less than 5 % between May and September. Thus, there is a need to grow plants that require lower amounts of water for growth. However, few studies have been made on the water use of container-grown plants and the impact of fertilization on water use (Burger *et al.* 1987 and Knox, 1989). The plants selected for this study were: *Malus trilobata*, *Cercis siliquastrum* and *Acer syriacum.*

Malus trilobata (Schneid) belongs to the family Rosaceae. It is an erect tree about 13m tall with linear horizontal branches. The leaves are three-lobed and maple-like and are attractively tinted from orange to red to deep purple in autumn. Hillier and Sons, (1973) reported the tree distribution in Eastern Mediterranean Region, and North East Greece adding that the species is comparatively rare and very distinct; however, Mouterde (1966) reported the species as being present only in Lebanon and rare. It is found in the Supramediterranean zone, at an altitude of 1000-1500 m in Lebanon along with other species such as *Ostrya, Sorbus, Fraxinus, Abies*.

Cercis siliquastrum L., "Judas tree", belongs to the family Cesalpinaceae. It is a medium height tree between 5-10 m. Its trunk is purple when young becoming gray-pink as it ages. The flowering period is March to April. Its flowers are pink and is considered an ornamental species because of its flowers and leaves. It is widely distributed in the Thermomediterranean zone (0-500 m altitude) and can be found up to 800 m altitude where it is associated with pine and oak forests. *Cercis siliquastrum,* like other redbud species, is reported to grow well in a variety of soil textures but best in soils where the pH is above 7.5 (USDA, 1990). Redbud species tend to be tolerant to nutrient deficient sites (USDA, 1990).

Acer syriacum (Boin and Gaill), belongs to the family Aceraceae. It reaches 8 m height with evergreen leaves. In Lebanon, it grows in the Thermomeditearranean zone (0-500 m altitude) and flowers between February and March. It produces inconspicuous white to yellow flowers, and has divergent samaras. The leaves are three-lobed, and turn yellow to purple color in Fall. It is indifferent to soil type but mainly found in calcareous soils (Anonymous,1999). It is distributed in the following countries: Syria, Lebanon, Cyprus, and Palestine.

The aim of this study was to study the effect of two fertilizer rates on water use of six sources of *Cercis siliquastrum*, two of *Malus trilobata* and one of *Acer syriacum* in container production during one growing season in Ohio and to identify water use efficient individuals within each species for asexual propagation and further testing.

5.3 Materials and Methods

The plant material was obtained by germinating seeds collected in Lebanon. *Cercis siliquastrum* pods were picked by hand in mid-August 2001, spread to dry in full sun for a few days before being manually opened and the seeds extracted. *Malus trilobata* fruits were cut using a knife and the seeds extracted by hand. *Acer syriacum* samaras wings were picked by hand. Ollowing dormancy breaking treatments, seedlings were immediately transplanted into 250-XL plastic containers (Nursery Supplies, Fairless Hills, PA) using MetroMix® 360 (Sun-Gro, Vancouver, British Columbia, Canada) substrate and placed in a heated greenhouse under natural photoperiods. The greenhouse temperatures were set at 22/ 21C (71.5/ 70.6F D/N). The relative humidity averaged 46.6 ± 2 %. Plants were watered as needed to avoid water stress. When seedlings developed two true leaves, they were fertilized once per week with 100 mg N per L of 20N- 8.3P- 4.6K (20-10-10, Peters water-soluble fertilizer O.M. Scotts Company, Marysville, OH). Plants were overwintered (from November to May) in a minimum heat (> 2 C / 35.6 F) polyhouse.

Twenty-four months later, (May, 2004), the plants were removed from the containers, root pruned, transplanted into #3- Spin-Out ®treated containers (1200 Classic, Nursery Supplies, Fairless Hills, PA) using a 3 pine bark:1 Comtil (composted municipal sewage sludge, City of Columbus), by volume substrate and moved to an outdoor gravel pad. The most vigorous shoot was trained into a central leader by tying it to a 2 m bamboo stake. The plants were placed on 45.7 cm (18 inches) within row spacing and 2 m (6 ft) between row spacing.

Half of the plants from each source were randomly assigned to one of two N fertility programs: 25 mg per L or 100 mg N per L from 21 N- 3.1 P - 5.9 K (21-7-7, Peters Water Soluble Fertilizer O.M. Scotts Company, Marysville, OH) applied at 0.5 L in each of two daily irrigation cycles (1 L total per day). The fertility treatments were initiated on 1 June and terminated on 20 September. Plants within a fertility treatment were arranged in a randomized complete block design with eight replications, and five plants per replication, species source and fertilizer rate.

Monthly during the study, individual plant water use was determined by saturating the containers early in the morning, allowing them to drain for one hour and approximately five hours later the plants were re-weighed. Plants were weighed using an ES 100 L balance, Ohaus®, New Jersey, USA . Water use was estimated by the difference between saturated weight and the weight five hours later. Hourly water use was determined by dividing the weight difference by the time between weighing. Also, at each water use determination, plant heights were measured on all plants. Water use was expressed as g H_2O per hour and as height-adjusted water use, g H_2O per cm height per hour.

For selecting the most water use efficient plants, g H_2O per cm height per hour was plotted against plant height. The tallest plants with the lowest water use per cm height were selected as efficient water use plants.

Water use and height data were analyzed using One-way ANOVA and GLM within SPSS (SPSS Institute, Chicago, IL) using a fixed effect model with eight replications. Equations describing adjusted water use (g per cm height per hour) during the season were developed using linear regression within SigmaPlot (Version 9.0).

5.4 Results

Weather data recorded for the dates when containers were weighed, was presented in Table 5.1. During the water use period, temperatures ranged from 8 to 29° C throughout the growing season (Table 5.1). All water use assessments were conducted during periods of low cloud cover.

Cercis siliquastrum

There were no significant source by fertilizer rate interaction for height, water use per seedling per hour and height-adjusted water use in June, July, August and September (Tables 1 and 2).

Growth of these species is described in details in Zahreddine et al. 2006 A & B; height growth data is also presented here to facilitate presentation of height-adjusted water use data. Plants grown at the low fertilizer rate were taller than those grown at the high fertilizer rate in June (84 vs 80 cm, respectively), July (103 vs 93 cm, respectively), August (115 vs 102 cm, respectively) and September (120 vs 104 cm, respectively, Table 5.2). Fertilizer rate affected water use per seedling per hour in June (0.056 g vs 0.023 g per seedling per hour at the low and the high fertilizer rates respectively, and July (0.118 g vs 0.096 g per seedling per hour at the low and high fertilizer rates respectively, Table 5.2). Fertilizer rates affected height-adjusted water use per cm height per hour in June (0.0007 g vs 0.0003 g per seedling per hour at the low and high fertilizer rates respectively, Table 5.2), July (0.0012 g vs 0.0011 g per seedling per hour at the low and high fertilizer rates respectively, Table 5.2) and August (0.0008 g vs 0.0010 g per seedling per hour at the low and high fertilizer rates respectively, $P < 0.001$, Figs.1 A and B, Table 5.3).

Seed source affected height in June, July, August and September. Plants from source CS1 grew the tallest than other sources in June, July, August and September (Table 5.2). On the other hand, seed source affected water use per seedling per hour and height-adjusted water use only in July (Tables 2 and 3). When averaged over fertilizer levels and over the study period, water use per seedling per hour and height-adjusted water use were highest in CS1, CS2 and CS6 and lowest for CS 4 (Tables2 and 3).

Malus trilobata

There were no significant differences in height due to source by fertilizer rate interactions. However there were significant differences due to source by fertilizer rate interactions in water use per seedling per hour in July and August, and in height-adjusted water use in June (Tables 4 and 5).

Fertilizer rates affected height in July, August and September (Table 5.4). Plants at the low fertilizer rate grew taller than those at the high fertilizer rate in July (111 vs 98 cm, respectively), August (137 vs 121 cm, respectively), and September (153 vs 134 cm, respectively, Table 5.4).

Seed source affected plant height in June (Table 5.4). When averaged over fertilizer rates, MT2 plants grew taller than MT3 plants in June (77 vs 68 cm, respectively). Seed source affected water use per seedling per hour in September (Table 5.4); when averaged over fertilizer rates, MT2 plants used more water than MT3 plants (0.058 vs 0.054 g per seedling per hr, respectively, Table 5.4). Seed source affected height-adjusted water use in July (Table 5). Averaged over fertilizer rates, MT2 plants used more water than MT3 plants (0.0007 vs 0.0006 g per cm height per hr, respectively, Table 5).

Acer syriacum

Fertilizer rates affected plant height in June, July, August and September. Plants at the low fertilizer rate grew taller than plants at the high fertilizer rate in June (62 vs 53 cm respectively), July (74 vs 61 cm, respectively), August (83 vs 66 cm, respectively) and September (87 vs 70 cm, respectively, Table 5.4). Fertilizer rates affected water use per seedling per hour and height-adjusted water use in June and July (Fig.3, Table 5.4). Plants at the low fertilizer rate used more water than plants at the high fertilizer rate in June (0.0003 vs 0.0002 g per cm height per hr, respectively) and July (0.0011 vs 0.0008 g per cm height per hr, respectively).

5.5 Discussion

There were no significant source by fertilizer rate interaction for height, water use per seedling and adjusted water use in *Cercis siliquastrum* (Tables 1 and 2), however there were significant source by fertilizer rate interactions for the water use per seedling in July and August and for the adjusted water use of *Malus trilobata* in June (Tables 3 and 4). MT2 plants used more water per cm height per hour than MT3 plants at the low fertilizer rate but used less water than MT3 at the high fertilizer rate. On the other hand, MT3 plants used same amount of water per cm height per hour regardless of fertilizer rate (Table 5.4).

The hypothesis that fertilizer rates affect water use and adjusted water use was true for *Cercis siliquastrum, Malus trilobata* and *Acer syriacum* although this was not applicable for every month during the study period. Plants from all three species grown at the low fertilizer rate used more water than those grown at the high fertilizer rate. In fact, plants at the low fertilizer rate were taller than those at the high fertilizer rate in June through September for *Cercis siliquastrum* and *Acer syriacum* and in July through September for *Malus trilobata*. Previous plants of *Cercis siliquastrum* from these six sources and *Malus trilobata* from both sources at the low fertilizer rate were taller and had greater total plant dry weights than plants grown at the high fertilizer rate (Chapters 4 and 5). Estimated daily water use of *Cercis siliquastrum* averaged over six sources was 591, 1547, 1282 and 730 mg per day, in June, July, August and September, respectively. Twenty-month water use averages for *Cercis occidentalis* grown in 15.6 L containers were 350 and 184 mg per day in Davis and Riverside, respectively (Schuch and Burger, 1997). It is worth noting that the estimated daily water use numbers calculated are likely high because water use recorded during the five peak hours of sun light (later divided by five to get the water use per hour) was used to estimate daily water use. Estimated daily water use of *Malus trilobata* was lower than that of *Cercis siliquastrum* and it averaged 370, 1030, 1220 and 684 mg per day in June, July, August and September, respectively. Estimated daily water use of *Acer syriacum* was 210, 990, 1086 and 856 mg per day in June, July, August and September, respectively, and was lower than that of *Malus trilobata* during the first 3 months of the study. No previous studies have been made on water use of container or field grown *Cercis siliquastrum*, *Malus trilobata* and *Acer syriacum*.

The second hypothesis that source differences in adjusted water use of *Cercis siliquastrum* and *Malus trilobata* exist was true. It is not surprising that *Cercis siliquastrum* sources (CS1, CS2, and CS6) and MT2 plants (the tallest sources) (Chapters 4 and 5), used more water compared to other shorter sources (CS4 and MT3). Although similar fertilizer rates did not affect growth of *Acer syriacum* (Chapter 5), in this study plants grown at the low fertilizer rate used more water per seedling and per cm height than those grown at the high fertilizer rate (Tables 3 and 4).

We defined water use efficient plants as plants which were among the tallest and used the least amount of water per seedling and per cm height. Selection of water use efficient plants was from plants grown under the low fertilizer rate since these plants used more water than those at the high fertilizer rate only in June in *Malus trilobata* and in June and July in *Cercis siliquastrum*. In *Acer syriacum*, selection of water use efficient plants was made from plants that were grown under the low fertilizer rate since these plants grew the tallest although they used more water per cm height than plants grown at the high fertilizer rate in June and July. Water use efficient plants (marked with arrows in Figs. 4 through 12), are being asexually propagated so that clonal studies can confirm water use efficiency. Asexual propagation of water use efficient plants from all species is ongoing and future water use experiments will be carried on the asexually propagated seedlings.

Different methods for collecting leachate volume and measuring retained water (Knox, 1989; Roberts and Schnipke, 1987; Fitzpatrick, 1983) have been used to measure plant water use. Other studies used crop coefficients (K_c) to classify plants into moderate, light or heavy water users (Burger *et al.* 1989 and Burger *et al.* 1987) . K_c crop coefficients are used to compare water use of crops to that of a reference crop ET, usually turf for woody plant purposes (Schuch and Burger, 1997; Costello *et al.* 1993, Regan, 1994, Burger *et al.* 1987). These coefficients help determine when to irrigate and how much water to apply to a particular crop. We calculated K_c values based on the formula used by Schuch and Burger (1997). We obtained a value for *Cercis siliquastrum* that was one tenth and one fifth of K_c values reported by Schuch and Burger (1997) for *Cercis occidentalis* in Davis and Riverside, respectively. Crop coefficients were first developed for agronomic crops with uniform canopies and have not been determined for most woody landscape plants (Regan, 1991 and Costello *et al.* 1993). Thus, there are some disadvantages using this method: K_c values are affected by site-specific environmental conditions such as wind speed, solar radiation, air temperature and air vapor density. Further, K_c have to be calculated for individual species or cultivars, stage of development, growth rate, planting date, the length of the growing season, irrigation frequency, pruning, size of beds, and container spacing (Schuch and Burger, 1997, Anonymous, 2001; Regan, 1991). The coefficients for container plants tend to be higher than those recorded for field values (Burger *et al.* 1987 and Schuch and Burger, 1997). Also, changes of K_c values in field crops are often proportional to canopy coverage, however in container crops, container surface area is not correlated to the canopy coverage. Allowances are not made for the change in canopy in K_c calculations in container crops. Another disadvantage is that some crop coefficients are developed using grass as the reference crop whereas others used alfalfa instead, which leads to lower K_c values (Anonymous, 2001).

5.6 Conclusion

Plants of *Cercis siliquastrum*, *Malus trilobata* and *Acer syriacum*, grown at the low fertilizer rate used more water than those at the high fertilizer rate during the beginning of the study, due to larger size than those grown at higher fertilizer rates. There were source differences in water use of *Cercis siliquastrum* and *Malus trilobata*. CS1, CS2, CS6 and MT2 were the tallest and used the most water. Water use efficient plants from each species and source were selected and their asexual propagation is underway. Future experiments will be planned to determine the relationship between water use efficiency and drought tolerance.

Fig.5.1. Average adjusted water use of *Cercis siliquastrum* under 25 (Fig. A) or 100 mg per L N (Fig. B) fertilizer. Each value is the mean of thirty plants per fertilizer rate. Plants were fertilized with 21-7-7 Peters Water Soluble Fertilizer. Height-adjusted water use of CS1 plants at 25 mg N per L (Fig. A) is predicted by the equation: WU = - 0.0542 + 0.0006 X - 0.000001 X^2, R^2 = 0.816, P = 0.0055; for CS2: WU = - 0.0319 + 0.0004 X - 0.0000009 X^2, R^2 = 0.467, P = 0.454; for CS3 plants: WU = - 0.0607 + 0.0006 X - 0.000001 X^2, R^2 = 0.644, P < 0.0001. For CS4 plants: WU = - 0.050 + 0.0005 X- 0.000001 X^2, R^2 = 0.776, P = 0.002; for CS5 plants: WU = - 0.0616 + 0.0006 X - 0.000002 X^2, R^2 = 0.818, P = 0.044 for CS6 plants, WU = - 0.0127 + 0.0002 X - 0.0000004 X^2, R^2 = 0.302, P = 0.884.

Height-adjusted water use of CS1 plants at 100 mg N per L (Fig. B) is predicted by the equation: WU = - 0.086 + 0.0008 X - 0.000002 X^2, R^2 = 0.767, P < 0.0001; for CS2: WU = - 0.086 + 0.0008 X - 0.000002 X^2, R^2 = 0.755, P < 0.0001; for CS3 plants: WU = - 0.0964 + 0.0009 X - 0.000002 X^2, R^2 = 0.605, P < 0.0001. For CS4 plants: WU = - 0.051+ 0.0005 X - 0.000001 X^2, R^2 = 0.565, P = 0.0017; for CS5 plants: WU = - 0.089 + 0.0009 X- 0.000002 X^2, R^2 = 0.594, P < 0.0001 for CS6 plants, WU = - 0.0842 + 0.0008 X - 0.000002 X^2, R^2 = 0.702, P = 0.03; where in all the above equations, WU = water use (in g per cm height per hour) and X= Julian day between 174 and 260.

Fig. 5.2. Average hourly height-adjusted water use of *Malus trilobata* under 25 or 100 mg N per L fertilizer. Each value is the mean of twenty-six plants per fertilizer rate. Plants were fertilized with 21-7-7 Peters Water Soluble Fertilizer. Height-adjusted water use at 25 mg N per L is predicted by the equation:

WU for MT2 = - 0.0339 + 0.0004 X - 0.00000009 X^2, R^2 = 0.780, P = 0.034; WU for MT3 = -0.0366 + 0.0004 X - 0.0000008 X^2, R^2 = 0.789, P = 0.283.

Height-adjusted water use at 100 mg per L N is predicted by the equation: WU for MT2 = - 0.0574 + 0.0006 X-0.000001 X^2, R^2 = 0.648, P = 0.049; WU for MT3 = - 0.0533 + 0.0005 X- 0.000001 X^2, R^2 = 0.690, P = 0.011 where WU = water use (in g per cm per hr) and X = Julian day between 174 and 260.

Fig. 5.3. Average adjusted hourly water use of *Acer syriacum* under 25 or 100 mg N per L fertilizer. Each value is the mean of twenty-seven plants per fertilizer rate. Plants were fertilized with 21-7-7 Peters Water Soluble Fertilizer. Height-adjusted water use at 25 mg N per L is predicted by the equation: WU = - 0.0759 + 0.0007 X - 0.000002 X^2, R^2 = 0.804, P = 0.029. Height-adjusted water use at 100 mg N per L is predicted by the equation: WU = - 0.0790 + 0.0007 X- 0.000002 X^2, R^2 = 0.769, $P < 0.0001$, where WU = water use (in g per cm per hr) and X= Julian day between 174 and 260.

Fig.5.4. Plant height (cm) of source 1 *Cercis siliquastrum* plotted against height-adjusted water use (g cm $height^{-1}$ $hour^{-1}$ * 10^{-3}) on the left axis and against water use per seedling per hour (g $seedling^{-1}$ $hour^{-1}$) on the right axis. The arrow indicates a specific plant's water use per seedling and height-adjusted water use per cm height per hour.

Fig.5.5. Plant height (cm) of source 2 *Cercis siliquastrum* plotted against height-adjusted water use (g cm height^{-1} hour^{-1} * 10^{-3}) on the left axis and against water use per seedling per hour on the right axis. The arrow indicates a specific plant's water use per seedling and height-adjusted water use per cm height per hour.

Fig.5.6. Plant height (cm) of source 3 *Cercis siliquastrum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against height-adjusted water use (g seedling^{-1} hour^{-1}) on the right axis. The arrow indicates a specific plant's water use per seedling and height-adjusted water use per cm height per hour.

Fig.5.7. Plant height (cm) of source 4 *Cercis siliquastrum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis. The arrow indicates a specific plant's water use per seedling and height-adjusted water use per cm height per hour.

Fig.5.8. Plant height (cm) of source 5 *Cercis siliquastrum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis. The arrow indicates a specific plant's water use per seedling and height-adjusted water use per cm height per hour.

Fig.5.9. Plant height (cm) of source 6 *Cercis siliquastrum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis. The arrow indicates a specific plant's water use per seedling and height-adjusted water use per cm height per

hour.

Fig.5.10. Plant height (cm) of source 2 *Malus trilobata* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis. The arrow indicates a specific plant's water use per seedling and height-adjusted water use per cm height per hour.

Fig.5.11. Plant height (cm) of source 3 *Malus trilobata* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis. The arrow indicates a specific plant's water use per seedling and height-adjusted water use per cm height per hour.

Fig.5.12. Plant height (cm) of *Acer syriacum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis. The arrow indicates a specific plant's water use per seedling and height-adjusted water use per cm height per hour.

	For five hours				For the entire day			
	174[z]	202	230	260	174	202	230	260
Temperature (° C, Max)	24	29	29	22	26	30	31	25
Temperature (° C, Min)	22	21	21	8	20	18	18	7
Temperature (° C, Avg)	21	26	25	16	23	24	25	15
PAR (µmol/m^2/s, Max)	1773	3199	3085	3299	1924	3578	3085	3304
PAR (µmol/m^2/s, Min)	96	133	59	32	9	9	9	9
PAR (µmol/m^2/s, Avg)	697	1746	1618	1883	581	1135	1016	993
RH (%, Max)	94	84	94	93	96	87	100	96

Continued

Table 5.1. Weather data recorded for 5 hours (between 0800 and 1400 hours) and for the entire day during the growing season between June and September, 2004.

Table 5.1 continued

RH (%, Min)	83	51	61	40		77	48	49	28
RH (%, Avg)	88	65	81	61		91	66	82	64
Wind speed (Km/hr, Max)	16.7	7.4	24.1	13.0		16.0	21.0	35.0	13.0
Wind speed (Km/hr, Min)	5.6	5.6	9.3	5.6		5.6	5.6	5.6	5.6
Wind speed (Km/hr, Avg)	9.8	6.5	17.3	10.3		5.0	8.0	16.0	6.0

[z] Numbers refer to Julian calendar days170, 202, 230 and 160, for June, July, August and September, respectively .

		Height (cm)				Water use (g per seedling per hour)				Estimated daily water use (g per seedling per day)			
Species	Fertilizer[v]	174[w]	202	230	260	174	202	230	260	174	202	230	260
CS1	25	88[x]	110	122	128	0.060	0.130	0.096	0.052	0.900[y]	1.895	1.303	0.636
	100	87	102	114	118	0.022	0.122	0.098	0.062	0.330	1.779	1.331	0.758
	Avg.	87	106	118	123	0.040	0.126	0.096	0.056	0.601	1.837	1.303	0.685
CS2	25	83	100	111	114	0.066	0.130	0.088	0.078	0.991	1.895	1.195	0.954
	100	87	99	107	111	0.022	0.104	0.098	0.050	0.330	1.516	1.331	0.611

Continued

Table 5.2. Height, average hourly water use per seedling and estimated daily water use for *Cercis siliquastrum* of six sources grown under low or high (25 or 100 mg N per L) fertilizer rates at various Julian dates.

Table 5.2 continued

	Avg.	85	99	109	112	0.044	0.116	0.092	0.064	0.661	1.691	1.249	0.783
CS3	25	92	110	118	123	0.056	0.112	0.110	0.052	0.047	1.633	1.494	0.636
	100	82	90	99	101	0.022	0.094	0.112	0.058	0.330	1.370	1.521	0.709
	Avg.	87	100	108	112	0.038	0.102	0.110	0.054	0.571	1.487	1.494	0.660
CS4	25	89	106	118	123	0.052	0.102	0.088	0.042	0.781	1.487	1.195	0.514
	100	76	87	93	96	0.020	0.064	0.076	0.056	0.300	0.933	1.032	0.685
	Avg.	82	96	105	109	0.036	0.082	0.082	0.048	0.541	1.196	1.113	0.587
CS5	25	77	94	109	112	0.048	0.122	0.086	0.046	0.71	1.779	1.168	0.563
	100	78	89	98	97	0.024	0.088	0.112	0.050	0.360	1.283	1.521	0.611
	Avg.	77	91	103	104	0.036	0.104	0.098	0.048	0.541	1.412	1.31	0.587

Continued

Table 5.2 continued

CS6	25	76	96	113	120	0.054	0.114	0.092	0.130	0.811	1.662	1.249	1.590
	100	72	90	99	103	0.030	0.104	0.090	0.048	0.450	1.516	1.222	0.587
	Avg.	74	93	106	111	0.042	0.114	0.090	0.088	0.631	1.662	1.222	1.076
ANOVA						P > F - Value							
Source (S)		**[z]	**	*	**	NS	**	NS	NS	NS	**	NS	NS
Fertilizer rate (FR)		*	**	**	**	**	**	NS	NS	**	**	NS	NS
S* FR		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Continued

Table 5.2 continued

[V] Plants under the low fertilizer rate (25 mg N per L) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high fertilizer rate (100 mg N per L) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the fertilizer and Comtil compost. Plants were fertilized with 21 N - 3.1 P- 5.1 K between 1 June and 20 September.

[W] 170, 202, 230 and 160 refer to Julian calendar days when water use readings were recorded in June, July, August and September, respectively.

[X] Means within a seed source and fertilizer rate are the average of thirty plants.

[Y] Numbers were obtained by multiplying water use per seedling per hour by the day length of the day when water use readings were taken. Day lengths were 15 hrs 1 min for June, 14 hrs 35 min for July, 13 hrs 35 min for August and 12 hrs 14 min for September.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha = 0.05$ and $\alpha = 0.01$ level, respectively.

		Height-adjusted water use (g per cm height per hr)			
Species	Fertilizer[x]	June	July	August	September
CS1	25	0.0007[Y]	0.0012	0.0008	0.0004
	100	0.0003	0.0012	0.0009	0.0005
	Avg.	0.0005	0.0012	0.0008	0.0004
CS2	25	0.0008	0.0013	0.0008	0.0007
	100	0.0003	0.0011	0.0009	0.0005
	Avg.	0.0005	0.0012	0.0008	0.0006
CS3	25	0.0006	0.0010	0.0010	0.0004
	100	0.0003	0.0011	0.0012	0.0006
	Avg.	0.0004	0.0010	0.0011	0.0005
CS4	25	0.0006	0.0010	0.0008	0.0004
	100	0.0003	0.0007	0.0008	0.0006
	Avg.	0.0004	0.0008	0.0008	0.0005
CS5	25	0.0006	0.0013	0.0007	0.0004

Continued

Table 5.3. Average hourly water use per cm plant height over between 0800 and 1400 hours for *Cercis silquastrum* of six sources grown under low or high (25 or 100 mg N per L) fertilizer rates.

Table 5.3 continued

	100	0.0003	0.0010	0.0012	0.0006
	Avg.	0.0004	0.0011	0.0009	0.0005
CS6	25	0.0007	0.0012	0.0008	0.0010
	100	0.0005	0.0013	0.0009	0.0004
	Avg.	0.0006	0.0012	0.0008	0.0007
ANOVA			P > F - Value		
Source (S)		NS[z]	**	NS	NS
Fertilizer rate (FR)		**	*	*	NS
S* FR		NS	NS	NS	NS

[x] Plants under the low fertilizer rate (25 mg N per L) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high fertilizer rate (100 mg N per L) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the fertilizer and Comtil compost. Plants were fertilized with 21 N - 3.1 P- 5.1 K between 1 June and 20 September.

[y] Means within a seed source and fertilizer rate are the average of thirty plants.

[z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha = 0.05$ and $\alpha = 0.01$ level, respectively.

		Height (cm)				Water use (g per seedling per hour)				Estimated daily water use (g per seedling per day)			
Species	Fertilizer[V]	174[W]	202	230	260	174	202	230	260	174	202	230	260
MT2	25	84[X]	114	135	149	0.044	0.084	0.090	0.054	0.661[Y]	1.225	1.222	0.660
	100	71	104	126	137	0.016	0.084	0.092	0.064	0.240	1.225	1.249	0.783
	Avg.	77	109	130	143	0.030	0.084	0.090	0.058	0.450	1.225	1.222	0.709
MT3	25	71	108	140	158	0.024	0.062	0.092	0.060	0.360	0.904	1.249	0.734
	100	66	93	117	131	0.016	0.054	0.090	0.048	0.240	0.787	1.222	0.587

Continued

Table 5.4. Height, average hourly water use per seedling and estimated daily water use for two mother trees of *Malus trilobata* and *Acer syriacum* grown under low or high (25 or 100 mg N per L) fertilizer rates at various Julian dates.

Table 5.4 continued

	Avg.	68	100	128	144	0.020	0.058	0.090	0.054	0.300	0.846	1.222	0.660
AS	25	62	74	83	87	0.020	0.084	0.084	0.088	0.300	1.225	1.141	1.076
	100	53	61	66	70	0.010	0.052	0.076	0.054	0.150	0.758	1.032	0.660
	Avg.	57	67	74	78	0.014	0.068	0.080	0.070	0.210	0.99	1.086	0.856
Malus trilobata													
Source (S)		**[Z]	NS	NS	NS	NS	NS	**	*	NS	NS	**	*
Fertilizer rate (FR)		NS	*	*	**	NS	**	**	**	NS	**	**	**
S* FR		NS	NS	NS	NS	NS	**	**	NS	NS	**	**	NS

Continued

Table 5.4 continued

Acer syriacum

Fertilizer rate (FR)	**	**	**	**	**	**	NS	NS	**	**	NS	NS

[v] Plants under the low N treatment (25 mg N per L) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high N treatment (100 mg N per L) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the fertilizer and Comtil compost. Plants were fertilized with 21 N - 3.1 P- 5.1 K between 12 May and 24 September.

[W] 170, 202, 230 and 160 refer to Julian calendar days when water use readings were recorded in June, July, August and September, respectively.

[X] Means within a seed source and fertilizer rate are the average of thirty plants.

[Y] Numbers were obtained by multiplying water use per seedling per hour by the day length of the day when water use readings were taken. Day lengths were 15 hrs 1 min for June, 14 min 35 min for July, 13 hrs 35 min for August and 12 hrs 14 min for September.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha = 0.05$ and $\alpha = 0.01$ level, respectively.

		Height-adjusted water use (g per cm height per hr)			
Species	Fertilizer[X]	June	July	August	September
MT2	25	0.0005[Y]	0.0007	0.0007	0.0004
	100	0.0002	0.0008	0.0007	0.0004
	Avg.	0.0003	0.0007	0.0007	0.0004
MT3	25	0.0003	0.0006	0.0007	0.0004
	100	0.0003	0.0006	0.0008	0.0004
	Avg.	0.0003	0.0006	0.0007	0.0004

Continued

Table 5.5. Average hourly water use per cm plant height over between 0800 and 1400 hours for two mother trees of *Malus trilobata* and *Acer syriacum* grown under low or high (25 or 100 mg N per L) fertilizer rates.

Table 5.5 continued

AS2	25	0.0003	0.0011	0.0010	0.0008
	100	0.0002	0.0008	0.0014	0.0008
	Avg.	0.0002	0.0009	0.0012	0.0008
Malus trilobata					
Source (S)		NS[Z]	**	NS	NS
Fertilizer rate (FR)		**	NS	NS	NS
S* FR		*	NS	NS	NS

Continued

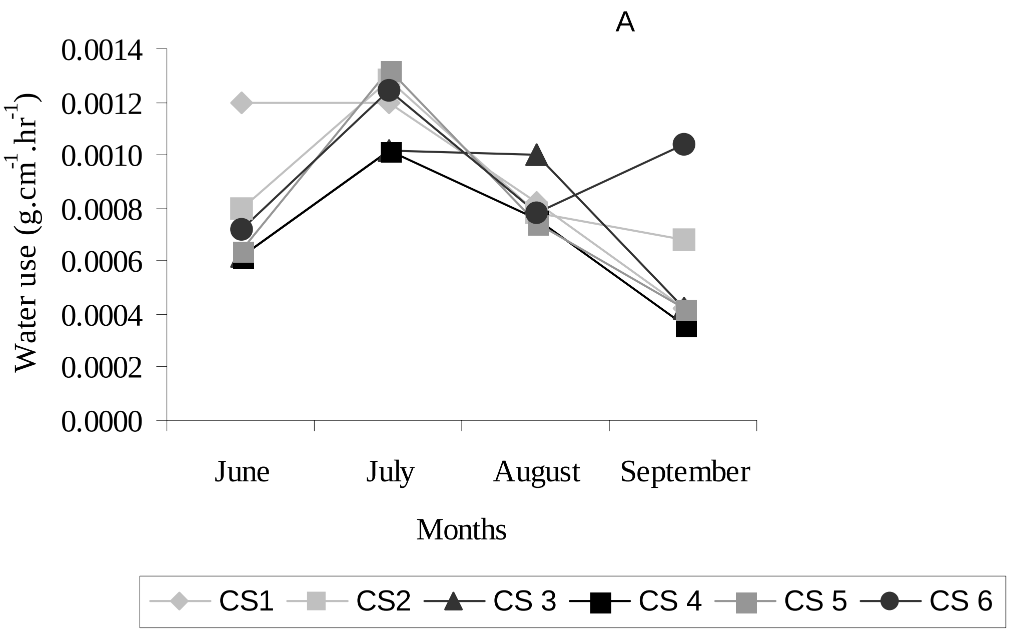
Table 5.5 continued

Acer syriacum				
Fertilizer rate (FR)	*	*	NS	NS

[x] Plants under the low N treatment (25 mg N per L) received 21.3, 40.3 and 10.8 g N, P, and K respectively between 12 May and 24 September, those under the high N treatment (100 mg N per L) received 31.3, 41.8, and 13.2 g N, P, and K respectively from the fertilizer and Comtil compost. Plants were fertilized with 21 N - 3.1 P- 5.1 K between 12 May and 24 September.

[y] Means within a seed source, and fertilizer rate are the mean of twenty six single plant replicates.

[Z] NS, * and ** indicate no statistical difference at $\alpha = 0.05$ level or significant at $\alpha = 0.05$ and $\alpha = 0.01$ level, respectively.



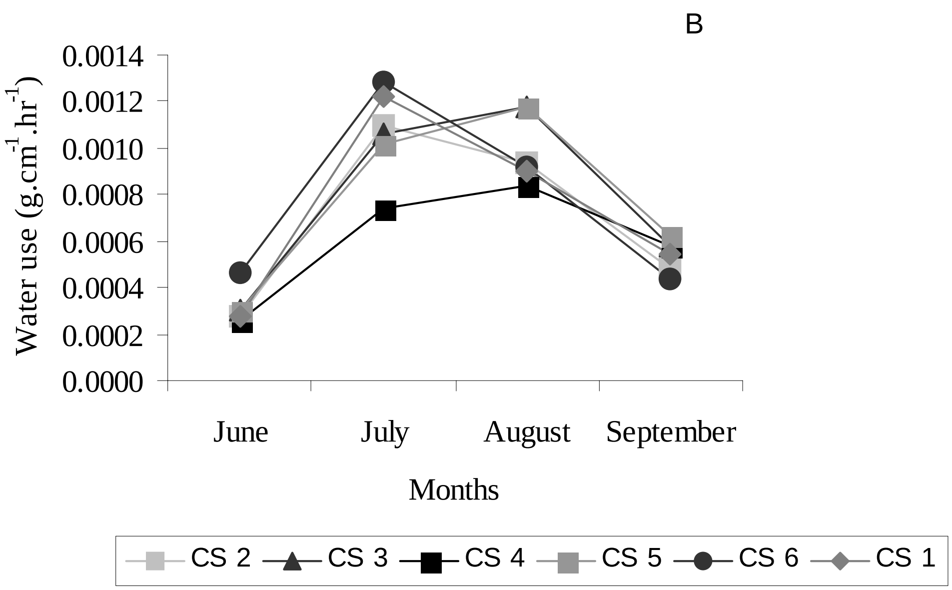


Fig. 5.1 Average adjusted water use of *Cercis siliquastrum* under 25 (Fig. A) or 100 mg per L N (Fig. B) fertilizer.

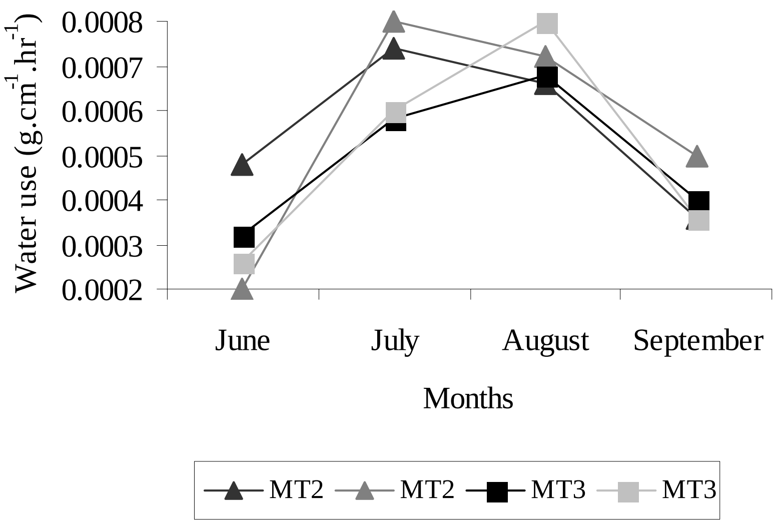


Fig. 5.2 Average hourly height-adjusted water use of *Malus trilobata* under 25 or 100 mg N per L fertilizer.

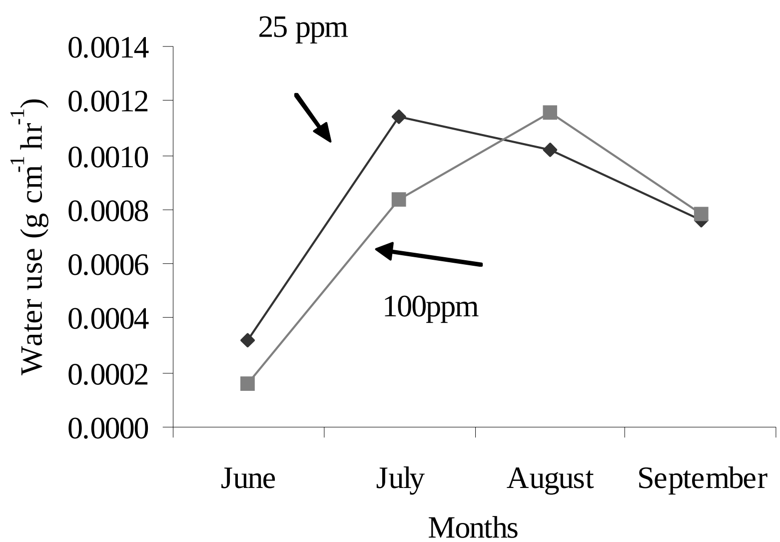


Fig. 5.3 Average adjusted hourly water use of *Acer syriacum* under 25 or 100 mg N per L fertilizer.

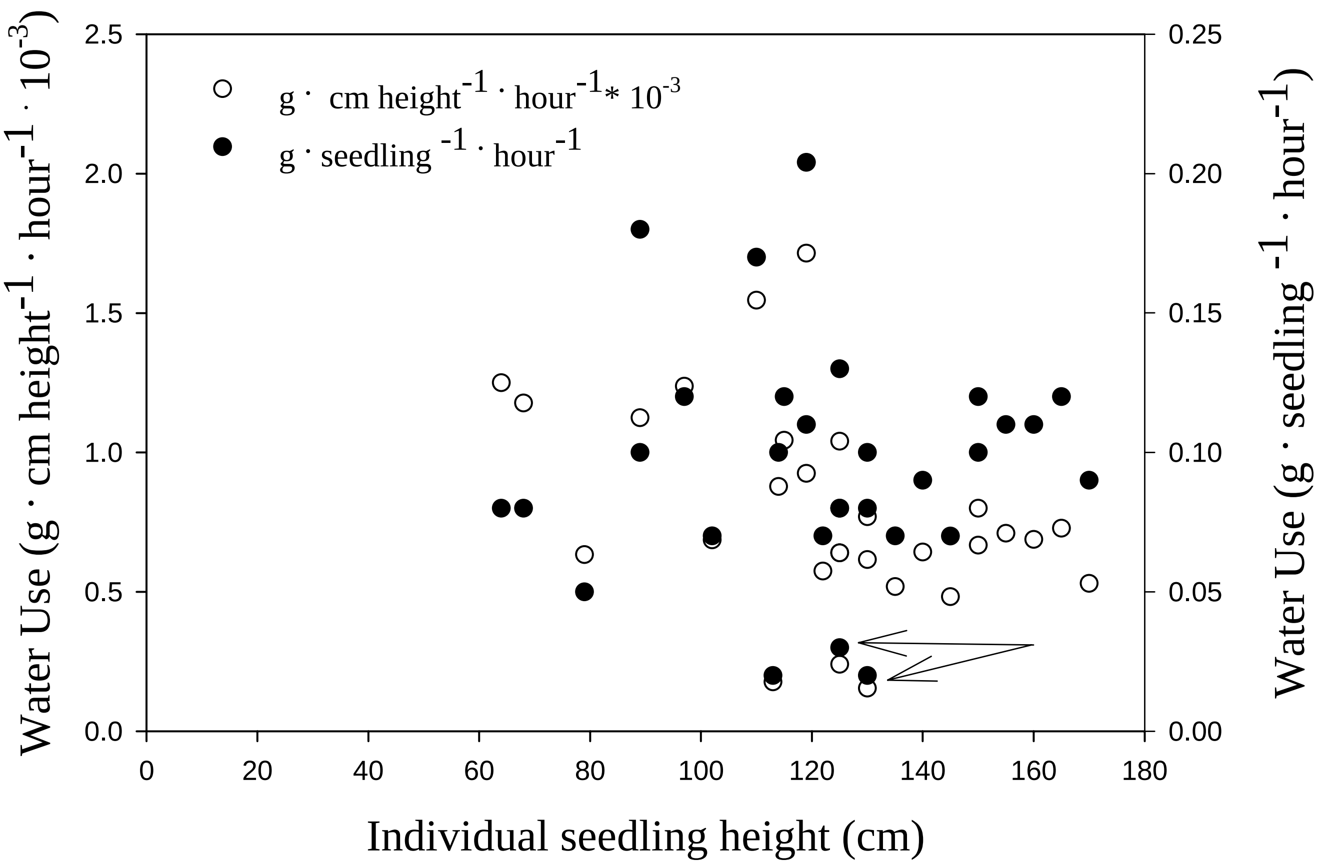


Fig. 5.4 Plant height (cm) of source 1 *Cercis siliquastrum* plotted against height-adjusted water use (g cm height^{-1} hour^{-1} * 10^{-3}) on the left axis and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis.

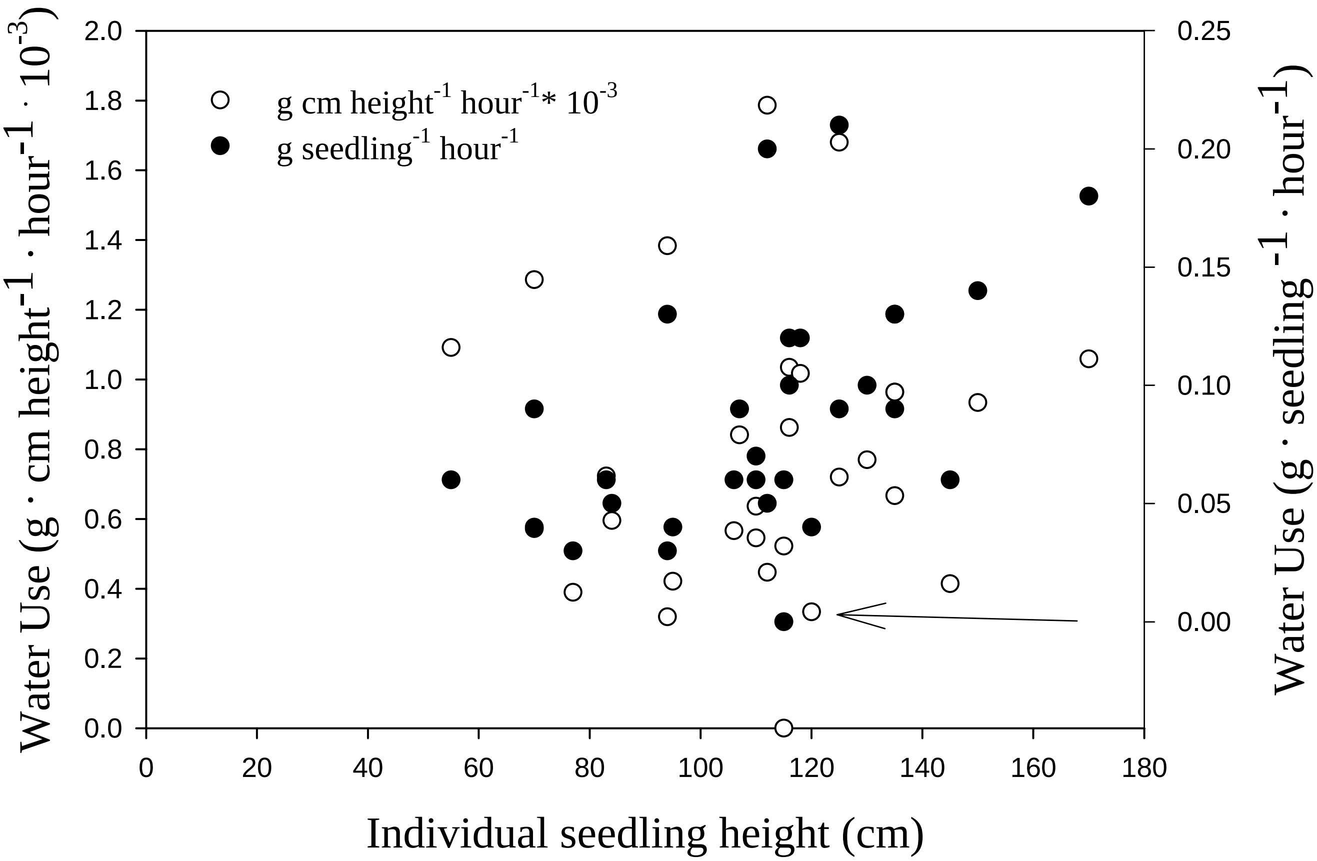


Fig. 5.5 Plant height (cm) of source 2 *Cercis siliquastrum* plotted against height-adjusted water use (g cm height^{-1} hour^{-1} * 10^{-3}) on the left axis and against water use per seedling per hour on the right axis.

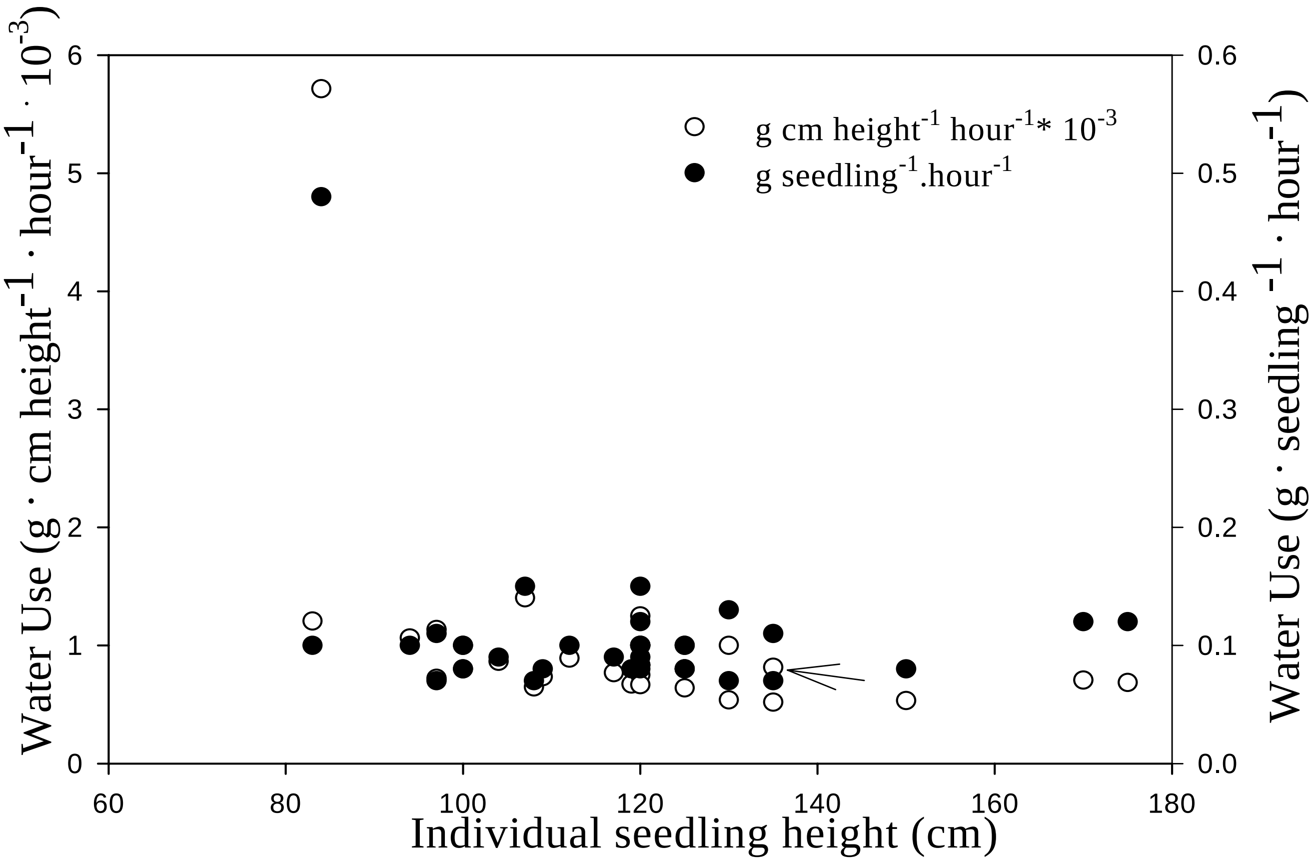


Fig. 5.6 Plant height (cm) of source 3 *Cercis siliquastrum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against height-adjusted water use (g seedling^{-1} hour^{-1}) on the right axis.

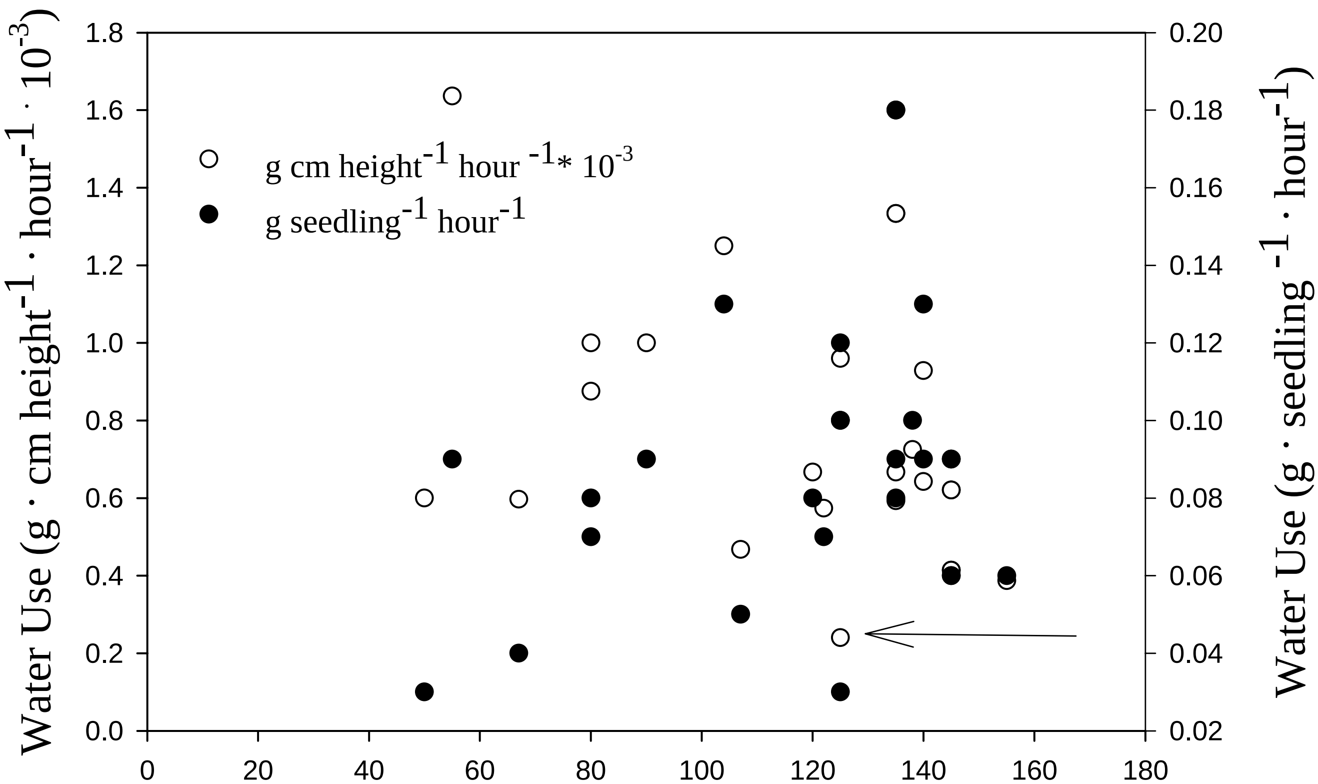


Fig. 5.7 Plant height (cm) of source 4 *Cercis siliquastrum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis.

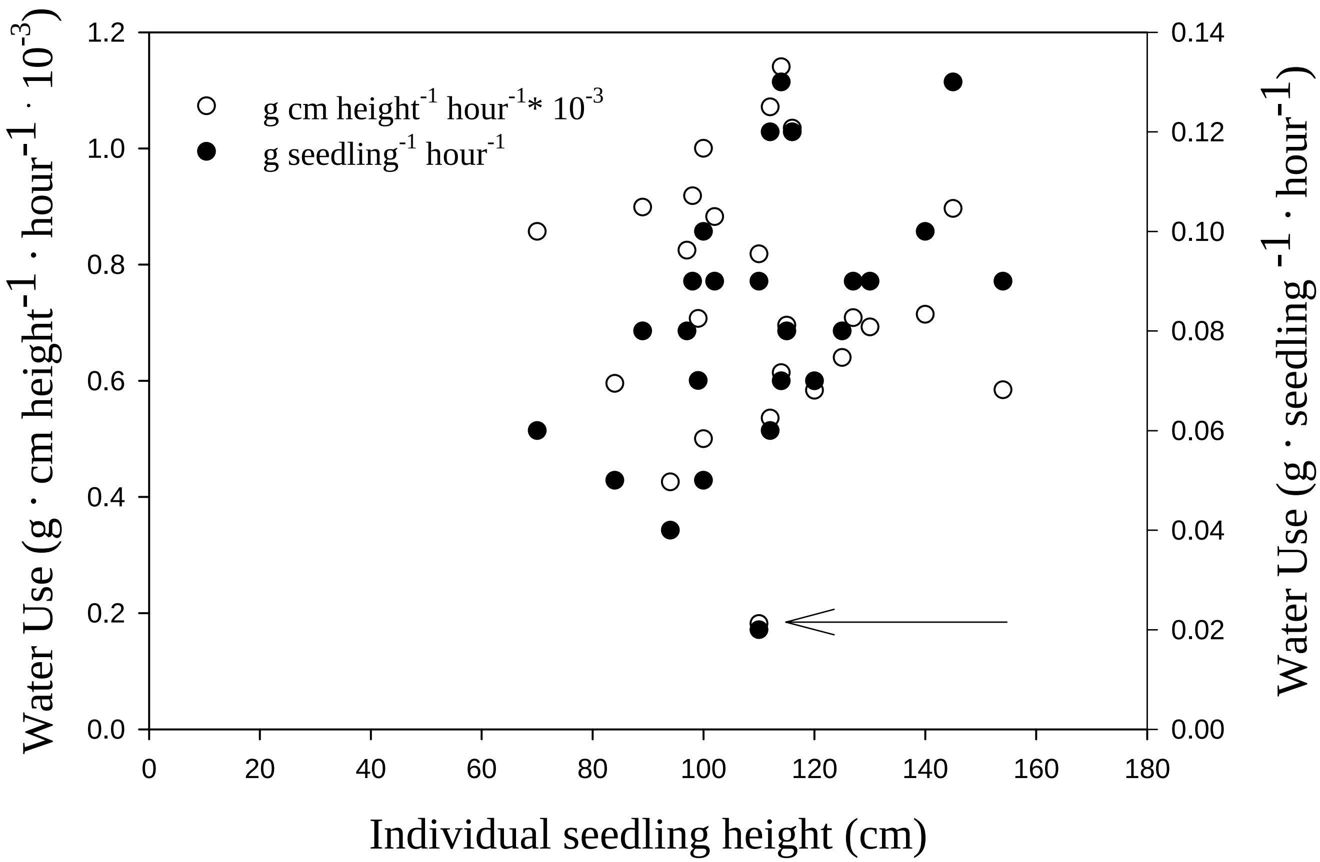


Fig. 5.8 Plant height (cm) of source 5 *Cercis siliquastrum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis.

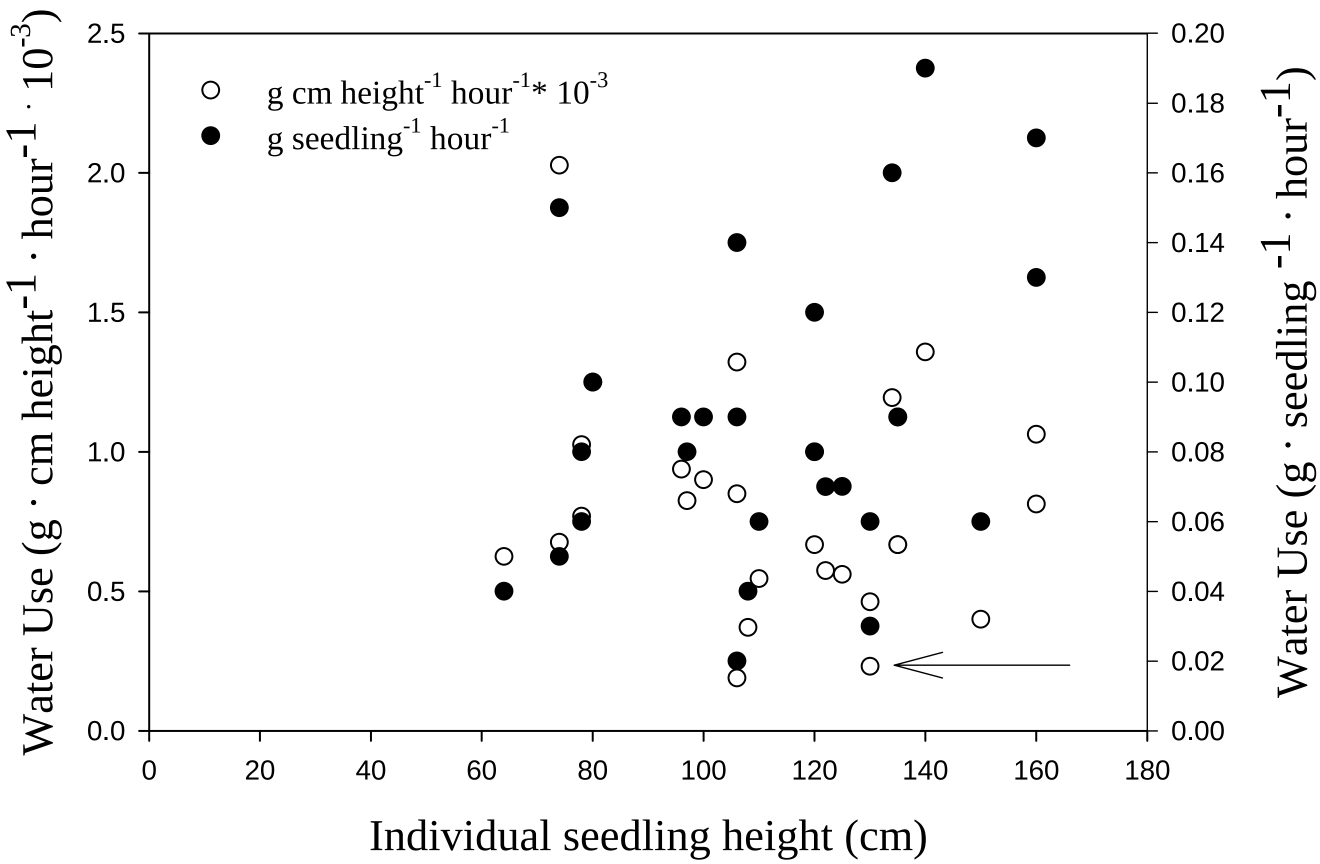


Fig. 5.9 Plant height (cm) of source 6 *Cercis siliquastrum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis.

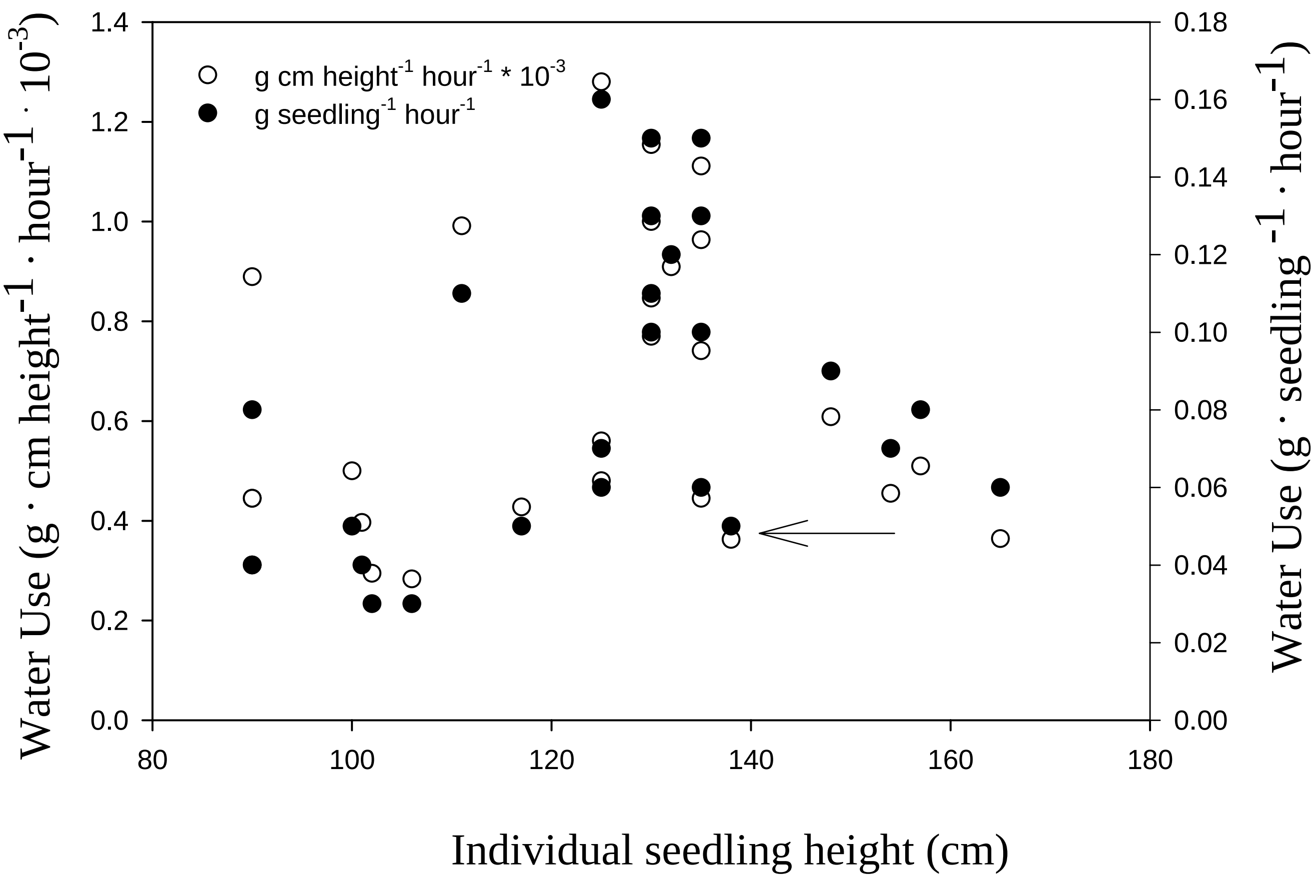


Fig. 5.10 Plant height (cm) of source 2 *Malus trilobata* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis.

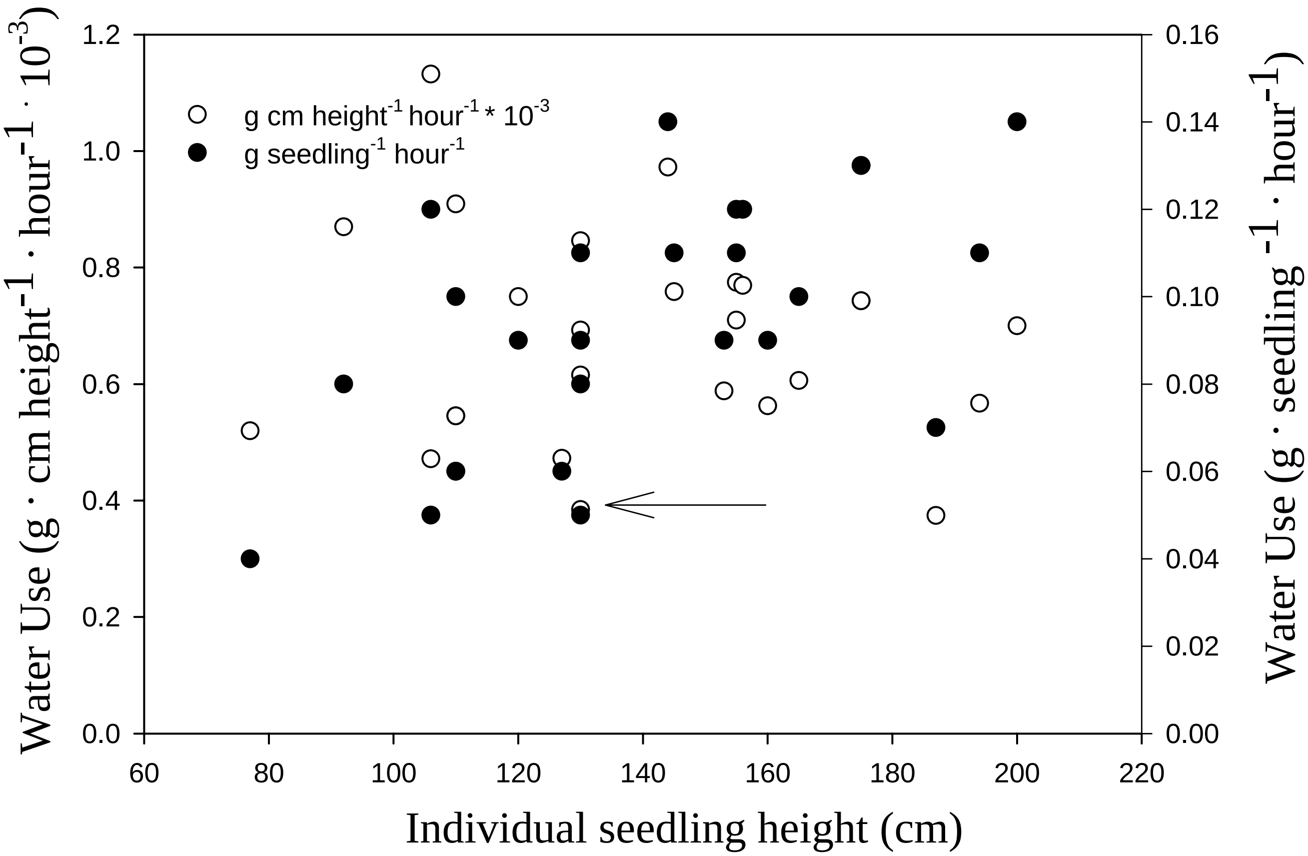


Fig. 5.11 Plant height (cm) of source 3 *Malus trilobata* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis.

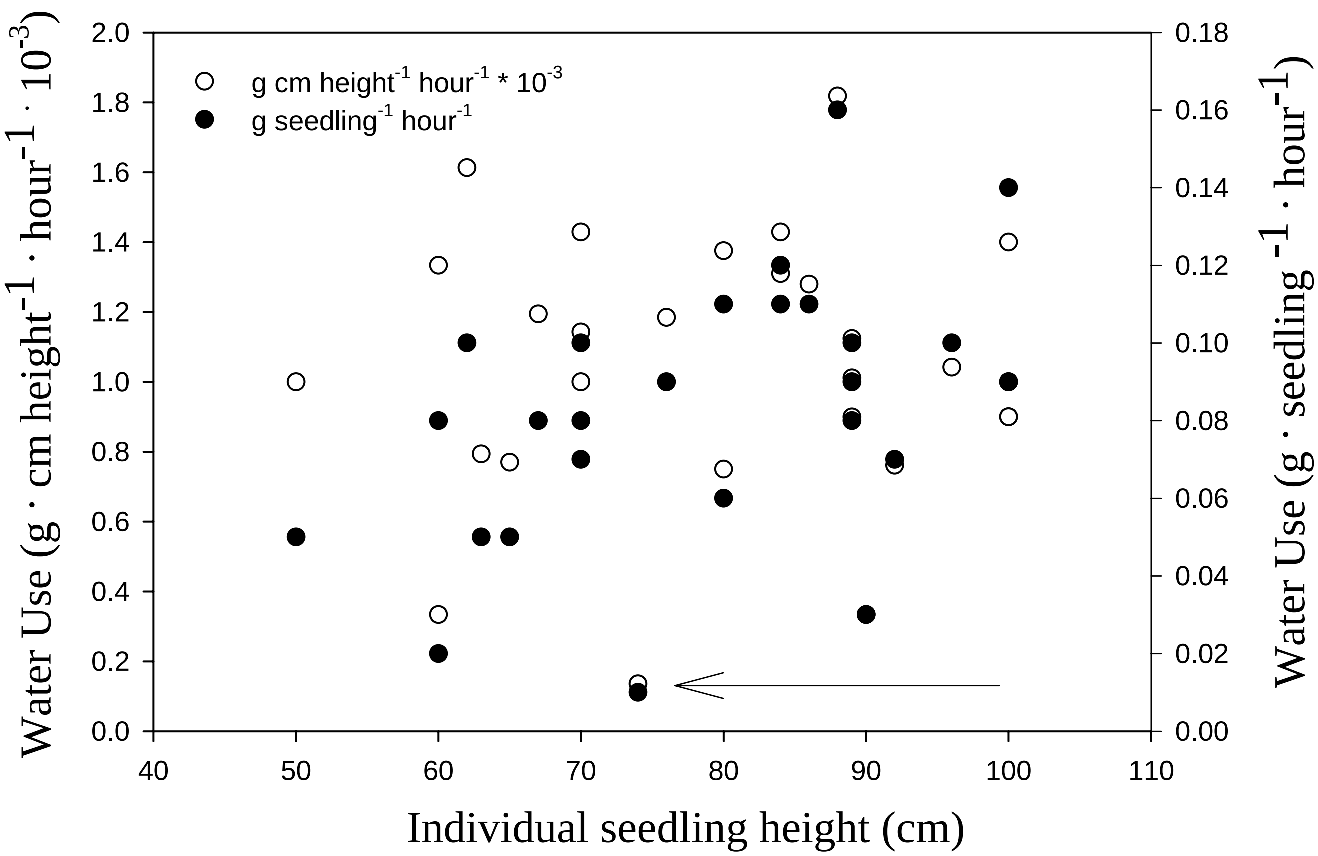


Fig. 5.12 Plant height (cm) of *Acer syriacum* plotted against height-adjusted water use on the left axis (g cm height^{-1} hour^{-1} * 10^{-3}) and against water use per seedling per hour (g seedling^{-1} hour^{-1}) on the right axis.

CHAPTER 6

Patterns of vegetation diversity in Lebanon as affected by climatic and soil properties[1]

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6.1 Abstract

Lebanese biodiversity is threatened by tourist and urban development, political instability, over-collection of medicinal and aromatic plants, lack of compliance to the regulations prohibiting over-collection from the wild, over-grazing and forest fires. A large number of the native species have unexplored economic potential for either medicinal or ornamental use. One way to preserve these species is by propagation and reintroduction into appropriate habitats. However, this requires an understanding of the species biology and environment. The relationship of nine species to the soil and climatic conditions in eight sites along an altitudinal gradient was studied. Individual species were counted and identified within transects at each site. Climatic data was collected and soil samples were taken and analyzed for soil texture, soil pH, EC, $CaCO_3$, organic matter content and the following nutrients: Ca, Mn, Na, Fe, P, K, Cu, Mg, and Zn. Each ecosystem had a unique environment that could be described using the first two factors (70.3 % of variation) in a Factor Analysis of the six most important variables. Some species' densities were affected by soil conditions (the first factor) while climatic conditions (the second factor) explained the densities of species. Recommendations are made for the in-situ preservation of the nine species and their ecosystems.

6.2 Introduction

Since the Lebanese flora was last described (Mouterde 1966 and 1970), the natural vegetation has experienced habitat fragmentation and destruction, due to tourist developments, overgrazing, rapid urban expansion, overexploitation of natural resources, and the impact of a war. Ironically, however, an increased abandonment of agriculture in some zones, particularly on the steeper terraced slopes of the coastal valleys, has allowed native vegetation to re-establish in areas that had been under continuous cultivation for centuries. United Nations Environment Program (1996) estimated the number of vascular plant species at 3,761. A large number of Lebanese tree species have unexplored economic potential as either ornamental or medicinal plants. Therefore, there is a need to identify those species with economic potential and understand the environmental factors that affect their growth. In addition, this process will contribute to reintroduction programs especially for endangered plants, where species are re-introduced into native or semi-natural habitats within their historical range (The World Conservation Union, 1998).

There are diverse climatic zones in Lebanon, and one consequence of this diversity is the wide range of species that are present. The Lower Mediterranean or Thermomediterranean zone (0-500 m altitude) is characterized by the presence of endemic genera such as *Ceratonia, Pistacia, Pinus*, and *Myrthus*; the Euremediterranean zone (500-1000 m altitude) is characterized by *Quercus, Pinus*, and *Cupressus;* the Supramediterranean zone (1000-1600 m altitude) is characterized by *Quercus, Ostrya, Fraxinus, Halimium,* and *Pinus*; the Mediterranean mountain zone (1500-1800 m altitude) is characterized by *Cedrus*, *Abies, Juniperus, Quercus,* and *Berberis*; while the harsh Oromediterranean zone (over 2000 m altitude) is characterized by *Junipers, Rhamnus, Berberis, Pyrus*, *Prunus, Daphne,* and *Cotoneaster*. In the Pre-steppe Mediterranean zone (900-2400 m altitude), located at the east side of Mount-Lebanon and north side of Anti-Lebanon in the Northern part of the country, only *Quercus* and *Juniperus* species dominate the degraded soils where drought and cold make it hard for plants to develop easily.

The selection of the species in this study was based on their threat category and the importance of the genera in the international market as landscape ornamental trees. *Quercus coccifera* is threatened by continuous harvest for fire wood, overgrazing [which is affecting the species natural regeneration], fires and the expansion of cultivated areas (United Nations Environment Program, 1996).

Quercus cerris is threatened by grazing, all year long fodder collection and habitat loss due to construction of residential properties (United Nations Environment Program, 1996).

Juniperus excelsa is threatened by grazing and fire wood collection. Natural regeneration is almost non-existent because of very low seed numbers from the cones, and their low seed quality (United Nations Environment Program, 1996).

Acer syriacum needs to be conserved through reintroduction to the wild. Its wood is commonly cut and used for firewood and in cabinet making (United Nations Environment Program, 1996).

Malus trilobata is endemic to Lebanon (Mouterde, 1966) and is reported to be comparatively rare and ornamentally very distinct (Hillier and Sons, 1973). Its leaves are maple-like, and with attractive yellow to red autumn color.

Cercis siliquastrum is reported to be an important landscape tree because of ornamental qualities heart shaped leaves and pink flowers (United Nations Environment Program, 1996).

Styrax officinalis and *Sorbus torminalis* are understory trees, with known ornamental characteristics (Anonymous, 1999). *Styrax officinalis* produces bell-shaped white flowers while *S. torminalis* leaves turn deep red color in the fall.

This study compared the vegetation characteristics of nine tree species ecosystems in Lebanon (*Acer syriacum*, *Cercis siliquastrum*, *Malus trilobata*, *Sorbus torminalis, Ostrya carpinifolia*, *Styrax officinalis*, *Quercus coccifera*, *Quercus cerris, Juniperus excelsa*) which dominate eight ecosystem types and related environmental and soil characteristics to their distribution. We hypothesize that each ecosystem has a unique set of climate and soil conditions that determines what plant species will exist.

6.3 Materials and Methods

Sites

Eight sites along an altitudinal gradient in Lebanon were selected because they harbored the species of interest and had relatively minimal disturbance levels compared to other sites in Lebanon (Table 6.1).

Information about the historical locations (cities and towns) of the above mentioned species across Lebanon, as well as their blooming period was gathered from local floras (Dinsmore and Post, 1933; Mouterde, 1966, 1970). Field visits were conducted in October 2003 and May 2004 to determine the current distribution and local species density.

Within each site, five 50 x 4 m (200 m^2) transects were randomly placed, and their locations recorded for subsequent measurement. Within each transect all individual trees and shrubs were counted and identified. Within each site, the latitude, longitude and altitude were recorded using a Global Positioning System (eTrex Vista® C model, GARMIN manufacturer). Mean annual temperature and average annual rainfall data were obtained from the closest weather stations to the eight sites (personal communication, Dr. Riad El Solh Al-Khoudary, Beirut International Airport). Wind speed and solar radiation data were not included in the analysis since they were available for only three sites.

Measurements

Soil samples were collected from three soil profiles within transects at seven sites. Soil samples were unavailable from the "Fnaideq" site. Soil was sampled using cores (5 cm diameter) to an average depth of 30 cm and sent to the American University of Beirut for soil texture, soil pH, $CaCO_3$, organic matter percent, electrical conductivity (EC), and the following nutrient content: Ca, Mn, Na, K, Mg, Zn, Cu, Fe, and P. Soil pH and EC were extracted at a ratio of soil:water 1:2.5 and read in pH and EC meters. Exchangeable Na and K were extracted by 1N ammonium acetate and read by a flame photometer (model AFP100, Biotech Engineering Management Co. Ltd., UK). Exchangeable Ca and Mg were extracted by 1N ammonium acetate and read in a double beam atomic absorption spectrophotometer (GBC 902, GBS Scientific Equipment, Australia). Available P was extracted by sodium bicarbonate, color development according to Watanable and Olsen (1965). Absorbance was read using a spectrophotometer (AQUAMATE, Thermo Electron Corporation, USA). Fe, Zn, Cu, Mn were extracted by DTPA-TEA according to Lindsay & Norvell, (1978). The reading was done using an atomic absorption (GBC 902 Double Beam Atomic Absorption Spectrophotometer). Soil texture was determined by the Bouyoucos Hydrometer Method. Soil organic matter was determined by dry digestion at 350°C, and soil calcium carbonate content by acid neutralization.

Measurements (per transect)

Tree diameter at breast height (DBH) was recorded for species more than 1 m tall. The basal area (BA) was derived from the DBH as follows: $BA = \pi.(DBH/2)^2$. The basal area of woody species that were less than 1 m height, was calculated by assuming the DBH = 2.5 cm (1 in).

All woody taxa encountered in these transects were identified to species. Voucher specimens were collected from each species at each site and identified in the Herbarium at The Ohio State University and at The American University of Beirut (personal communication, Elsa Sattout).

Recorded tree and shrub species were sorted among three categories: deciduous, evergreen angiosperm, or conifer. The data were coded before processing: A. syr., C. sil., J. exc., M. tril., O. carp., Q. cer., Q.coc., S. tor., and S. off. refer to the studied species respectively (*Acer syriacum, Cercis siliquastrum*, *Juniperus excelsa, Malus trilobata*, *Ostrya carpinifolia, Quercus cerris, Quercus coccifera, Sorbus torminalis, Styrax officinalis)*, OC (other coniferous), OE (other evergreen), and OD (other deciduous). Trees (T), shrubs (S), and sub shrub (SS) species within the three latter categories of OC, OE and OD were recorded.

Calculations and statistical analysis

Two measures of diversity were calculated: Shannon's and Simpson's. The Shannon's index of diversity was calculated as: SHDI = 1- $\sum p_i * \ln p_i$, where p_i the proportional abundance or the basal area of the *i*th species.

The Simpson index was calculated as: SIDI = 1- $\sum p_i * p_i$.

Thus, two values for every diversity index for every site were provided; one based on species' basal areas and another based on species' densities.

A total of 17 variables were recorded for each study site. These were classified into three subgroups: soil physical characteristics [% sand, % clay, % organic matter, electrical conductivity (EC) (mS/cm), pH], soil chemical characteristics [% $CaCO_3$, and ppm of Ca, Mn, Na, K, Mg, Zn, Cu, Fe, and P] and environmental characteristics [altitude, mean annual temperature, and average annual rainfall]. The matrix of Pearson correlation coefficients of the linear relationship between these 17 variables, the average density per 200 m^2 of every species and the diversity indices (calculated for the number of woody species or their basal area) was calculated using PROC CORR of SAS (The SAS System for Windows Release 8.02, SAS Inst. Inc., Cary NC). Six variables were selected for subsequent analysis: two represented environmental variables (mean annual temperature and altitude), two represented soil physical properties (soil organic matter and soil pH) and two represented soil nutrient status (soil Fe and Mn concentrations (ppm)). These soil and climatic variables were selected because they had the highest correlation coefficients (R^2) relative to the average R^2 of the data matrix described above.

Factor analysis was performed using the six variables using PROC FACTOR of SAS. The analysis was customized using Method=PRIN, and "Varimax' pre-rotations and rotations to enhance the interpretation of the factor component structure. The first three factors were used for subsequent analysis since these accounted for 87 % of the information of the six variables. Factor analysis scores derived from the factor components were plotted against the density of each species.

6.4 Results

Diversity indices

Average total number of species per 200 m^2 varied between sites: 36 in Beshwat, 59 in Ehden, 133 in Batloun, 96 in Damour, 110 in Kfarnabrakh, 232 in Ayn w Zayn, and 106 in Mazra'at Kfarzebian (data not shown).

Shannon and Simpson diversity indices calculated from the number of species were higher than those calculated from the species basal area. Based on basal area calculations, Shannon's diversity index ranged from 1.02 (Beshwat) to 2.12 (Mazra'at Kfarzebian), while Simpson's index ranged from 0.04 (Beshwat) to 0.64 (Kfarnabrakh and Ayn w Zayn) (Table 6.4). Based on the species number calculations, Shannon's diversity index ranged from 1.96 (Ayn w Zayn) to 2.86 (Nahr Damour), while Simpson's index ranged from 0.48 (Ay w Zayn) to 0.81 (Nahr Damour) (Table 6.4).

Woody species diversity, measured with Shannon's diversity index based on the number of species and that based on the basal area, were negatively correlated with altitude (R^2 = 27-28 %, Fig.6.1). Woody species evenness, based on the basal area, measured with Simpson's index, followed a similar pattern (R^2 = 37 %) unlike that calculated based on the number of species that was negligibly affected by increasing altitude (R^2 = 15 %, Fig.6.1). Although both indices identified the same sites as having the least and most diversity, when calculated based on the number of species, there was a larger variation in Shannon's diversity index among sites with increasing altitude than with Simpson's index. The latter showed a minimal variation with increasing altitude (Fig.6.1).

Based on the number of species, Shannon's and Simpson's indices showed a higher correlation with Factor 1 (51 % and 33 % respectively) than with factors 2 and 3 (Fig.6.2). On the other hand, based on the basal area, Shannon's index showed the highest correlation with Factor 2 (45 %) compared to factors 1 and 3, while Simpson's index showed the highest correlation with Factor 1 (33 %, Fig.6.2).

Soil analysis

All soil pH readings exceeded 7.2, except for Mazraat Mazra'at Kfarzebian with a pH of 6.41 (Table 6.2). Altitude varied from 35 m (Nahr Damour) to 1695 m (Beshwat) and the mean annual rainfall ranged from 410 mm (Beshwat) to 1170 mm (Ayn w Zayn, Batloun and Kfarnabrakh). Sites also varied in their soil physical and chemical properties (Table 6.2).

Variable that were significantly correlated with species density are presented in Table 6.3. Since six variables had to be chosen for the statistical analysis, only relationships with $R^2 > 20\%$ were shown in Table 6.3. The aim was to select two environmental variables, two soil physical characteristics and two soil chemical characteristic. The variables, average annual temperature, altitude, pH, organic matter percent in the soil, $CaCO_3$, and Fe were then chosen for the SAS factor analysis. The first three eigenvalues that resulted from the analysis accounted for 87 % of the information provided by the six variables (Table 6.5). Factor 1 was mainly weighted by soil pH (-0.80), soil $CaCO_3$ content (-0.86) and Fe concentration (0.82); Factor 2 was weighted by the climatic variables (-0.97 for mean annual temperature and 0.72 for altitude), while Factor 3 was mainly weighted by soil organic matter content (0.98).

Species density

Tree density varied between the study sites (Table 6.6). Tree species varied in the response o density to the three factors. The density of some species had higher correlation with Factor 1 (*S. officinalis, Q. cerris* and *J. excelsa)*; other species were most affected by Factor 2 (*Q. coccifera*, *M. trilobata*, *S. torminalis*, *O. carpinifolia*, and *A. syriacum*), while only *C. siliquastrum* density was affected by Factor 3 (Fig. 6.3)

The correlations between *S. officinalis, Q. cerris and J. excelsa* with Factor 1 were 52, 35 and 37 %, respectively. *Quercus coccifera* density was better correlated with Factor 2 ($R^2 = 0.49$) than with Factors 1 and 3 ($R^2 = 0.22$ and 0.17, respectively). *Sorbus torminalis*, *M. trilobata* and *O. carpinifolia* had same correlates with factors 1, 2 and 3 ($R^2= 0.27$, 0.55 and 0.13, respectively, Fig. 6.3). *Acer syriacum* was better correlated with Factor 2 than Factors 1 and 3 ($R^2= 0.53$ vs 0.12 and 0.24, respectively) (Fig. 6.3). *Acer syriacum* density was negatively correlated with altitude ($R^2= 0.72$) and with rainfall ($R^2= 0.24$) but positively correlated with mean annual temperature ($R^2= 0.34$, data not shown). *Cercis siliquastrum* had low correlates with both Factors 1 and 2 (Fig. 6.3). Among all 17 variables, *C. siliquastrum* was best correlated with soil Mg content ($R^2= 0.21$) and soil O M ($R^2= 0.51$).

Evergreen shrub density and evergreen tree density had higher correlation with Factor 2 ($R^2= 0.17$ and 0.57, respectively, Figs. 4 and 5) than Factors 1 and 3. Conifer tree density was better correlated with Factor 1 than Factors 2 and 3 ($R^2= 0.47$ vs 0.001 and 0.44, respectively, Fig. 6.4) unlike conifer shrub density which was better correlated with Factor 2 than Factors 1 and 3 ($R^2= 0.52$ vs 0.27 and 0.07, respectively, Fig. 6.5). The density of deciduous trees was poorly correlated with Factors 1, 2 and 3 ($R^2 < 0.10$, Fig. 6.4). Deciduous shrub density was better correlated with Factor 3 than Factors 1 and 2

(R^2= 0.61 vs 0.08 and 0.0009, respectively, Fig. 6.5). Low correlation was observed between the evergreen sub shrub category and the three Factors, whereas the deciduous sub shrub category was better correlated with Factor 3 than Factors 1 and 2 (R^2= 0.26 vs 0.08 and 0.02, respectively, Fig. 6.5).

6.5 Discussion

Site effects

The vegetation characteristics of the 8 dominant tree ecosystems in Lebanon (*Acer syriacum*, *Cercis siliquastrum*, *Malus trilobata*, *Sorbus torminalis, Ostrya carpinifolia*, *Styrax officinalis*, *Quercus coccifera*, *Quercus cerris, Juniperus excelsa*) were different (Table 6.6). The hypothesis that each ecosystem has a unique environment (climate and soil) that allows certain plant species to grow was supported by the data in the study.

The Beshwat ecosystem had low annual rainfall, dry summers, an average annual temperature of 12 C and a clayey soil texture. However the soil nutrients of K, Ca, Mg, P, Fe, Na and Mn, occurred at medium to very high concentrations (Table 6.2) with the exception of Cu (data not shown). The site was less subject to human influence due to its unfavorable conditions for crop production, but was susceptible to soil erosion which allows xerophytes species such as *Astragalus species* to exist. Overgrazing and soil erosion at this site, kept the trees and shrubs small and less than 1 m tall. With the exception of *J. excelsa* which showed a basal area ranging from 175 up to 11500 cm^2 in 1000 m^2, most other identified shrubs and trees were much smaller in size and may have been overestimated because actual stem caliper was less than that assigned (DBH= 2.5 cm, see materials and methods).

Ayn w Zayn and Kfarnabrakh sites had similar floristic diversity (Tables 1 and 4). The locations had similar altitude, similar climate, soil texture and soil chemical characteristics, with the exception of soil P (very high in Kfarnabrakh, 61.5 ppm, and very low in Ayn w Zayn, 2.1 ppm), soil organic matter content (6.6 vs 3.1 %) and soil calcium carbonate (69.6 vs 28.2 %, Table 6.2). Based on the Simpson index, the two sites had a similar distribution (with respect to the basal area) of species present.

Surprisingly, sites such as Ayn w Zayn, and Batloun, although they shared similar climatic, soil physical and chemical characteristics, differed in the number and type of species present (Tables 1, 4 and 6). Ayn w Zayn was the least diverse site in terms of number of species and species evenness based on Shannon and Simpson indices. Ayn w Zayn is an open site where *Quercus* species dominated. The site was subject to grazing and anthropological disturbance from cutting trees, cultivation and building houses. Shrubs such as *Spartium junceum*, *Calycotome villosa*, *Cistus reticus*, and *Salvia fruticosa,* species generally associated with degraded sites, grow with *Q. coccifera*. Other tree species include *Pinus pinea*, *Pinus brutia*, *Acer syriacum*, *Ceratonia siliqua*, *Pistacia lentiscus*, *Arbutus andrachne*, and *Phyllirea media*.

The Nahr Damour site was the most diverse in species number based on Simpson and Shannon's indices. The site had a closed canopy of *Acer*, *Cercis, Laurus*, *Quercus*, *Pistachia,* and *Nerium*, in near equal abundance. Climatic variables were critical in determining species richness patterns and were the strongest predictors of species diversity (Chiarucci *et al.* 2001; Richerson and Lum, 1980). It might be that climatic conditions in this site resulted in a higher species richness than in other studied sites (Table 6.6). Nahr Damour, relative to the other sites, had the mildest climate, lowest elevation, frost free winters and hot dry summers that last 6 months, and received an annual rainfall of 600 mm per year with an average annual temperature of 20 C. The clayey loam soil in Nahr Damour was nutrient rich with high to very high concentrations of K, Ca, Mg, and Cu; medium concentrations of Fe, Zn, Mn, but a very low P concentration.

The Mazra'at Kfarzebian site, according to the Shannon's index, calculated from the basal area, was the most diverse. The site has its own uniqueness with respect to the vegetation type. The soil was loamy sand with a pH of 6.4, lower than the pH of other sites and is characterized by very low concentrations of K, Ca, Mg, and P, medium concentrations of Cu and Zn while Fe and Mn concentrations were high. This site was mainly dominated by mature stands of *Q. cerris* with a basal area ranging from 495 to 181180 cm^2, other species such as *Coronilla emeroides*, *Fumana thymifolia* and *Rhododendron ponticum* var *brachycharpum* fill the gap between the tree stands.

Species richness

Average total number of species per 200 m^2 varied among sites and was lowest in Beshwat and highest in Ayn w Zayn. Other studies have shown that species richness can vary among sites along an altitudinal gradient (Hegazy *et al.* 1998), however in this study; the difference in Shannon's and Simpson's diversity indices was small among sites from different altitudes. Simpson and Shannon's diversity indices are among the most widely accepted diversity indices (Poole, 1974). While the Simpson index expresses the relative evenness of the abundances of all the species or the degree of dominance of the predominant species, the Shannon index uses site diversity as indicated by the number of species to measure diversity. The diversity indices when calculated based on the number of species gave different results with regard to the least and most diverse sites from when they were calculated based on the basal area. Ayn w Zayn was identified as the least diverse site in terms of number of species and species evenness based on Shannon and Simpson but the richest in species number, and Nahr Damour as the most diverse site in terms of species number.

Shannon and Simpson's diversity indices both identified Beshwat as the least diverse site when they were calculated from species basal area. This might be due to the predominant presence of smaller size plants than *J. excelsa* which were assigned a DBH o 2.5 cm. However, results varied with respect to the most diverse sites which were Kfarnabrakh or Ayn w Zayn and Mazra'at Kfarzebian (according to Simpson and Shannon indices, respectively). A previous study showed that variation and opposing tends in response of the two indices can be expected (Nagendra, 2002).

Both diversity indices showed that woody species diversity decreases with increasing altitude (Fig.6.1). Evergreen tree density compared to deciduous and conifer tree densities, was the only one influenced by altitude (it decreased with increasing altitude). On the other hand, conifer tree density was best correlated with soil physical and chemical properties (pH, $CaCO_3$, Fe, and OM). The three factors from this study failed to explain the density of evergreen shrubs and sub shrubs species as well as deciduous tree density. Only soil OM content was related to deciduous shrub and sub shrub species density.

Tree species occurrence

Our model that included six variables was suitable for explaining the density of all eight species. Targeted species were not found in every studied site. *Cercis siliquastrum* was found in Nahr Damour, Batloun and Ehden sites. It was positively correlated with Mg (R^2= 0.21) and with soil OM (R^2= 0.51) which explains its strong correlation with Factor 3 (Fig. 6.3). Our data confirmed previous reports (Ano, 1999) that the species is widely distributed in the Thermomediterranean zone in Lebanon (0-500 m altitude) and can be found up to 800 m altitude where it is associated with pine and oak forests. This species is indifferent to soil types (Ano, 1999). The regeneration potential of *C. siliquastrum,* expressed as the ratio of saplings to tree, in all three sites, averaged 0.55 per 200 m^2. It was observed that *C. siliquastrum* seed pods become insect infested during their development in August through October, which destroys the seeds inside the pods. Therefore, chances for natural regeneration of the species were very low unless seeds were released from the pod before insect attacks. Recommendations are to identify the insect and prevent the seed loss in an effort to conserve the species at other sites throughout Lebanon.

Juniperus excelsa was present only in Beshwat and its density was negatively affected by rainfall (R^2= 0.57) but positively influenced by soil K content (R^2= 0.79), Ca content (R^2= 0.36), Fe content (R^2= 0.89), and by altitude (R^2= 0.25) (data not shown). In fact, the species was most influenced by Factor 1 (R^2 = 0.37), which was mainly weighted by soil physical and chemical properties. *Juniperus excelsa* grows only in the Oromediterranean zone in Lebanon (Abi Saleh and Safi, 1988). It was observed that the species tends to be the only tree species in this zone with *Rhamnus libanotica* and shrub species such as *Berberis libanotica*, *Prunus prostrata*, *Cotoneaster nummularia* and *Pyrus syriaca*. In the site, *J. excelsa* had a ratio of saplings to trees of 1.1 per 200 m^2. The high K content in the soil (720 ppm) maybe related to the K function as an osmoticum and for stomatal control, increasing drought resistance in some species (Tisdale *et al.* 1998).

Acer syriacum was only found in Nahr Damour. We observed that *A. syriacum* produces a good seed set every other year. The ratio of saplings to trees was 5 per 200 m^2 in this site, the highest of all targeted species.

Quercus coccifera density was mainly influenced by climatic variables such as mean annual temperature and altitude ($R^2 = 0.61$). The species was present in Nahr Damour, Ehden, Batloun, Kfarnabrakh, and Ayn w Zayn. The species density was negatively correlated with altitude ($R^2 = 0.78$), and positively correlated with average annual temperature ($R^2 = 0.27$) (data not shown). The species grows on the coast up to 1500 m altitude (United Nations Environment Program, 1996). The ratio of saplings to trees, averaged 1.0 per 200m^2 .The forests, where *Q. coccifera* is found, are degraded due to its continuous cutting for timber, fuel, agricultural tools; and land cultivation. Overgrazing and wood harvesting keep trees below 4-5 m in height. The species' area of coverage varies between 5 and 40 % with the high proportion in areas most difficult to access (United Nations Environment Program, 1996).

Malus trilobata, O. carpinifolia and S. torminalis densities are best explained by climatic variables. In fact, the three species are reported to grow in the same vegetation zone, the Supramediterranean zone, at altitudes between 1000-1500 m in Lebanon (Abi Saleh and Safi, 1988). They were all found in the Ehden site which was characterized by a sandy loam soil and a pH of 7.8. The soil analysis revealed a high Ca (2277 ppm) and $CaCO_3$ content resulting in a positive correlation between *Malus trilobata, O. carpinifolia and S. torminalis* densities with $CaCO_3$ (R^2= 0.51). *Sorbus torminalis* was reported to occur most frequently on silt soils but can be found on calcareous, well drained and / or organic soils (Ano, 1999), however in the study, there was a low correlation of *S. torminalis* density with soil OM (R^2= 0.14). Isolated individuals of *O. carpinifolia and S. torminalis* were seen during field visits. Later visits confirmed poor quality seed set from these trees in seed testing studies. The poor quality seed set was mainly due to the lack of pollinators and out crossing. *Malus trilobata* is reported to be rare (Mouterde 1966 and Hillier and Sons, 1973) and it is endemic to Lebanon (Mouterde, 1966). The ratio of saplings to trees was 0.2, 0.1 and 0.0 for *M. trilobata, O. carpinifolia and S. torminalis* per 200 m^2 in Ehden location. Although the site was a protected area and not subject to human interference, this data shows the need for reintroduction projects of the three species for better pollination and therefore conservation purposes.

Styrax officinalis was found at three sites (Ehden, Qammouaa, and Naes), however the latter two were not included in this study. These sites share different altitude, rainfall and mean annual temperature (personal observation). This confirms our results that its density was best explained by soil physical and chemical characteristics. The ratio of saplings to trees averaged 2.1 per 200 m^2 in Ehden, a medium average compared to the other species.

Quercus cerris was found in Mazra'at Kfarzebian that has the lowest soil pH of all sites. In Italy, the species is reported to grow in slightly acidic soils (Chiarucci *et al.*

2001), which could explain why the density of *Q. cerris* was better correlated with Factor 1 (R^2=0.35). *Quercus cerris* was found in isolated stands and is a threatened species in Lebanon because of grazing, pruning branches all year long to provide it as fodder for livestock and from habitat loss for construction purposes. Its wood was prized for house construction until the later 20th century, until the more widespread used concrete. Most forests where this species grows were replaced by intensive cultivation of apple trees (Abi Saleh and Safi, 1988). Natural regeneration was very low; in fact the ratio of saplings to trees calculated was equal to 0.43 per 200 m^2. The acorns are damaged by an unidentified insect, in addition there are galls formed on the branches. Not only this is decreasing the species regeneration potential, but also during our field visits, we noticed that Mazra'at Kfarzebian site, is becoming a sand excavation site and some trees were already destroyed.

Other factors affecting vegetation

This study shows that there are other non measured factors that can affect species diversity such as site history, slope, drought index, wind speed, and site aspect that influence solar radiation and evapotranspiration, and total nitrogen. The latter factors proved to be among the main factors influencing plant richness and characteristics (Fu *et al.* 2004 and Richerson and Lum, 1980). Unlike other studies, there was no recognizable pattern between soil fertility and species richness, and between the sites with the highest available P and K contents and species diversity (Fu *et al.* 2004). Nahr Damour, which was shown to be the most diverse site in terms of species number, had the lowest soil organic matter content and a very low P content. On the other hand, Beshwat, was the least diverse site, had the highest K concentration and a high P concentration. Available phosphorus in most sites was low (< 2.1 ppm) mainly caused by high soil pH levels. In basic soils, it is reported that the availability of soluble phosphates is reduced because phosphorus can complex with Ca to form insoluble calcium phosphates (Tisdale *et al,* 1998).

Ecosystem preservation and species conservation

The results from this study constitute the baseline for further studies and decision-making regarding the conservation of some species and their ecosystems. Some of the studied ecosystems had their unique set of climatic and soil characteristics, which determined the type of vegetation that grows in them. The species of interest are endangered and one way to conserve them is by encouraging their ex-situ conservation through propagation and cultivation. Cultivation of these species will satisfy both commercial and conservation purposes. Reforestation projects and future reintroduction activities will return these threatened species to their native habitats.

6.6 Conclusion

Each ecosystem of the eight species of interest provided a unique environment (climate and soil) that allowed a different type of vegetation than other ecosystems to exist. Nahr Damour was identified as the most diverse site in terms of species number whereas Ayn w Zayn was the least diverse. The least diverse site based on species basal area was Beshwat and the most diverse were Ayn w Zayn and Mazra'at Kfrazebian. Woody species diversity decreased with increasing altitude. Species of interest were not present at every studied site and for some; their density was better related to climatic conditions while others densities were better related to soil conditions. Recommendations are to promote the domestication of these species which will help preserve them and their ecosystems through reforestation and reintroduction activities.

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Fig.6.1. Woody species diversity (average number per 200 m^2) plotted against altitude (m). The upper graph is woody species diversity calculated from the number of species. The bottom graph is woody species diversity calculated from the species basal area.

Fig.6.2. Shannon and Simpson's diversity indices calculated either from number of species or basal area, plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively.

Fig. 6.3. Tree species density (from top to bottom: *C. siliquastrum*, *Q. coccifera*, *S. torminalis*, *O. carpinifolia*, *S. officinalis*, *A. syriacum*, *M. trilobata*, *Q. cerris* and *J. excelsa*) plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively.

Fig. 6.4. Evergreen, conifer and deciduous tree density (average number per 200 m^2) plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively.

Fig. 6.5. Evergreen, conifer and deciduous shrub and sub shrub density (average number per 200 m^2) plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively.

Site	Elevation (m)	Latitude (N)	Longitude (E)	Description
Beshwat	1694.8	34° 12 07.6	036° 08 05.5	Habitat on the highest peaks of the western chains of Mount Lebanon, that overruns to the east side of Mount Lebanon. Open canopy where species such as *Juniperus*, *Rhamnus, Berberis*, *Pyrus*, *Prunus, Astragalus, Daphne,* and *Cotoneaster* survive the harsh environment (very dry and hot weather in summer and snowy and cold in winter). Overgrazing is the main type of disturbance.
Nahr Damour	34.8	33° 42 01.1	035° 29 06.7	Steep, north facing slope facing the Mediterranean Sea to the south; dense canopy with little understory (very few herbaceous plants). Mostly, closed canopy of *Acer*, *Cercis, Laurus*, *Quercus*, *Pistachia,* and *Nerium.* Highly erosive and calcareous gravel soil.

Continued

Table 6.1. Description of the study sites selected along the altitudinal gradient in Lebanon.

Table 6.1 Continued

Kfarnabrakh	867.33	33° 41 56.0	035° 37 04.3	Open area on the west side of Mount Lebanon. Dominant species are *Quercus*, *Pistachia*, *Cercis*, *Sarcopotereum*, *Spartium*, *Caclycotome*, and *Prunus*. Few hundred meters away from a minor human disturbance
Ayn w Zayn	1054.6	33° 40 54.8	035° 37 06.1	Open area in the west side of Mount Lebanon running south and parallel to Beirut. Very rocky and calcareous habitat on old abandoned terraces. Dominant species are *Quercus*, *Pistachia*, *Juniperus*, *Sarcopotereum*, *Spartium*, *Daucus*, and *Prunus*. Grazing and cutting trees are the major types of disturbance.

Continued

Table 6.1. Continued

Batloun	1045.8	33° 40 57.6	035° 38 06.2	Open area in the west side of Mount Lebanon running south parallel to Beirut. Very calcareous and rocky habitat. Residential construction is underway in the surrounding areas. Dominant species are *Quercus*, *Juniperus*, *Cercis*, *Sarcopotereum*, *Cistus*, and *Calycotome*.
Ehden	1365	34° 18 58.8	035° 58 51.8	National reserve on the north east side of Mount Lebanon. A protected area with closed canopy forest dominated by *Pinus brutia*. Understory species include *Juniperus*, *Styrax*, *Sorbus*, *Cercis, Fraxinus*, *Malus*, and *Pistachia.*
Mazra'at Kfarzebian	1471	33° 59 49.2	035° 47 17.3	Habitat on the west side of Mount Lebanon running north parallel to Beirut. Closed canopy largely dominated by *Quercus cerris* leaving some space for other *Quercus sp.*, *Juniperus*, *Coronilla, Fumana* and *Rhododendron*. Types of disturbance: grazing, sand excavation.

Location	Rainfall (mm)	Texture	clay (%)	pH	EC (mS/cm)	K (ppm)	Ca (ppm)	Mg (ppm)	P (ppm)	Fe (ppm)	Mn (ppm)	$CaCo_3$ (%)	OM (%)
Kfarnabrakh	1170	loam	24	7.2	367	340	4101	340	61.5	6.0	18.8	69.6	6.6
Damour	600	sandy clay loam	26	7.7	187	252	4466	745	1.6	5.1	2.4	50.3	1.3
Beshwat	410	clay	48	7.5	192	720	6062	205	38.7	20.0	12.6	2.5	3.2
Ehden	1000	sandy loam	8	7.8	181	49	2277	145	2.0	4.8	0.5	95.9	1.6
Kfarzebian	1090	loamy sand	8	6.4	103	81	636	95	2.0	10.0	12.6	1.3	2.2
Ayn w Zayn	1170	loam	22	7.4	246	240	3424	1100	2.1	5.0	9.7	28.2	3.1
Batloun	1170	clay loam	33	7.6	188	240	4596	950	1.1	5.1	3.7	26.3	4.0

Table 6.2. Mean annual rainfall and soil characteristics (texture, % clay, pH, Electrical conductivity (EC), K, Ca, Mg, P, Fe, Mn, $CaCo_3$ and soil organic matter (OM)) for seven sites in Lebanon.

	Altitude	Mean annual temperature	Rainfall	Percent clay	pH	EC	K	Ca	Mg	P	Fe	Mn	$CaCo_3$	OM
A.syr	0.72	0.34	0.24	*	*	*	*	*	*	*	*	*	*	*
C.sil	*	*	*	*	*	*	*	*	0.21	*	*	*	*	0.50
J.exc	0.25	*	0.57	0.56	*	*	0.79	0.36	*	*	0.89	*	0.21	*
M.tril	*	0.78	*	0.26	*	*	0.20	*	*	*	*	0.29	0.51	*
O.carp	*	0.78	*	0.26	*	*	0.20	*	*	*	*	0.29	0.51	*
Q.cer	*	*	*	0.26	0.76	0.33	*	0.57	*	*	*	*	0.23	*
Q.coc	0.78	0.27	*	*	0.24	*	*	*	*	*	*	0.28	*	*
S.tor	*	0.78	*	0.26	*	*	0.20	*	*	*	*	0.29	0.51	*
S.off	0.25	*	*	*	0.49	*	*	*	*	0.22	*	0.72	0.41	020
OC (Shrub)	*	0.77	*	0.28	*	*	0.30	*	*	*	*	0.39	0.42	*
OC (Tree)	0.21	*	*	*	0.39	*	*	*	*	*	*	0.55	0.46	0.40

continued

Table 6.3. Correlation coefficients between selected tree species, tree, shrub and sub shrub densities and climatic and soil characteristics

Table 6.3. Continued

	Altitude	Mean annual temperature	Rainfall	Percent clay	pH	EC	K	Ca	Mg	P	Fe	Mn	$CaCo_3$	OM
OD (Shrub)	*	*	0.50	*	*	0.53	*	*	*	0.27	0.22	0.25	*	0.50
OD (Tree)	*	*	0.29	0.37	*	*	0.28	0.42	*	0.22	*	*	*	*
OD (sub shrub)	*	*	*	*	0.71	*	*	*	0.61	*	0.34	0.20	0.30	*
OE (shrub)	*	0.20	0.32	*	0.43	*	0.22	0.36	*	*	*	*	0.27	*
OE (Tree)	0.74	*	0.36	*	0.21	*	*	*	*	*	*	0.27	*	*
OE (Sub shrub)	*	*	*	*	*	*	0.58	*	*	*	*	*	*	
SHDI (basal area)	0.24	0.39	*	*	*	*	*	*	*	*	0.25	*	*	*
SHDI (species)	0.34	*	*	*	0.38	*	*	*	*	*	0.26	0.53	0.39	*

continued

Table 6.3. continued

SIDI (basal area)	0.35	*	0.46	*	*	0.41	*	*	0.40	*	0.65	*	*	*
SIDI (species)	0.24	*	*	*	*	0.26	*	*	*	*	*	0.42	0.27	*
Average R^2	0.41	0.54	0.39	0.32	0.30	0.49	0.31	0.43	0.40	0.33	0.45	0.38	0.37	0.40

* indicates correlation coefficients < 0.20.

Location	SHDI basal area	SIDI basal area	SHDI number of species	SIDI number of species
Beshwat	1.02	0.04	2.06	0.59
Ehden	1.13	0.30	2.74	0.77
Batloun	1.89	0.46	2.57	0.75
Damour	1.89	0.45	2.86	0.81
Kfarnabrakh	2.08	0.64	2.31	0.65
Ayn W Zayn	1.70	0.64	1.96	0.48
Mazra'at Kfarzebian	2.12	0.27	2.16	0.61

Table 6.4. Shannon diversity index (SHDI) and Simpson's diversity (SIDI) index calculated based on the number of woody species per site and the basal area of the species.

	Factor		
	1	2	3
Eigenvalue	2.5627	1.6572	1.0206
Cumulative	0.4271	0.7033	0.8734
Mean temperature	0.2127	-0.9728	-0.0435
Altitude	0.6692	0.7194	0.1329
OM	0.0037	-0.1108	0.9852
pH	-0.8056	0.1118	-0.0739
$CaCO_3$	-0.8632	0.3740	0.016
Fe	0.8219	0.1689	-0.1571

Table 6.5. Eigenvalues of the Correlation Matrix that resulted from PROC FACTOR of SAS.

Species	Locations						
	Beshwat	Ehden	Batloun	Damour	Kfarnabrakh	Ayn w Zayn	Mazra’at Kfarzebian
A.syr	0.00	0.00	0.00	10.80	0.00	0.00	0.00
C.sil	0.00	0.20	11.80	1.00	2.33	0.00	0.00
J.exc	5.80	0.00	0.00	0.00	0.00	0.00	0.00
M.tril	0.00	1.20	0.00	0.00	0.00	0.00	0.00
O.carp	0.00	4.00	0.00	0.00	0.00	0.00	0.00
Q.cer	0.00	0.00	0.00	0.00	0.00	0.00	15.40
Q.coc	0.20	3.60	5.60	29.20	1.67	1.60	0.20
S.tor	0.00	0.20	0.00	0.00	0.00	0.00	0.00
S.off	0.00	0.60	0.20	0.60	0.00	0.00	0.00
OC (S)	0.00	14.20	3.60	0.40	0.00	1.20	1.60
OC (T)	0.00	7.60	0.00	7.20	0.00	0.20	0.00
OD (S)	9.00	22.00	31.80	16.00	56.33	24.40	25.20

Continued

Table 6.6. Average number of plants per 200 m^2 at each site.

Table 6.6 Continued

OD (T)	0.60	4.80	1.40	0.20	1.00	7.60	4.80
OD (SS)	0.00	0.20	0.00	1.00	5.00	0.00	0.00
OE (S)	0.00	0.20	32.40	17.40	18.33	36.00	58.80
OE (T)	0.00	0.00	0.20	0.60	0.00	0.00	0.00
OE (SS)	20.20	0.00	45.80	11.60	25.00	161.40	0.00

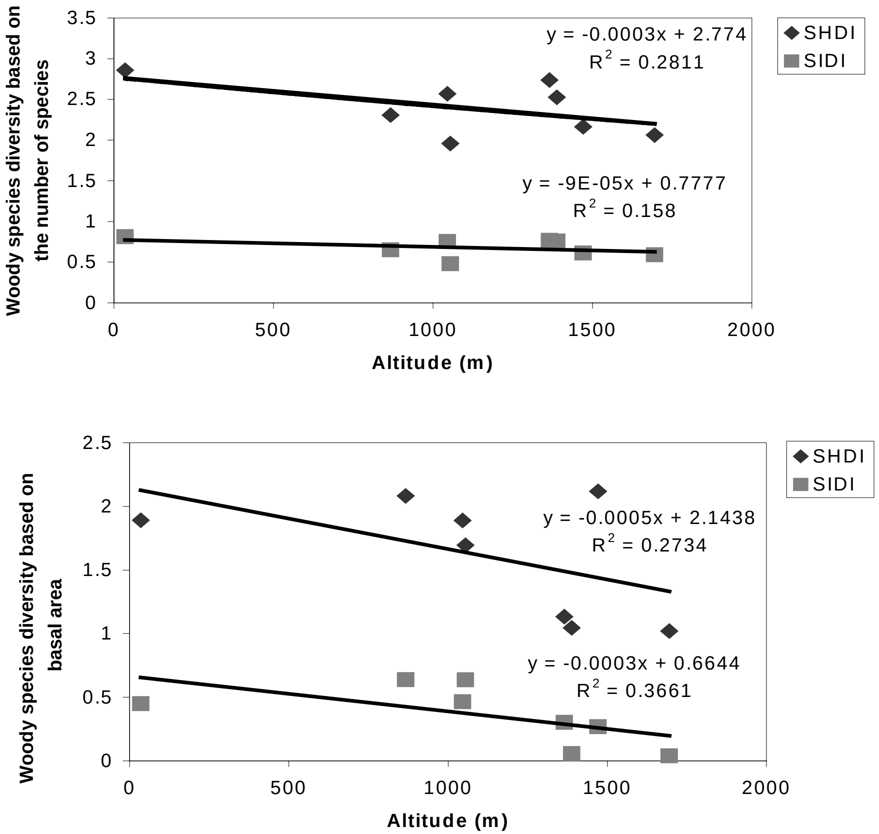


Fig. 6.1 Woody species diversity (average number per 200 m^2) plotted against altitude (m).

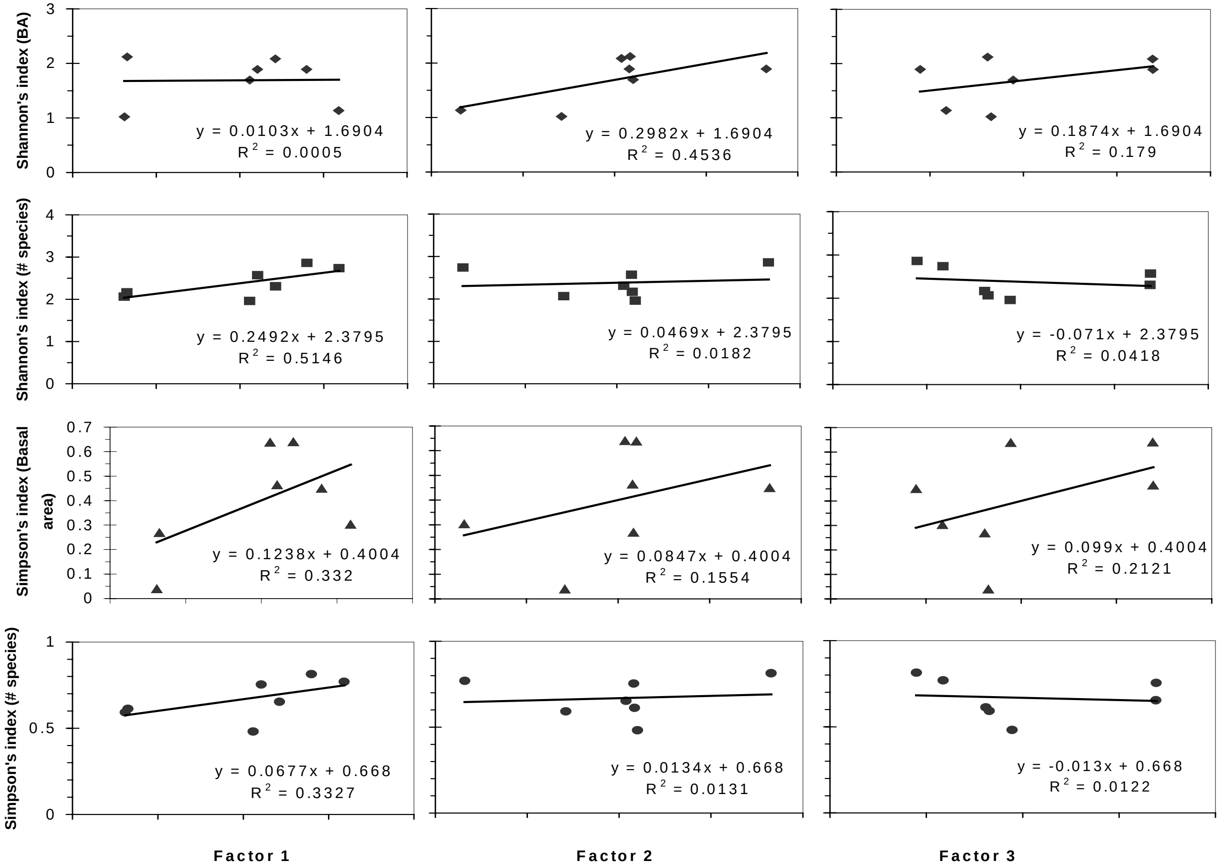
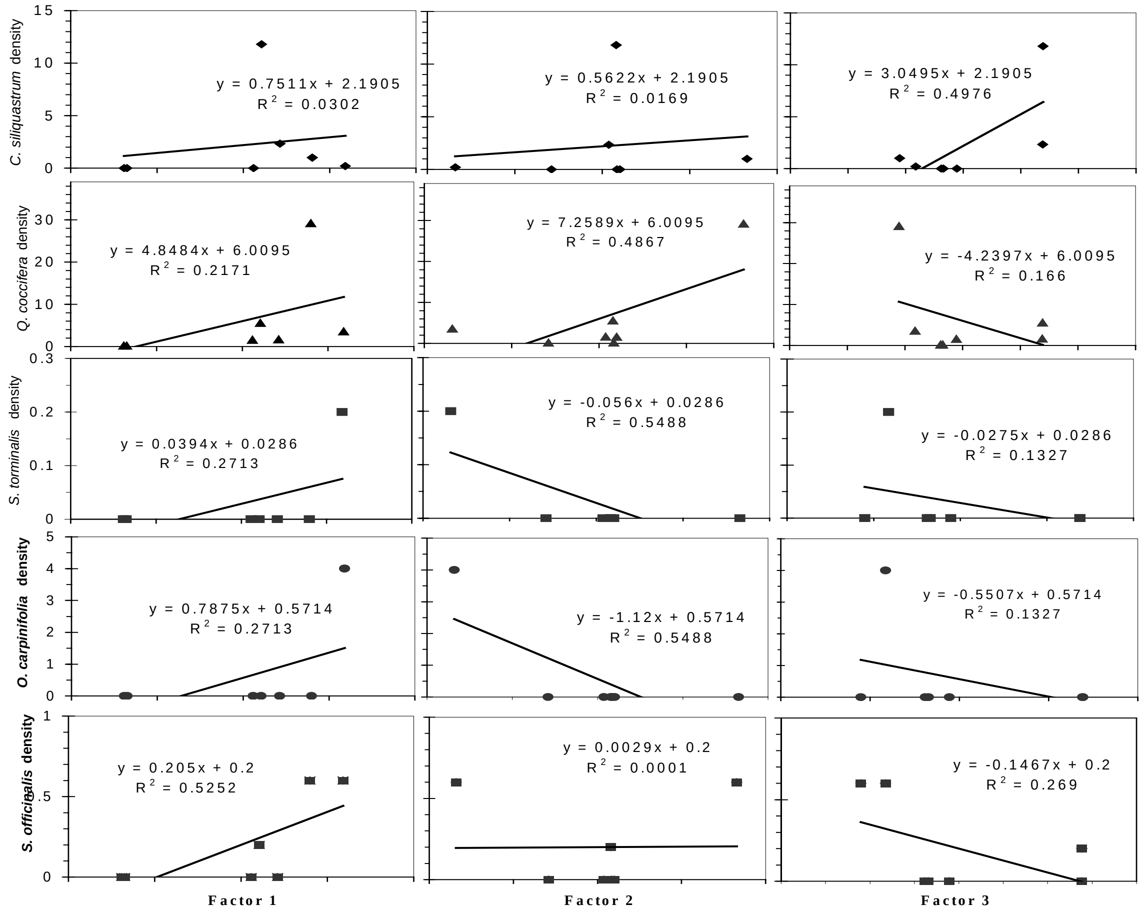


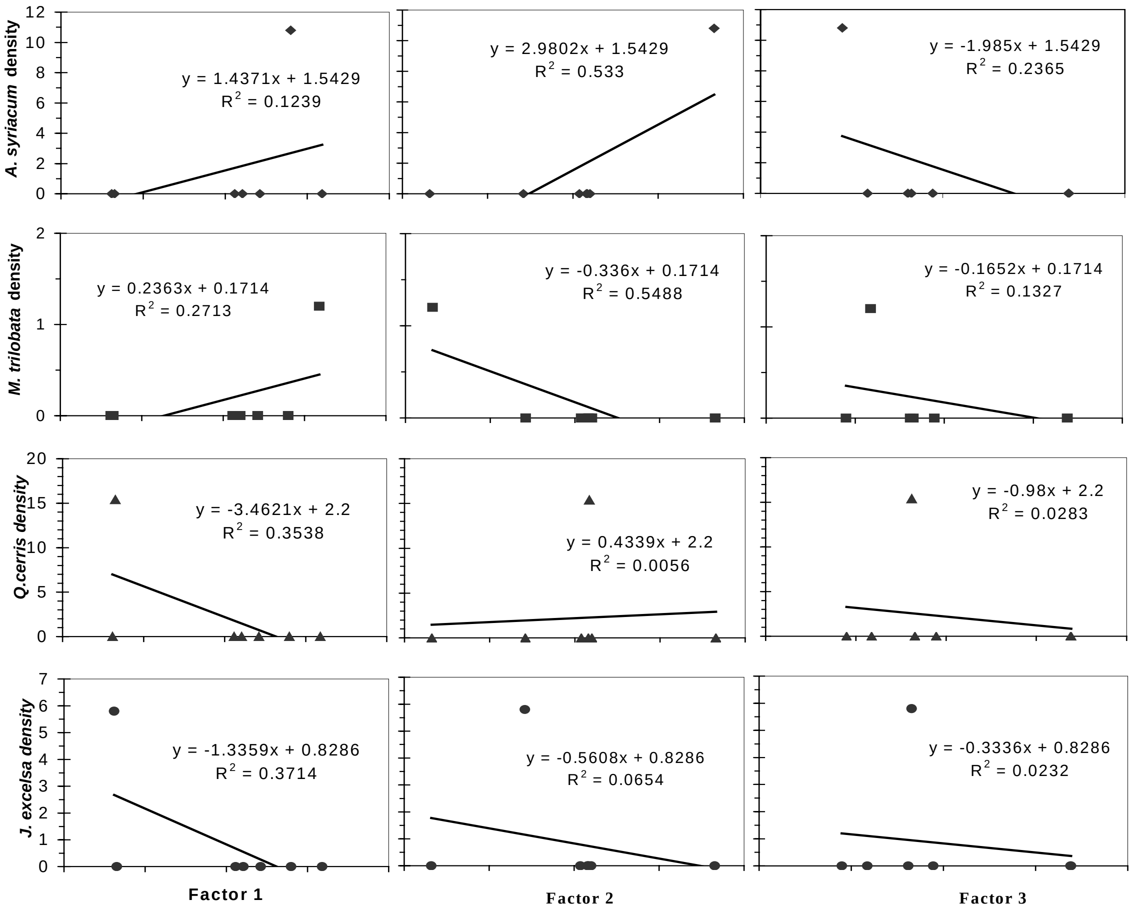
Fig. 6.2 Shannon and Simpson's diversity indices plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively.



Continued

Fig. 6.3 Tree species density plotted against Factor 1, Factor 2 and Factor 3 from left to right respectively.

Fig. 6.3 Continued



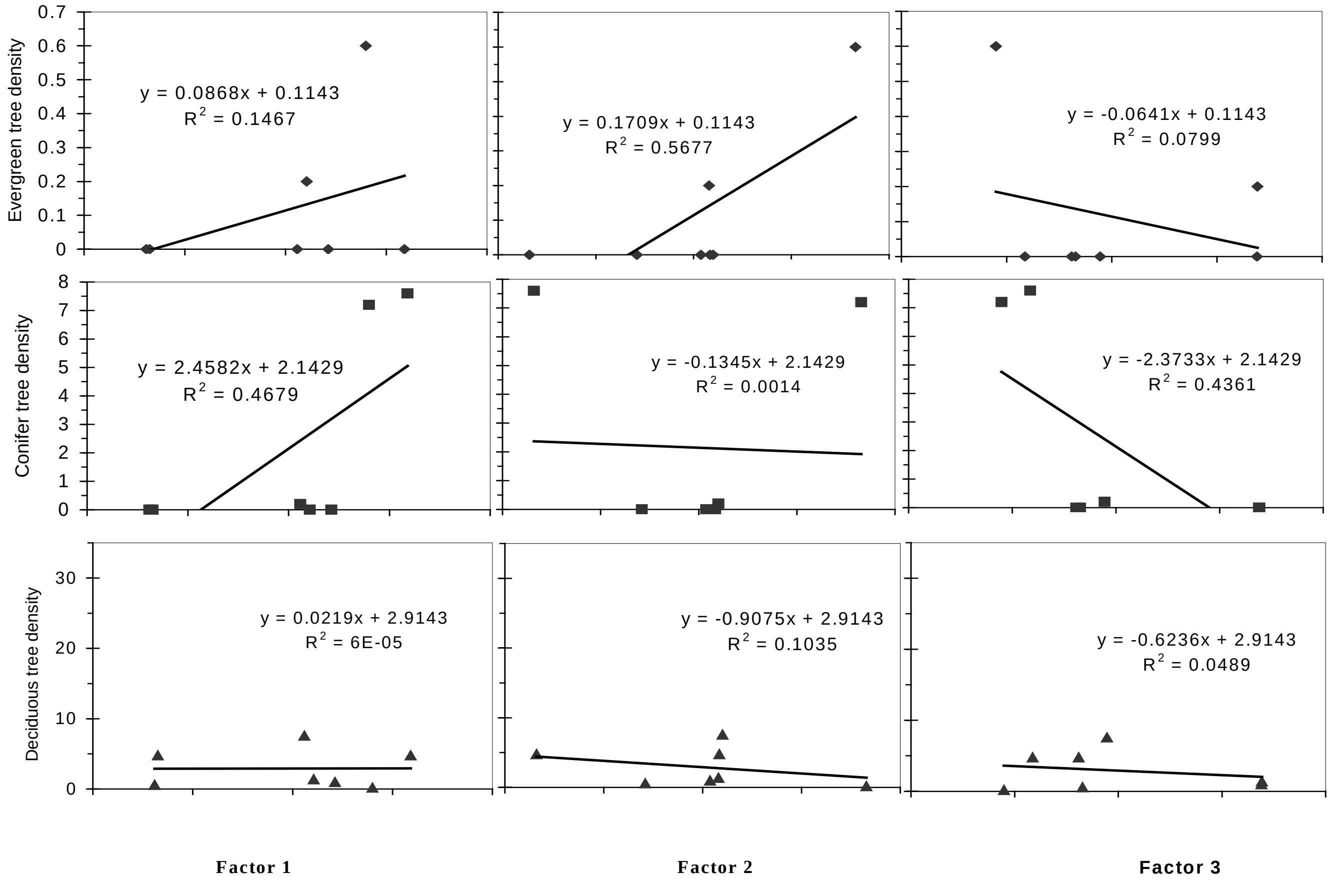


Fig. 6.4 Evergreen, conifer and deciduous tree density plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively.

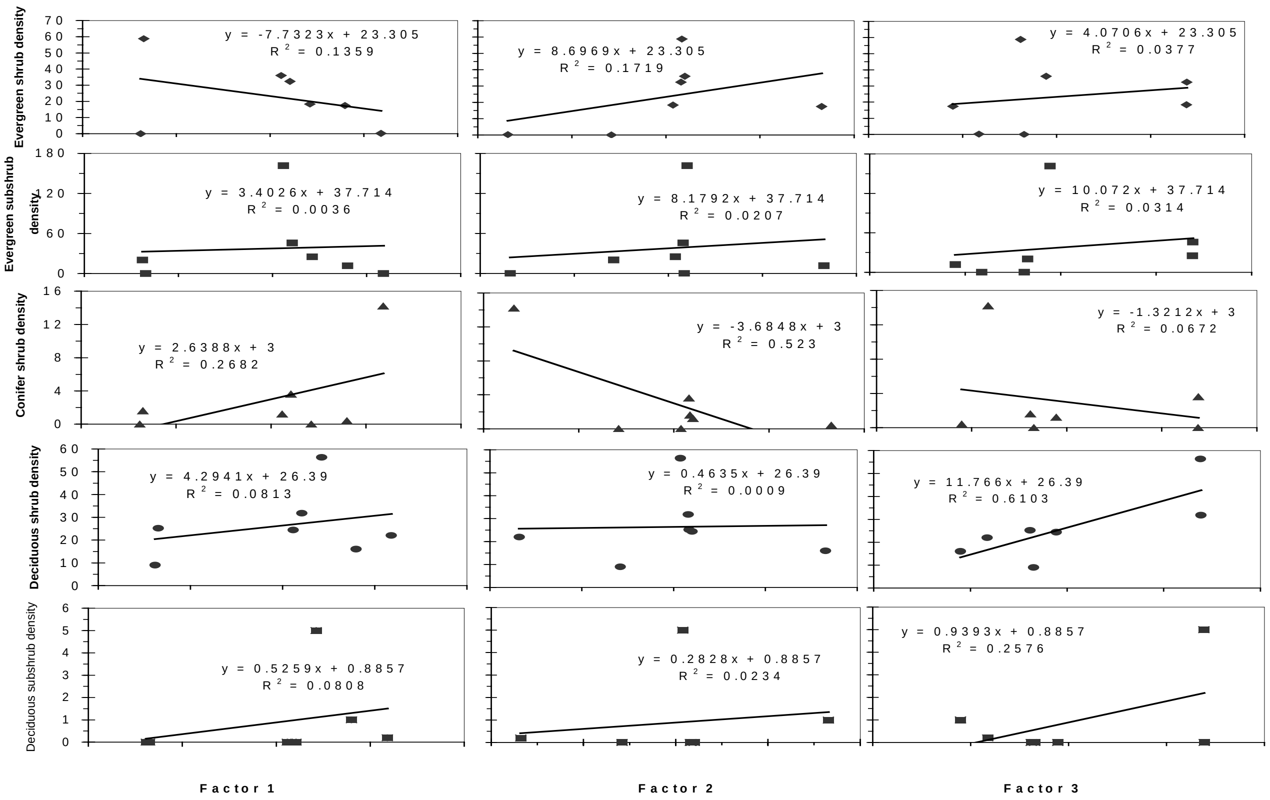


Fig. 6.5 Evergreen, conifer and deciduous shrub and sub shrub density plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively.

CHAPTER 7

DISCUSSION

The demand for landscape plants has been increasing in Lebanon. However most of the landscape plants used is imported although there is a great potential for native plant production industry. Production and marketing systems in Lebanon are not as sophisticated as in those countries from whom they import plants. The government should collect economic data on Lebanese nurseries production and sales. Additional methods of technology transfer need to be developed to supplement current government programs. Subject areas include: technical advice on fertilization and pest control, propagation techniques, compost and substrate, water quality and irrigation techniques. Because of nursery small size, nursery managers are responsible for all aspects of the nursery business. This does not allow them to focus their efforts in developing domestic and foreign markets or increasing the sophistication of their production techniques. Better management practices should be developed for the Lebanese nursery industry.

The challenges for developing a native plant market in Lebanon are many. The public is not familiar with plant names and is unaware of the benefits from using native plants. Another problem is the lack of information on the cultivation of native plants, sexual or asexual propagation, and application of the appropriate fertilizer and irrigation rates in field production. Other challenges we were faced with while conducting research were the degradation or loss of natural habitats and the lack of information related to the current distribution of the species of interest. The last information was gathered forty years ago by a French botanist, Paul Mouterde (1966 and 1970). Thus, we carried out the distribution study to locate selected species and tried to understand how a species density relates to the soil and climatic factors within its ecosystem. Eight habitats along an altitudinal gradient were studied and were characterized in terms of plant species, soil and climatic characteristics. Each ecosystem had a unique environment that could be described using the first two factors (70.3 % of variation) in a Factor Analysis of the six most important variables. Some species' densities were affected by soil conditions (the first factor) while climatic conditions (the second factor) explained the densities of species. Recommendations are made for the in-situ preservation of the nine species and their ecosystems. Overgrazing and soil erosion in Beshwat kept the trees and shrubs small and less than 1 m tall with the exception of *J. excelsa.* Also, the climatic conditions allowed a lower species diversity relative to other habitats, to exist. Ayn w Zayn and Batloun sites, although they had similar climatic, soil physical and chemical characteristics, varied in the number and type of species they harbored. The Mazra'at Kfarzebian with its lower pH relative to other sites had its own uniqueness with respect to its vegetation type where *Q. cerris*, *Coronilla emeroides*, *Fumana thymifolia* and *Rhododendron ponticum* var *brachycharpum* survive. Most of the populations of *Quercus coccifera* were very disturbed. Isolated individuals of *Sorbus torminalis*, *Malus trilobata* and *Ostrya carpinifolia* were seen. These trees suffer from lack of pollination resulting in a poor seed set and low quality seeds.

One way of preserving those species is by their propagation and reintroduction into their natural habitats. For this reason, three species native to Lebanon were selected for further studies. *Cercis siliquastrum* has nice ornamental characteristics in addition to being well adapted to semi-arid conditions and tolerant to pollution. *Malus trilobata* and *Acer syriacum* are two other native trees with ornamental attributes.

Germinated seeds from the three species were used to determine the potential for production of six Lebanese native *Cercis siliquastrum* sources, two of *Malus trilobata* and one of *Acer syriacum*, by exploring the growth, dry weight and N, P, and K nutrient uptake efficiency, and mineral nutrient partitioning during one growing season under two fertilizer rates. Our first hypothesis, that higher fertilizer rate results in better growth was false. The three species responded differently to fertilizer rates. Plants grown at the low fertilizer rate had greater root and total plant dry weight than those grown at the high fertilizer rate in *Cercis siliquastrum*. Also, height and caliper were not increased by the higher fertilizer rate. *Malus trilobata* plants grown at the low fertilizer rate were taller than those at the high fertilizer rate. Also, caliper, dry weights of shoot, root and leaf, and leaf area were not increased at the high fertilizer rate. In contrast, *Acer syriacum* growth was not affected by fertilizer rates. In conclusion, the rate 25 mg per L of the fertilizer 21-7-7 gave better growth in *Cercis siliquastrum, Malus trilobata* and *Acer syriacum*. It was therefore recommended that daily applications of 25 mg N per L be applied from the fertilizer 21 N- 3.1 P - 5.9 K (21-7-7) on *Cercis siliquastrum Malus trilobata* and *Acer syriacum.* A fertilizer savings of 75 % could be realized without reduced plant growth. Additional testing is needed to determine the optimum fertilizer rate for these species in this production system. Results in Ohio need to be confirmed in the Mediterranean climate of Lebanon. Also, different fertilizer rates (0, 10, 15, 25, 35, 50, 75 and 100 mg per L) should be tried out to find the optimal rate. Nutrient uptake and nutrient content were not affected by fertilizer rates in all three species. On the other hand, nutrient concentration increased in *Cercis siliquastrum* and *Malus trilobata* grown under the high fertilizer rate, a phenomenon referred to as “nutrient loading”. Nutrient loading has an advantage for conservation purposes (reforestation or reintroduction of species to their native habitats) because it increases the competitive ability for resources of species in weed-prone or heavily vegetated sites. However, possible benefits from this phenomenon should be confirmed by field trial experiments to determine whether the benefits of nutrient loading outweighs the decrease in plant quality (lower dry weight, higher shoot to root ratios that occurred in *Cercis siliquastrum*) when plants are transplanted.

Seed sources in *Cercis siliquastrum* and *Malus trilobata* affected growth and nutrient content; CS2 seedlings had the highest height, caliper and dry weight. CS1 and CS6 grew the fastest among other sources. There was significant within source variation: sources CS2, CS3 and CS4 came from the same geographical location, but seedlings of CS2 were significantly taller than those of CS3 and CS4; MT2 and MT3 came from the same location but MT2 grew better. These findings showed the need for seedlings from additional sources in Lebanon to be tested. Therefore, it was suggested that performance trial be carried out for individual tree collection in different sites in Lebanon.

Lebanon’s Mediterranean dry summer climate has created demand for landscape plants with low water requirement. Thus, we studied water use of container-grown plants and the impact of fertilization on water use in the three previously mentioned species. Fertilizer rates affected water use and adjusted water use per cm height in *Cercis* *siliquastrum*, *Malus trilobata* and *Acer syriacum.* No previous studies have been made on water use of container or field grown *Cercis siliquastrum*, *Malus trilobata* and *Acer syriacum*. In this study, plants grown at the low fertilizer rate used more water per cm height than those at the high fertilizer rate especially during the first two months of the study (Chapter 6). This was due to the fact that these plants were taller under the low fertilizer rate than those at the high fertilizer rate (Chapters 4 and 5). *Cercis siliquastrum* seedlings used the most water per seedling per hour followed by *Malus trilobata* then *Acer syriacum*. In addition, there were differences in water use among and within seed sources of *Cercis siliquastrum* and *Malus trilobata*. Sources CS1, CS2, CS6 and MT2 were the tallest (Chapters 4 and 5) and used the most water while those that grew the least used the least amount of water (CS4 and MT3). Water use efficient plants that were selected during the study from every species and source will be asexually propagated so that clonal studies confirm water use efficiency. It is recommended that future experiments be planned to determine the relationship between water use efficiency and drought tolerance.

Similar seed germination studies, growth, nutrient and water use experiments need to be carried out on more woody species with ornamental attributes native to Lebanon. In addition, Update information on the distribution of these species need to be published and made available to the public and local nursery managers.

Based on this research, we have identified propagation and production protocols for three species. In doing so we have discovered significant within source variation for economical important traits (growth rate and water use). Initial clonal propagation trials via rooted cuttings indicate that cutting propagation is possible. This allows for possibility of clonal testing and cultivar development for Lebanese and MidEastern climates. I have demonstrated *ex situ* conservation of endangered native flora through production is possible, and could serve as adjunct to *in situ* preservation efforts. What is the promise of native flora? It can be used to develop small farm enterprises, produce regionally-adapted species and cultivars, and give Lebanon a sense-of-place and national pride and possibly serve as a method for building national unity and contribute to regional stability and peace.

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APPENDIX A

Leaf, shoot, root, and total plant dry weights, N concentrations and content in leaf, shoot, root, and total plant tissues of *C.siliquastrum* sources harvested at the start of the experiment in May 2004.

Species	Dry weights (g)				Nitrogen concentration (%)				Nitrogen content (g)			
	Leaf	shoot	root	total plant	leaf	shoot	root	total plant	leaf	shoot	root	total plant
CS1	3.38	4.07	5.64	13.09	2.59	1.32	1.44	5.36	0.09	0.05	0.08	0.70
CS2	4.06	6.18	7.48	17.71	2.08	0.82	1.27	4.17	0.08	0.05	0.09	0.74
CS3	4.09	4.56	6.24	14.89	2.12	0.95	1.40	4.47	0.09	0.04	0.09	0.66
CS4	3.38	4.94	4.66	12.98	1.98	0.91	1.33	4.23	0.07	0.04	0.06	0.55
CS5	4.34	4.46	5.30	14.10	2.22	0.80	1.34	4.35	0.10	0.03	0.07	0.61
CS6	2.29	3.51	6.18	11.98	1.93	0.79	1.35	4.08	0.04	0.03	0.08	0.12

APPENDIX B

Leaf, shoot, root, and total plant dry weights, P concentrations and content in leaf, shoot, root, and total plant tissues of *C.siliquastrum* sources harvested at the start of the experiment in May 2004.

Species	Dry weights (g)				Phosphorus concentration (ug/g)				Phosphorus content (g)			
	Leaf	shoot	root	total plant	leaf	shoot	root	total plant	leaf	shoot	root	total plant
CS1	3.38	4.07	5.64	13.09	2547	2100	2277	6925	0.008	0.008	0.001	0.009
CS2	4.06	6.18	7.48	17.71	1798	1742	1849	5185	0.007	0.001	0.001	0.009
CS3	4.09	4.56	6.24	14.89	1635	1866	2135	5636	0.006	0.008	0.013	0.083
CS4	3.38	4.94	4.66	12.98	1632	2173	2631	6436	0.005	0.010	0.012	0.083
CS5	4.34	4.46	5.30	14.10	2054	1646	2519	6216	0.009	0.008	0.013	0.088
CS6	2.29	3.51	6.18	11.98	1970	1596	2546	6112	0.004	0.005	0.016	0.073

APPENDIX C

Leaf, shoot, root, and total plant dry weights, K concentrations and content in leaf, shoot, root, and total plant tissues of *C.siliquastrum* sources harvested at the start of the experiment in May 2004.

Species	Dry weights (g)				Potassium concentration (ug/g)				Potassium content (g)			
	Leaf	shoot	root	total plant	leaf	shoot	root	total plant	leaf	shoot	root	total plant
CS1	3.38	4.07	5.64	13.09	17758	8384	12942	39084	0.06	0.03	0.07	0.51
CS2	4.06	6.18	7.48	17.71	17578	8635	11948	38160	0.07	0.05	0.09	0.67
CS3	4.09	4.56	6.24	14.89	13219	9336	15747	38302	0.05	0.04	0.09	0.57
CS4	3.38	4.94	4.66	12.98	13217	7510	10818	31545	0.04	0.04	0.05	0.41
CS5	4.34	4.46	5.30	14.10	16934	8336	15721	40992	0.07	0.04	0.08	0.58
CS6	2.29	3.51	6.18	11.98	13664	8037	11238	32940	0.03	0.03	0.07	0.39

APPENDIX D

Leaf, shoot, root, and total plant dry weights, N concentrations and content in leaf, shoot, root, and total plant tissues of *M. trilobata* sources and *A. syriacum* harvested at the start of the experiment in May 2004.

Species	Dry weights (g)				Nitrogen concentration (%)				Nitrogen content (g)			
	Leaf	shoot	root	total plant	leaf	shoot	root	total plant	leaf	shoot	root	total plant
MT 2	1.30	3.07	3.63	8.00	3.01	1.38	2.20	6.60	0.04	0.04	0.08	0.53
MT 3	2.97	8.49	6.79	18.26	2.04	1.67	2.22	5.93	0.06	0.14	0.15	1.08
AS	2.75	2.90	4.23	9.88	2.22	1.08	1.63	4.92	0.06	0.03	0.07	0.49

APPENDIX E

Leaf, shoot, root, and total plant dry weights, P concentrations and content in leaf, shoot, root, and total plant tissues of *M. trilobata* sources and *A. syriacum* harvested at the start of the experiment in May 2004.

Species	Dry weights (g)				Phosphorus concentration (ug/g)				Phosphorus content (g)			
	Leaf	shoot	root	total plant	leaf	shoot	root	total plant	leaf	shoot	root	total plant
MT 2	1.30	3.07	3.63	8.00	2525	1278	2348	6151	0.003	0.004	0.008	0.049
MT 3	2.97	8.49	6.79	18.26	2096	1426	2187	5708	0.006	0.010	0.014	0.104
AS	2.75	2.90	4.23	9.88	1671	1363	1965	4999	0.004	0.004	0.008	0.049

APPENDIX F

Leaf, shoot, root, and total plant dry weights, K concentrations and content in leaf, shoot, root, and total plant tissues of *M. trilobata* sources and *A. syriacum* harvested at the start of the experiment in May 2004.

Species	Dry weights (g)				Potassium concentration (ug/g)				Potassium content (ug)			
	Leaf	shoot	root	total plant	leaf	shoot	root	total plant	leaf	shoot	root	total plant
MT 2	1.30	3.07	3.63	8.00	13434	7795	5114	26342	0.02	0.02	0.02	0.21
MT 3	2.97	8.49	6.79	18.26	15168	7133	6224	28525	0.04	0.06	0.04	0.52
AS	2.75	2.90	4.23	9.88	11157	12108	9579	32844	0.03	0.03	0.04	0.32