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Safeguarding and Restoring Lebanon's Woodland Resources Project

Technical Report

MINISTRY OF ENVIRONMENT - UNDP - GEF
NATIONAL REFORESTATION PROJECT

Recommendations for Improving Reforestation Practices in Lebanon Based on Results of Field Trials

Ministry of Environment

Safeguarding and Restoring Lebanon's Woodland Resources Project

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Beirut, Lebanon
December 2014

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Safeguarding and Restoring Lebanon's Woodland Resources Project

Technical Report

Recommendations for Improving
Reforestation Practices in Lebanon
Based on Results of Field Trials

Executed by
Ministry of Environment

Funded by
Government of Lebanon
Global Environment Facility (GEF)

Implemented by
United Nations Development Programme (UNDP)

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Foreword

Since ancient times, Lebanon's once world famous forests have been overexploited and destructed by many civilizations. Latest statistics indicate that forests cover only about 13% (137,000 Ha) of the total area of Lebanon.

Considerable efforts were exerted in the past decade by all concerned parties aiming at increasing Lebanon's forest cover up to 20%, which represents the average of the Mediterranean countries.

However, our traditional methods seemed outdated and very costly. Survival rates of the planted seedlings remained modest in most cases.

There was need to introduce a major change in our approaches and to adopt modern reforestation techniques both in terms of seedling production and planting practices.

Hence, the Ministry of Environment implemented the "Safeguarding and Restoring Lebanon's Woodland Resources" Project, in coordination with the United Nations Development Programme (UNDP) and funding from the Global Environment Facility (GEF).

One of the major objectives of the SRLWR Project was assessing new techniques of reforestation through trials in different pilot sites distributed over the country. No such trials were ever implemented in Lebanon since the 1960's.

Initial observations indicated 100% survival of seedlings and 72% survival of direct sown seeds reached through the application of certain best practices without any irrigation and at low costs.

The current publication is the summary of the findings of these trials, along with recommendations regarding successful and low-cost modern reforestation techniques that were found suitable to the Lebanese conditions. Many of these best practices have already been implemented successfully on large-scale applications.

The Ministry of Environment presents this report to all parties concerned, with the prospect of paving a new path of reforestation in our beloved homeland, Lebanon.

Mohamad Al Mashnouk
Minister of Environment

Acknowledgements

The Safeguarding and Restoring Lebanon's Woodland Resources (SRLWR) Project team would like to express its deep gratitude and appreciation to all partners (governmental institutions, local administrations, non-governmental organizations and the private sector) for the unlimited support provided throughout the implementation phases of the project, sharing of information on their previous experiences with the project, their commitment and dedication towards the adequate planning and execution of the field trials, as well as their kind involvement and participation in all project activities.

Meeting all project objectives and exceeding some expectations were made possible only through this fruitful collaboration and sharing the same vision of joining efforts for introducing a new era of modern, successful and low-cost reforestation in Lebanon.

The SRLWR Project team thanks in particular:

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Acronyms and Abbreviations

AECID	Spanish Agency for International Development Cooperation
AFDC	Association for Forests, Development and Conservation
FAO	Food and Agricultural Organization of the United Nations
GEF	Global Environmental Facility
HP	hand-tool soil preparation
IRR	conventional irrigation
IUCN	International Union for Conservation of Nature and Natural Resources
LBP	Lebanese Pound
LRI	Lebanon Reforestation Initiative
MoA	Ministry of Agriculture
MoE	Ministry of the Environment
MP	mechanical soil preparation
NGO	nongovernmental organization
NIRR	no irrigation
NP	no soil preparation
NRP	National Reforestation Plan
NRSW	non-rechargeable solid water
RSW	rechargeable solid water
SC	silt-clay soil
Sd	sandy soil
SP3	3 seeds planted per basin or spot
SS200	200 seeds sown in a patch
SRLWRP	Safeguarding and Restoring Lebanon's Woodland Resources Project
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USD	U.S. Dollar
USDA	United States Department of Agriculture

Executive Summary

The “Safeguarding and Restoring Lebanon’s Woodland Resources Project” (SRLWRP) is an ambitious effort by the Lebanon Ministry of Environment (MoE), through funding from the Global Environment Facility (GEF) and with implementation by the United Nations Development Programme (UNDP) , to help advance reforestation efforts underway in Lebanon, a country world famous for its formerly vast forests.

This report presents the results of 3 different sets of field trials implemented by the project in 8 pilot sites on different new reforestation techniques, extending from 2011 till 2014. Because of current high costs of reforestation in Lebanon estimated at around 7,000 USD per hectare (at a density of 800 seedlings/Ha), the main objective of the field trials was to assess the prospects of successful reforestation in Lebanon at low costs and possibly without any irrigation. This report also provides context for the Project’s work in terms of the need to preserve and expand the historic Cedars of Lebanon as well as other forests; their past depletion, current forest conditions, and the many reforestation efforts underway by government and nonprofit sectors. It outlines SRLWRP technical assistance to the MoE in launching the third phase of its National Reforestation Programme, aimed at building capacity for large-scale forest restoration and maintenance over the next two decades. SRLWRP goals included developing a management framework to restore degraded forest areas, pilot-testing novel planting practices for improved seedling survival at lower cost, and diffusing innovative practices into restoration efforts. Towards these ends, the SRLWRP helped the MoE improve reforestation contracts with municipalities, provided technology transfer to improve nursery and reforestation practices, facilitated the first degree program for foresters in the country, and participated in the creation of an oversight group among all entities to guide future reforestation.

Direct sowing of seeds appeared to be an attractive method despite of low germination/ survival rates, due to the very low cost of this technique. Natural regeneration capabilities are limited in Lebanon, due to the low availability of seeds. There are a few mature cedars and pines, but these are heavily harvested for seeds and nuts. Therefore, in the past years, planting of seedlings has been the most widely used method of reforestation in Lebanon. However, direct sowing of seeds can be another successful method and it can provide excellent results at lower cost, if implemented at the right timing and in proper soil conditions. Broadcast seeding has been used successfully in Turkey with *C. libani*, but soil preparation was required and planting worked better where soil was deeper.

Containerized plants produce higher quality seedlings for outplanting. Good quality substrate, deep containers, mycorrhizal inoculation, fertilization, additional of hydrogel, and drought preconditioning may increase survival and/or growth, depending on site conditions and species. Both *C. libani* and *P. pinea* are fairly sun tolerant, so shading treatments are probably not needed except in extreme situations. Common irrigation methods in Lebanon include hand-watering, drip irrigation, or deep pipe systems; hydrogels (“solid water”) are a relatively new method of supplementing water at reforestation sites and have been tested by the SRLWR

Project for the first time in Lebanon. Cost estimates for reforestation in Lebanon range from 4,400 USD to over 10,000 USD per ha and are higher than those reported in most countries. Although under past nursery practices, older seedlings were thought to regenerate better, the SRLWRP planting trials indicated that younger seedlings (8–10 months old) actually do as well as the 18 months old seedlings.

SRLWRP's greatest achievement was the implementation of three successive sets of trials throughout Lebanon for testing new techniques to reduce planting costs and improve seedling survival. These are described after reviewing recent literature on reforestation practices from the United States, Europe, and the Mediterranean, with focus on species of interest, such as the Lebanon cedar (*Cedrus libani*) and stone pine (*Pinus pinea*). The SRLWRP planting trials were the first test of new reforestation techniques in the country in almost 50 years. Irrigation (including two novel methods), seedling age, seeding techniques, soil preparation methods and soil texture were compared. Data gathered was used to condense and compare costs of treatment combinations for *P. pinea* graphically and with a generalized linear mixed model statistical analysis. *C. libani* results were only for one silt-clay site, where high germination for irrigated seed planting but minimal overall survival was observed.

Overview of Arz-Bcharre trial site

One of the most promising findings is that direct seeding without irrigation can be used in some cases at very low costs. Test results showed that for *Pinus pinea*, the most promising cost-effective (<1,500 USD/ha at a density of 800 seedlings per ha) planting method was seed planting without irrigation on sandy soil. Just under half of *Cedrus libani* seeds planted without irrigation on a silt-clay site germinated but zero survived. The next best choice was planting seedlings on sandy soil without irrigation (2,300-3,900 USD/ha of 800 seedlings). Survival was not different among the different ages tested (range of 8 to 18-months old seedlings). Novel water methods did not increase survival rate as compared to conventional hose irrigation, and some of these were much more costly than conventional irrigation.

Overall, survival of *Pinus pinea* was better in sandy soils than on silt-clay soils, but further study on silt-clay soils is needed. Different soil preparation methods (hand or mechanical preparation, or none) did not result in significant differences in survival.

In parallel, the project provided technical support to local tree seedling producing nurseries aiming at raising their capacities and enable them to shift from conventional production methods to modern nursery techniques. It is worth mentioning that during the past 5 years there has been remarkable progress in the production of tree seedlings by Lebanese nurseries. Whereas till 2009 most nurseries produced seedlings in nylon bags, production trends have shifted towards the use of plastic containers, as recommended by international experts and as practiced in modern nurseries of the USA and Europe.

The process of production of container seedlings passed through several stages, and between 2010 and 2014, 3 generations of container seedlings were produced. While the first generation seedlings (used in set 1 trials) were of relatively low quality, the third generation seedlings (used in set 3 trials and the large-scale field applications) were practically comparable to seedlings produced in developed countries.

The SRLWRP acknowledges the fact that if such seedlings were available and used in the trials of both sets 1 and 2, performance and survival of these seedlings would have been considerably better.

The importance of the project trials lies in the fact that no trials on new reforestation techniques were ever been implemented in Lebanon since the 1960's, when the Ministry of Agriculture has tested several methods, such as direct seed sowing, minimization of irrigation and terracing. Unfortunately however, the results of these trials were lost during the past years. Therefore, the current trials along with the results obtained and recommendations on the most successful and cost effective methods are expected to pave the way for the adoption of modern reforestation concepts in Lebanon.

CHAPTER ONE: Introduction

1.1 A Brief History

1.1.2 Abundance and Exploitation

From ancient times the great forests of Lebanon have been a symbol of power and been overused by the civilizations of the world. This report describes an ambitious project to help restore trees to the denuded mountains of Lebanon.

With its soaring mountains rising from the Mediterranean Sea and afternoon mists bathing the front range, the area is well suited for growing trees. Historical records and recent pollen studies indicate that Lebanon was once covered with great forests of cedar (*Cedrus libani*). There were also significant populations of 9 other conifers including Cilician fir (Abies cilicia), Mediterranean cypress (*Cupressus sempervirens*), several juniper varieties (Juniperus spp.), Calabrian pine (*Pinus brutia*), and Aleppo pine (*P. halepensis*) (Talhouk et al. 2001). Forest cover in prehistoric time was estimated to exceed 70% (UNDP 2008). The massive *C. libani*, with its undulating network of branches, is the national emblem of Lebanon, featured on its flag and coat of arms. The large evergreen has been praised as a symbol of beauty, majesty, and healing (Cedars Forever 2009).

The ancient Mediterranean probably looked like northern Europe does today, with great coniferous forests in Lebanon, Turkey, and Corsica, and oaks and beeches in Italy. The perennial springs of higher Lebanon were probably fuller and more constant, the lower slopes green and moist; there may have been greater annual rainfall through recirculation of water on the western slopes by forest transpiration. "The forests and animals were thought to be inexhaustible," according to Masri (1995).

Historical and religious literature indicates the civilizations of the region had been overexploiting the woodlands of Lebanon for millennia: the Epic of Gilgamesh, written around 2700 BCE, refers to a story even 2000 years earlier where a Mesopotamian ruler overcomes gods protecting a cedar forest and cuts the forest. Some pollen studies indicate Neolithic people may have been clearing cedar even earlier—around 7700 BCE (Yasuda et al. 2000)—and that warmer climate during the Holocene also altered the range of forests (Hajer et al. 2010). Bible records (circa 600 BCE) mention Cedars of Lebanon as building material for King David's House of the Forest and Solomon's Temple; as a symbol of divine power; their destruction as a symbol of human conquest; and their future restoration as a symbol of restored harmony between the Creator, the earth, and humankind.

The Phoenicians, an earlier civilization in Lebanon, financed their great international trading empire on export of *Cedrus libani* wood to Egypt. The Assyrians, Babylonians, Romans and Turks of the Ottoman Empire all exploited *C. libani*. Remaining stands were used during World War I for railroad fuel, and during World War II British forces cut Abies cilicia and oak to build a railway between Tripoli and Haifa (Mikesell 1969).

Local settlers also contributed to woodland decimation. As early as the 7th century, groups moved into rural areas and established villages at high elevations; cutting of mature trees and destruction of seedlings by grazing livestock depleted stands of cedar and fir. Juniper

(*Juniperus excelsa* and *J. foetidissima*) seedlings on the heights of Mount Lebanon were eliminated by goats. As cedar and fir were depleted, juniper was also cut for building material and fuel. At lower elevations, cutting, browsing, and burning greatly modified the oak woodland. Since oaks sprout vigorously when cut, burned, or grazed, this woodland became a stunted shrubland or maquis (Mikesell 1969).

Illegal logging

Grazing

Lebanon's woodlands have more recently been exploited for firewood, agriculture, and for lime furnaces and quarries (Talhouk et al. 2001). The Lebanese Civil War (1975–1990) also caused more people to leave urban areas and move to the mountains, creating urban sprawl and further deforestation and land degradation (UNDP 2008).

1.1.3 Early Reforestation Efforts

Experts dispute whether stone pine (*Pinus pinea*) is native to Lebanon, but there is evidence that the species was at least introduced fairly early in history. According to the prominent late historian Philip Hitti (1965) a 12th century Arabic geographer, Al-Idrissi, observed pine forests around Beirut of more than 3,000 hectares. Hitti attributes the further expansion of this forest currently known as "Beirut forest" to Emir Fakhreddine II, who lived around 1590–1635 CE and contributed to the large distribution of pine trees in many regions of Mount Lebanon.

Early Reforestation Efforts

There were no major reforestation activities in Lebanon before its independence in 1943, except some limited *P. pinea* plantations through personal initiatives around 1930–1940 (Sfeir 2011). Between 1960 and 1975, the most ambitious reforestation occurred under the “Green Plan” initiated by the Lebanese Government. This resulted in the establishment of mixed stands of conifers and hardwoods and in starting national nurseries. Efforts were also initiated to restore *Cedrus libani* in the Shouf Mountains (Talhouk et al. 2001). Successful reforestation occurred in Barouk and Falougha in Mount Lebanon; Lala, Ain Yaacoub, and Rachaya in the Bekaa region and Kfarhazir in the Casa of Koura in North Lebanon. Political instability and lack of funding during the civil war years prevented any further large-scale reforestation activities.

1.2 Lebanon’s Forests: the Present Situation

A 2005–2006 Forest Resource Assessment based on a forest map developed in 1965 estimated Lebanon forest cover at 13% and other woodlands at 10%. Of the woodlands, 32% is conifer composed of 23% *Juniperus excelsa*, 18% *Pinus pinea*, 5% *Cedrus libani*, 3% *Cupressus sempervirens*, and 40% a mix of *Pinus brutia* and Pinus halepensis (Daalsgaard 2005). The nonconifer woodlands (68%) are dominated by evergreen and deciduous oak. The assessment, done by the Food and Agriculture Organization of the United Nations (FAO) in cooperation with the Lebanon Ministry of Agriculture (MoA) and based on 222 permanent sampling plots, also found 85% of their sample forests to be degraded, 60% in private ownership (providing difficulties for any national sustainable management effort), and 14% impacted by fire. The famous Cedars of Lebanon (*C. libani*) have been reduced to only 12 stands (over 2000 hectares) throughout the country (Masri 1995); some are protected as reserves. Talhouk et al. (2001) reported continuing trends of degradation:

> The mountain ecosystems of Lebanon are characterized by steep slopes, intense winter rainfall and long dry summers. Recent uncontrolled expansion of coastal cities and summer mountain resorts, and agricultural expansion in rural areas, have exacerbated land degradation caused by landslides, flash floods and forest fires…. It is estimated that 800,000 sheep and goats are using woodlands and degraded highlands for at least 2 months per year….Continuous overgrazing has prevented regeneration of forests, especially the slow growing conifers, and compounded the effects of deforestation.

Degraded forest in Aitanit

The impoverished adjacent village communities are dependent on these areas for grazing and firewood cutting.

With the onset of climate disruption, higher temperatures and drought, forest fires, and insect attacks have been increasing in frequency and severity of deforestation (Talhouk et al. 2001). Because of potentially higher temperatures, less rain, shorter winters, and less snow in the mountains of the Mediterranean region due to climate change (Lebanon's Second National Communication report to the UNFCCC 2011), the International Union of Conservation for Nature (IUCN) has added *Cedrus libani* to its Red List of Threatened Species (IUCN 2014). The IUCN also notes specific insects that recently have targeted and weakened the cedar along with encroaching housing development. Future scenarios of warming indicate that *C. libani* might be limited to the highest elevations. Currently most *C. libani* forests thrive at an elevation of 1,100-1,900 meters. They can survive at elevations of 2,400 meters (Khouzami 2014). This leaves a migration margin of just around 500 meters of altitude. Some scientists say that *C. libani* groves already near the mountaintops literally may have nowhere to go (Hajar et al. 2010).

Cephalcia tannourinensis symptoms on cedars in Bcharre

1.3 Reforesting Lebanon in the New Millennium

1.3.1 Lebanese Government Efforts Prior to 2009

The new millennium has seen renewed efforts and interest in reforesting Lebanon. The largest effort has been the National Reforestation Plan (NRP) of the Ministry of Environment (MoE), which was created in 1993 and started sharing reforestation responsibilities with the MoA, specifically overseeing protected forests and establishment of new forests since 2001. MoE was then allocated approximately 16.7 million USD to initiate the NRP. The NRP aimed at a short-term reforestation effort and a longer term (30-year) strategy to restore Lebanon forest cover to 20% (requiring restoration of 100,000 hectares) (MoE 2014).

From 2002-2006 the first two phases of reforestation on 580 hectares of degraded lands were accomplished by the MoE. Sites were selected according to a specific criteria developed on the basis of land-cover use maps of Lebanon that showed areas appropriate for reforestation, as well as applications from municipalities interested in reforestation, emphasizing restoration of degraded rangelands and watersheds as well as land ownership factors (government rather than private ownership was preferred to ensure sustainability). Depending on area, sites were replanted with indigenous species of pine (*Pinus pinea*, *P. brutia*, *P. halepensis*), cedar (*Cedrus libani*), juniper (*Juniperus excelsa*), cypress (*Cupressus sempervirens*), fir (*Abies cilicica*), carob (*Ceratonia siliqua*), wild almond (Prunus amygdalus), and Pistachio of Palestine (*Pistacia palaestina*). During these first two phases, the MoE contracted private firms for the implementation of reforestation and maintenance works.

NRP Phase 1 (Jezzine)

NRP Phase 2 (Hammana)

The implementation of reforestation works was carried out according to the specific criteria set by the NRP, which can be summarized as follows:

Seedling age: 1 to 2 years (as a minimum)

Container type: nylon bags of 1,000 cm^3

Hole sizes: 50 x 50 x 50 cm

On-site irrigation: twice during the 1^{st} year

Maintenance: clearing of weeds 4 times during the first 2 years (twice per year)

These requirements made reforestation costs in Lebanon reach up to 8.67 USD/seedling, summing up to around 6,936 USD/Ha/800 seedlings (including seedling cost, transplantation, irrigation and maintenance over 2-3 years). This cost is extremely higher than most developed countries of the world and countries of the region, where it usually does not exceed 2,000 USD/Ha/800. Table 1 below summarizes the major differences between the NRP specifications and modern reforestation concepts:

Table 1: Table 1: Comparison between NRP requirements and modern nursery techniques

	NRP	Modern reforestation
Seeding age	1 to 2 years	8 months
Container type	Nylon bags of 1,000 cm^3	Re-usable plastic containers of 350-450 cm^3
Hole sizes	50 x 50 x 50 cm	20 x 20 x 20 cm
On-site irrigation	Twice during the 1st year	No irrigation at all
Maintenance	Clearing of weeds 4 times during the first 2 years (twice per year)	Clearing of weeds 4 times during the first 2 years (twice per year)

Taking these differences into account, there was need to introduce a major change and take a step forward towards modern reforestation concepts in Lebanon. This was the main objective of the “Safeguarding and Restoring Lebanon’s Woodland Resources Project” (SRLWRP).

1.3.2 The SRLWR Project: National and International Collaboration

In early 2009 the Ministry of Environment (MoE) launched the “Safeguarding and Restoring Lebanon’s Woodland Resources Project” funded by the Global Environment Facility (GEF), a partnership for international cooperation on global environmental issues, and implemented by the United Nations Development Programme (UNDP).

The overall objective of the SRLWRP was to “complement the on-the-ground investments undertaken through the National Reforestation Program through the creation of an enabling environment and by building capacity for sustainable land management as a contribution to greater ecosystem stability, enhanced food security and improved rural livelihoods.” Three key outcomes were anticipated:

1. An appropriate management framework and management capacities for safeguarding and restoration of degraded forest areas. This included institutional acceptance of the strategies, ideally improvements to current forestry law, a single entity to guide future restoration work, and increased numbers of forest engineers (resource managers) trained in restoration.

2. A set of innovative technologies and instruments for the rehabilitation of forests and woodlands and their subsequent sustainable management. This has been designed and validated in pilot areas, and included methods for

more community involvement and testing novel planting practices on representative field sites for improved seedling survival at lower cost.

3. Monitoring, learning, adaptive feedback, and management. This included public awareness, outreach, and diffusion of innovative practices in large-scale restoration efforts and monitoring for continuous improvement adaptation.

Project achievements are briefly outlined below. The innovative technologies tested and validated (objective 2), the main subject of this report, are detailed in Chapter 3 (SRLWRP Field Trials).

1.3.2.1 Local Reforestation Management

In early 2010, the SRLWR Project assisted the MoE in the launching of a new phase of reforestation (phase 3). To improve implementation in this phase, the SRLWR Project proposed a new contracting modality, based on a participatory approach of contracting directly interested municipalities to accomplish reforestation works in their respective regions, rather than contracting private firms and third parties (which produced little ownership by local governments and communities in the planting and maintenance works). The MoE would select among municipalities that submitted proposals, based on site selection criteria developed by the Project in coordination with the Service of Conservation of Nature at MoE. MoE would also provide training and monitoring to the municipality staffs involved in reforestation activities.

Following the adoption of this new unprecedented modality, the Project team worked with the Ministry of Finance to develop a new contract model for working directly with municipalities. Thus, between 2010 and 2011, MoE contracted 48 municipalities to conduct reforestation on 191 hectares of land. Most of these plantations were *Pinus pinea*, which provides high economic returns (40-50 USD per kg of unpeeled seeds, Stephan 2013 – around 70 USD while the preparation of this report) and is intensively managed (most trees are pruned periodically). These projects provided community awareness of forest benefits, training to the local communities on modern planting and maintenance techniques, and creation of short and long-term job opportunities in the villages (MoE 2014).

MOE signing contracts with municipalities

Bassil (2014) developed an in-depth report on the benefits of this approach with recommendations on how to sustain it. Stephan's (2013) study discussed potential economic benefits of the various agroforestry crops, wood products, and non-wood products as well as the additional benefits of skill development, job creation, and public awareness.

1.3.2.2 Institutional Capacity

A Steering Committee convened for Project oversight in 2012 and 2014 has become the coordinating entity for reforestation with representatives of MoA, MoE, universities, and participating nongovernment organizations (NGOs). In addition, the Project team's coordination with the Spanish Agency for International Development Cooperation (IDAF) and University of Cordoba (Spain) has resulted in the creation of the first B.Sc. program in forestry at the Lebanese University. The Project team also facilitated a broad number of capacity-building exercises, as discussed below, and assisted a nature reserve committee and 2 monasteries (which offered land space for the Bnabil field trials and Wadi Al-Karm large-scale plantations: see Set 3 trials below) in creating their own nurseries, each producing 20,000 seedlings a year.

Nursery of St. Michael Monastery in Bnabil

1.3.2.3 Reforestation Studies Initiated and Results Implemented

The SRLWRP also initiated field trials on seven different sites throughout Lebanon, testing 18 different treatments on growing *Pinus pinea* and *Cedrus libani* with the main objective of decreasing reforestation costs in Lebanon. Details, findings, and recommendations are detailed in Chapters 3 and 4.

Initial "best practices" shown cost effective and successful in the field trials have been implemented in eight large scale reforestation projects carried out in cooperation with and participation of several municipalities, monasteries, local communities, NGOs, universities, schools, scout associations, and others. A total area of 25 ha has been reforested during fall 2013–winter 2014.

1.3.2.4 Capacity Building Through Expert Visits and Training

SRLWRP has helped build capacities of local nurseries by coordinating several training sessions conducted by international experts, including a field trip for some Lebanese experts to visit nurseries in the United States and learn new planting techniques. The Project also organized a customized training in Turkey for 8 Lebanese nursery experts on modern techniques of extraction of *C. libani* seeds from cones and germination of Juniperus seeds, methods with which Lebanese nursery operators were not yet familiar. Partly due to Project assistance, training, and cooperation with other entities, the nursery sector has shifted from conventional practices to modern techniques practiced in the United States and Europe, such as shifting from seedling production in plastic bags to modern containers. Over the past 5 years, quality of new seedlings produced by local nurseries has greatly improved, with characteristics and performance similar to those produced by high-tech nurseries in the United States and Europe. New seedlings have withstand drought and long hot seasons better than those produced in the past and have a high survival rate under tough climatic conditions even with limited or no irrigation at all.

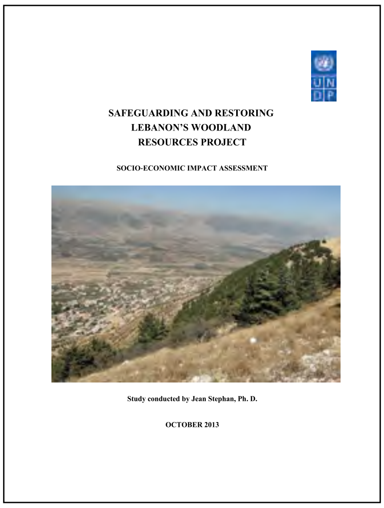
Training in Mersin

Training in Mersin

1.3.2.5 Studies Sponsored by the Project

The Project also sponsored several complementary studies to advance reforestation in the country:

- An assessment of the socio-economic impact of the Project on the local communities where reforestation activities were undertaken and field trials implemented. This report gave very detailed information on the economic returns to the local communities in terms of incomes earned in reforestation works and maintenance practices (and projected work/incomes once the seedlings planted are a harvestable *Pinus pinea* crop) as well as benefits of skill training and participatory management.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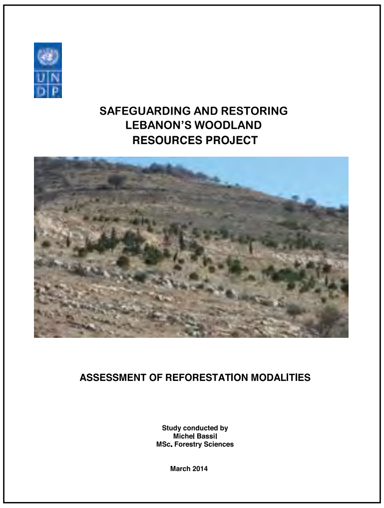
LEBANON'S WOODLAND
RESOURCES PROJECT

SOCIO-ECONOMIC IMPACT ASSESSMENT

Study conducted by Jean Stephan, Ph. D.

OCTOBER 2013

- A comparison of the advantages and disadvantages of each contracting modality adopted by the MoE in the past years, assessment of the impacts of the different modalities on local communities, study of other modalities adopted by other entities and policy recommendations and concrete lessons learned. This information can be published in a report for public dissemination and can be used by the Government in future reforestation activities. This study has been completed and the report has been presented to the MoE for its consideration and adoption.


SAFEGUARDING AND RESTORING
LEBANON'S WOODLAND
RESOURCES PROJECT

ASSESSMENT OF REFORESTATION MODALITIES

Study conducted by
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1.3.2.6 Education and Outreach

The SRLWR Project activities such as field tours have attracted news media attention in Lebanon. Several news outlets have asked for Project findings. The Project team has become a popular media source for expert opinions on reforestation issues and has been asked to speak on SRLWRP findings and the necessity of reforestation and conservation on TV and radio interviews, at secondary schools, and at universities. The Project team has participated in several environmental exhibitions. A case study on the Project was published in the "State of Biodiversity in West Asia" report, by the Biodiversity Programme of United Nations Environmental Programme Regional Office of West Asia. The Project team has also coordinated among committees managing Nature Reserves to facilitate field trips for secondary school students and raise awareness on forest conservation.

The Project hired a professional photographer to shoot 2,500 photos of the tree parts (trunk, branches, leaves, flowers, cones, seeds) of the most important 10 native trees of Lebanon. These photos were featured in 10 technical illustrated booklets on the native trees of Lebanon in Arabic and English languages which the Project published and distributed.

Booklets on 10 Lebanese native species

1.3.3 Civil Society Efforts

The Project worked closely with a number of local and international NGOS involved in reforestation.

Committee of the Friends of the Cedar Forest was founded in 1985. It protects and maintains the most famous and oldest *Cedrus libani* grove, the Cedars of God in the high basin above the village of Bcharre, runs a nursery for growing *C. libani* seedlings for reforestation and has implemented an ambitious project to reforest the entire basin above the grove. So far, around 100,000 seedlings have been planted over an area of 400 hectares with the goal of planting 2,000 hectares and bridging the major 2 regions of *C. libani* forests of Bcharre and Tannourin. The NGO has a unique funding mechanism of soliciting individual donors around the world to "adopt a cedar" and pay for its planting and maintenance for 18 years.

Reforest Lebanon was founded to preserve the green identity and unique forest heritage of Lebanon. It is involved in establishing two nurseries and in four reforestation projects, each about 100 ha, the latter are in the basin above the Cedars of God, in the Valley of Kadisha, and in two burnt sites where pine is being planted.

The Association for Forests, Development and Conservation (AFDC) began in 1993 in response to the forest fire which occurred in the Ramlieh area. AFDC initiated work with reforestating Ramlieh and establishing a nursery. Since then, the NGO expanded into six nurseries, in addition to activities aiming at capacity building, research, environmental education, and reforestation programs in cooperation with municipalities and other entities.

Cedars Forever plans to reforest cedars in the Shouf Nature Reserve in Barouk, the largest nature reserve in Lebanon with three remnant cedar groves. It has an “adopt a cedar” program as well.

Jouzour Loubnan (Roots of Lebanon) has planted around 150,000 native trees since it started in 2008.

1.3.4 International Efforts

The Lebanon Reforestation Initiative (LRI) is an internationally funded collaborative initiative in Lebanon to restore Lebanon's native forests and to instill commitment to reforestation and wildfire prevention and response through capacity building of local communities and organizations. It is funded by the United States Agency for International Development (USAID) and other international donors, and uses the technical capacity of the United States Department of Agriculture. LRI has helped form a cooperative of nurseries to improve nursery practices and seedling survival rates, and cooperated with local NGOs such as Association for Forest Development and Conservation (AFDC), Committee of the Friends of the Cedars Forest, and Reforest Lebanon in large-scale native tree planting projects. Since 2011, more than 380,000 native tree seedlings have been planted on 10 sites throughout Lebanon. LRI has also created maps and reforestation “best practices” guides. The USDA Forest Service has provided technical assistance to Lebanon since 2010 in improving the quality of native tree seedlings, outplanting and forest mapping techniques, wildfire prevention and response, and forestry and wildfire education. Forest Service nursery and reforestation experts have also helped the SRLWRP efforts to improve national reforestation capacity.

Additionally, Large multipurpose international NGOs like World Wildlife Fund have partnered with AFDC and other local NGOs for planting projects. International foundations like The René Moawad Foundation based in Washington D.C. have sponsored cedar adoption and planting projects.

CHAPTER TWO: International Progress Made in Reforestation Techniques and Cost

2.1 Introduction

During the past decades international reforestation programs have explored a variety of techniques related to advances in nursery and outplanting practices aiming at the improvement of overall tree survival in reforestation efforts.

Lebanon cedar (*Cedrus libani*) has symbolic, aesthetic, and historical value. Given its current scarcity in its namesake land, this tree could not be sustainably harvested for many years, but its unique decay-resistant, durable, aromatic wood (Boydak 2003) has proven its value throughout history, and harvestable plantations elsewhere (e.g., Turkey; Boydak 2003, Carus and Catal 2010) suggest potential value in the distant future. Jean Stephan (2013) calculated that *C. libani* forests in Lebanon managed for a 100 year rotation could produce 300 m3 of wood for timber, furniture, fuel, and handicrafts over the course of a century on one hectare of cedars (value of 362,500 USD).

Pine nut production generates more income than other Lebanese forest resources (Stephan 2013), and the market is growing due to their high nutritional value (Fady 2004). Other products from *Pinus pinea* include lumber and firewood, resin, bark for tannin extraction, and empty cones and shells for fuel (Fady 2004, Sfeir 2011). A *P. pinea* plantation reaches full production 25 years after planting (Stephan 2013, Masri et al. 2006). Stephan estimated that a hectare of *P. pinea* at 400 trees/ha would produce an economic return of 16,000 USD/year after 15-20 years and 32,000 USD/year after 25 years. This species is also useful for erosion control on sandy slopes (Sabra and Walter 2001).

2.2 Nursery Practices

Modern nursery practices developed in the United States, Europe, and some Mediterranean countries aim at improving seedling survival, especially in degraded or water-limited areas.

Generally, seedling quality is affected by seed provenance and genetics, as well as nursery practices (LRI 2014). Quality seedling production focuses on root system growth through water-holding capacity of the substrate, use of appropriate containers, and hardening techniques to promote drought resistance and efficient water use (Vallejo et al. 2012).

2.2.1 Propagation

Many European countries have initiated seed collection programs to ensure high-quality planting stocks for reforestation. Usually healthy and vigorous stands (mother plants) of indigenous origin are identified for seed collection. Good seed sources produce better quality planting stock and lead to improved seedlings, high survival rates and related cost savings.

Pine cones harvested

Tunisian efforts showed that *P. pinea* is easily propagated by seed, with high germination rates (Adili et al. 2013). In Turkey, Gülcü and colleagues (2010) studied appropriate sowing time and depth in spring for *Cedrus libani*. Seeds were sown at 6 different dates and 5 different depths under natural conditions in randomized block design with 3 replications of 1,000 seeds each. For seeds sown at 5 mm depth as early as possible in February, a 65% germination rate was obtained. Greek researchers found that storage and treatment of seeds can affect Cedrus deodara and *C. libani* germination success (Takos and Merou 2001). In vitro propagation techniques have also been explored as a rapid vegetative propagation method that may be used to conserve genetic material, e.g., from threatened old-growth *C. libani* stands (Khuri et al. 2000) or *P. pinea* in Spain (Cortizo et al. 2009).

2.2.2 Containers

Seedling need to develop roots quickly enough to reach deep moist layers of soil, in order to survive their first drought period. Therefore, facilitating deep rooting and growth of the root system beyond the planting hole is important (Vallejo et al. 2012). Deep narrow plastic containers which prevent water loss, root intersections, and J-root or root spiraling are particularly favored for seedlings that develop a long taproot, such as *C. libani* (Boydak 2003, Dominguez-Lerena et al. 2006, Chirino et al. 2009). The ideal potting mixture contains organic fertilizer (almost 30% compost or manure was recommended by Mitri [2008] for a variety of species in Lebanon), has a high water-holding capacity, and optimizes oxygenation of the root system.

Container seedling

2.2.3 Nursery Treatments

Usually the seedlings' first year is crucial (Pardos et al. 2010), and treatments in the nursery can help ameliorate transplant shock and promote survival.

Many Lebanese nurseries apply inorganic fertilizers to supplement the organic nutrients in the potting material, primarily nitrogen, phosphorus, potassium (NPK) and sometimes iron (Mitri 2008). In most cases fertilizer use has produced better quality seedlings. Foliar fertilizers combined with solid water have been used to increase survival and biomass in China (Wang et al. 2007). Studies were also conducted (Oliet et al 2013) on "nutrient loading" of seedlings(application of high rates of fertilizers, leaving nutrients available after outplanting). However, this has not lead to outplanting success, due to other factors such as water availability in particular. In a *P. pinea* seedlings nursery in Spain, drought preconditioning increased overall stress tolerance, but nitrogen fertilization reduced it (Villar-Salvador et al. 2013). Fertilization outcomes may also depend on the severity and timing of drought. Nutrient-limited plants may fare better when drought occurs shortly after planting (Cortina et al. 2013).

Experts of restoration of arid/semi-arid lands usually recommend to harden seedlings before outplanting, whether started in greenhouse, shadehouse or full sun. Hardening involves gradually exposing seedlings to full sunlight, wind, and reduced water so that they do not go into shock when planted in dry, hot conditions (Bainbridge 2007). Drought preconditioning or water hardening, where seedlings are exposed to mild to moderate drought stress in the nursery, has been used to induce drought-resistance in *P. pinea* in Spain (Villar-Salvador et al. 2013) and in *C. libani* in Turkey (Boydak 2003). Some Spanish specialists have reviewed this technique in depth in Mediterranean environments and found that stress levels are species-specific and the conditioning needs to be carried out in the months right before outplanting (Vallejo et al. 2012).

2.3 Practical Outplanting Techniques

2.3.1 Preparation for Outplanting

It is important to select good quality seedlings, keep them cool, moist, and upright at the planting site, minimize their time at the site before planting and handle them carefully.

2.3.2 Planting Material

2.3.2.1 Seeds

Direct seeding has been avoided in dryland areas because of limited precipitation, available soil water and predation on seeds. Under such conditions in Spain, seedlings have been more commonly used (Chirino et al. 2009). Melih Boydak (2003, 2007) however, reported success with broadcast seeding of *C. libani* in bare karstic lands in Turkey, where soil depths were shallow to medium with bedrock cracks. He recommended broadcast seeding just before snowfall to reduce predation by insects and birds, and found that direct sowing of seeds worked even better where soil was deeper.

Bainbridge (2007) strongly recommended use of site-adapted seeds: “Seeds from local stands of native plants should be used because local genotypes are more likely to survive and reseed on the site.” He also discussed the importance of capturing as much of the genetic variability as possible, by collecting from different populations and a large number of parent trees. Various direct sowing methods include broadcast seeding, seed drilling, and imprinting (creating micro-pits in the soil surface), as well as releasing seeds only after a flood.

2.3.2.2 Seedlings

Recent reforestation efforts have focused more on seedlings grown in nurseries. Bainbridge (2007) noted the tradeoffs between container size, survival, and cost in terms of seedling planting. In arid lands long tap roots increased survival prospects of seedlings, ranging from 15% survival for seedlings with 29 cm root to 75% for 68 cm.

In the past decades older seedlings with ages varying from 1 to 3 years with large root collar diameters were preferred. However, in the recent years this approach has shifted towards the use of younger seedlings of 8 to 12 months old, which cost remarkably less and provide excellent survival rates if produced according to the modern nursery techniques and well hardened prior to outplanting.

2.3.3 Water

Direct seeding of *C. libani* in Turkey was successfully conducted without any supplemental irrigation (Boydak 2003, 2007). Other studies using different species besides pines and cedars showed that 30% of the species and provenances had survival rates of 50-100% after 35 years without any irrigation. However, water availability is generally one of main limiting factors in seedling establishment and is likely to be even more important as climate change effects increase (Vallejo et al. 2012). Historically *C. libani* seedlings were blanketed upon germination by deep snows in high protected sites, bathed in humid air channeled through mountain valleys, and sprinkled with mist that condensed on the trees and dripped onto the forest floor (Beals 1965). But for native trees planted on restoration sites, landscapes have changed, and land has been degraded. Climate disruption is expected to bring to the Mediterranean area times of increased temperature, decreased precipitation, changing rainfall patterns, reduction of soil moisture, and an overall decrease in water availability (Dios et al. 2007). A variety of techniques, as described below, can be used to conserve and efficiently use available moisture in restoration sites and reduce plant water needs. Nevertheless, in some cases supplementary water may be needed in order to establish outplanted seedlings.

P. pinea is one of the most important species in Lebanon. it is utilized as an important cash crop, since pine nut production is a major source of income to many municipalities. In planting trials in Spain, *P. pinea* showed a high sensitivity to the combined effects of drought and high temperatures at the end of the drier and warmer summers (Rubio-Casal et al. 2010). Its net photosynthetic rate also decreased with warmer temperatures. This lower thermo-tolerance of *P. pinea* to higher temperatures was also supported by laboratory results.

Selection of proper planting time so that seedlings are provided with maximum time to grow out roots is critical. Planting in Lebanon generally should be done in fall and when soil moisture is high (LRI 2014) or above 20%. Upslope planting holes may help in harvesting precipitation runoff and reducing water costs. Fog collectors may also be used, as shown effective in Spain (Chirino et al. 2009, Vallejo et al. 2012). Incorporation of hydrogels, polymers that can absorb and deliver water, into planting holes may promote seedling survival (Pery et al. 1995, Chirino et al. 2009, Forest Science Centre of Catalonia 2013).

Reforestation efforts in Turkey (Boydak 2007), Spain (Chirino et al. 2009, Vallejo et al. 2012, Forest Science Centre of Catalonia 2013), and the United States (USDA Forest Service 2013) have shown that mulch (plastic sheets, plant debris, stones, etc.) reduces raindrop energy at the surface, increases water infiltration, reduces evaporation, and helps control competing vegetation. In Spain (Chirino et al. 2009, Vallejo et al. 2012) and Lebanon (LRI 2014), tree shelters or shade-cards have been used to protect seedlings from sun, wind, and predators, as well as provide them a greenhouse microclimate. A review of this technique (Chirino et al. 2009) demonstrated increased survival and height as a result of its use for non-coniferous seedlings in Portugal, Spain, and Greece.

Wherever irrigation is inevitable, design and location of irrigation systems should be determined before planting (LRI 2014). A variety of irrigation techniques have been utilized in arid/semi-arid lands in the Sonoran and Chihuahua deserts in the United States, in Kenya and Pakistan (Bainbridge 1991, 2002) and in Lebanon (LRI 2014). A practitioner in the United States reviewed a variety of systems (Bainbridge 2002) and concluded that the best system for any given site depends upon factors such as survival and growth goals, water availability, species-specific water demands, workers available and their skill levels, and budget. Costs can be reduced by having an adequate water source close to the site (LRI 2014). Techniques include the following:

- Hand-watering
- Basin irrigation: planting and watering in hand-dug pits
- Watering into tree shelter: shelter inserted into ground around seedling, water periodically poured to fill line
- Buried clay pot (with or without wicks) or porous capsule: controlled water delivery to the root zone
- Porous hose: vertically placed section of porous hose connected to bottle, tank, or irrigation system
- Perforated pipe: buried perforated horizontal drainage pipe along the root zone
- Drip: irrigation system delivering slow drip of water directly to seedling
- Deep pipe: open vertical pipe concentrates water in deep root zone
- Solid water: water-absorbing synthetic polymers for gradual water release to the root zone

Drip irrigation efficiently delivers water directly to seedlings. However, it is expensive and requires regulated pressure and filtration, as well as routine inspection and maintenance. Animals tend to chew tubing and pipes. Emitters might become blocked, and repairs can be expensive (Bainbridge 2002).

Methods used most often in Lebanon are hand-watering and drip irrigation. Some work has been done using deep pipe and solid water techniques. Hand-watering with bottles or buckets is only practical for very small sites, but larger areas can be covered with hand irrigation when on-site water storage or water trucks with hoses are available. This is still labor-intensive and requires a well-planned watering schedule be adhered to so that all seedlings receive enough water (LRI 2014).

Conventional irrigation

Deep pipe systems, which are currently undergoing testing in Lebanon (LRI 2014), are a simple low-cost way to concentrate water in the deep root zone near seedlings, and help the plant develop a much larger root volume than with other irrigation systems. They can be filled from a watering can, inverted bottles in pipe openings, water truck or hose, or fitted drip emitter. High-quality water, skilled labor, or elaborate delivery systems are not required, and they are more easily repaired than buried drip systems (Bainbridge 2002).

Hydrogel, or "solid water" is a product that comes in two types: rechargeable and non-rechargeable. Rechargeable solid water (RSW) is a cross-linked polymer in a woven bag, with a small amount of clay as an activator; this biodegradable product is soaked in water and inserted underground near the root zone of the seedling. It then slowly releases the absorbed water for up to 30-90 days depending on conditions, and recharges with rain or watering. Bags can last for up to two years, allowing seedlings time to become established (Outside the Box 2014). Non-rechargeable solid water (NRSW) is a product consisting of a bag of water entrapped in a cellulose fiber compound that breaks down under bacterial action in the soil, slowly releasing water. Bags are cut and placed in pipes buried near each seedling, ensuring that the gel is in contact with wet soil (WaterScientific 2014).

Rechargeable & Non-rechargeable solid waters

These absorbent polymer amendments have aided seedling survival in some cases in the United States and elsewhere, primarily where water is available at regular intervals (Pery et al. 1995, Bainbridge 2007, Chirino et al. 2009, Forest Science Centre of Catalonia 2013), but have not been found as useful when irrigation rates are low (Bainbridge 2007). In Spain, hydrophilic polymers were tested with *P. pinea* seedlings under both field and greenhouse conditions. In both cases, hydrogel increased seedling survival (Pery et al. 1995). More study is needed to determine the situations where increased survival might justify the cost (Bainbridge 2007).

2.3.4 Site preparation

Proper site preparation can reduce transplant shock and can be key to seedling success. Unwanted vegetation must be cleared from a site either by using hand tools or by scalping and decompacting the soil with small excavators (LRI 2014). In Turkey, soil treatment was recommended prior to broadcast seeding of *C. libani* if soil on bare karstic lands was compacted and/or weeds were dense. For such cases a ripper mounted on an agricultural tractor or crawler tractor was suggested (Boydak 2007). The USDA Forest Service (2013) suggests hand tools for scalps of 18-24 inches (45-60 cm) wide and consideration of mechanical or herbicide treatments for larger areas. Herbicides have been used, for example in USA, but they vary in ability to enhance seedling survival and growth and in their potential for negative effects on newly planted seedlings. Limited and localized applications in small-scale plantations may minimize toxic effects. Scalping, scalping followed by ripping, and herbicide application were applied on dry grass-dominated sites in British Columbia. All were equally effective in increasing soil water supply (Fleming et al. 1994). In comparing five tending methods in field test sites in Latvia, Daugaviete (2000) found that over two years, stem increment increase in pine plantings was greater than the control by 44% for herbicide application, 30% for mowing grass around seedlings and 25% for hoeing up weeds. However, this work was conducted on a converted farmland.

Soil preparation (Spain)

Bainbridge (2007) observed that mechanized treatment is faster and more effective than hand tools for compacted soil. Little work may be needed on a denuded but otherwise unchanged linear disturbance of a native site. More disturbed sites may need substantial soil work, reshaping, and weed suppression. A weed-infested site may need persistent work for long-term weed suppression. Weed control often is very challenging on disturbed sites with a large soil seed bank of noxious weeds. Repeated water and tillage, burning, solarization, or soil treatment may be needed. Weed control should start 2 to 3 years before planting on difficult sites.

Lof, Navarro and Jacobs (2012) synthesized current knowledge for mechanical site preparation for improved tree establishment in different forest restoration situations. They found that mechanical site preparation often results in improved seedling survival and growth, but cautioned that it should be implemented carefully because of potentially large environmental impacts. Unless intensive methods are used to greatly disturb soil, mechanical preparation is an ineffective tool for controlling competing vegetation. Methods such as scarification, mounding and subsoiling cause multiple interactions among soil physical and chemical properties that affect plant survival and growth, so that it may be difficult to determine the actual cause–effect relationship of any positive seedling responses. Only a few conifer species have been studied in terms of impacts of mechanical preparation on site production. Due to the fact that seedling responses differ among tree species, there is need for additional research on this matter.

Querejeta and colleagues (2001) evaluated influence of site preparation method on soil moisture and seedling performance in the drought resistant species Pinus halepensis in a degraded semiarid rangeland in southeastern Spain. They tested three different land preparation methods: manual terracing, mechanical terracing, and mechanical terracing with organic soil amendments (additions). Mechanical terracing increased soil water storage up to 40% more indicated that seedling access to water stored in deeper layers was constrained by high soil penetration resistance in the manual terraces. Adding an organic amendment (urban waste) further increased water reserve in mechanically terraced soils up to 40% from enhanced water infiltration and diminished soil surface evaporation. This treatment allowed early root penetration to the deeper and wetter layers of the profile, increasing water availability for the seedlings. Because of limited water, seedling survival after dry summers of 1994 and 1995 was only 62% in manual treatment area as compared with 98% in the mechanical terraces.

Other trials have tested addition of material to soil. Compost or other organic material was added in South Provence, France (Larchevêque et al. 2006). In Spain, municipal waste was used. It was found that nutrient load should be limited and application is best restricted to planting holes (Chirino et al. 2009). Large, highly disturbed sites can require extensive soil stabilization and preparation in the field (Bainbridge 2007, LRI 2014).

Planting holes can be created by hand digging, excavators, or augers depending upon the site (LRI 2014). Tree seedlings should be planted deeply enough to accommodate their fully extended roots. The recommended minimum seedling planting hole size is at least 7.62 cm of diameter at the top, 2.54 cm of diameter at the bottom, and 2.54 cm deeper than the plug length (USDA Forest Service 2013). Fencing to exclude livestock may be needed before planting (Boydak 2007).

Manual digging of holes in Lala

2.3.5 Soil Texture

On karstic lands in Turkey, *C. libani* was reported growing on sandy loam, clayey loam, and loam soil with 1-4% organic content, good drainage, and high water-holding capacity (Boydak 2007). Heavy soil texture, along with a high water deficit, may have been a factor for low survival of *C. libani* seedlings at another site in Turkey (Semerci 2005). In southwest Spain, the best sites for *P. pinea*, were those with higher sand content and less clay and silt content (Bravo-Oviedo and Montero 2005).

2.4 Reforestation Costs

Reforestation costs vary greatly depending upon the location and condition of the site, tree species, irrigation methods, and maintenance, although few published studies provide detailed and accurate cost data. Puertolas et al. (2012) studied the costs and benefits of different nursery practices for *P. pinea* and *P. halepensis*, concluding that the best growth for the minimum cost was achieved with 300 cm3 containers and fall fertilization. Christopoulou (2011) calculated a reforestation cost of about 2,000 USD/ha in Greece.

Dryland reforestation costs can range from a few hundred dollars (US) to as high as 100,000 USD/ha according to U.S. reforestation experts: "Everything has to be done correctly at the right time, and water usually has to be provided for initial establishment" (Bainbridge 2007). Direct seeding is appealing because it is relatively inexpensive, with costs ranging from less than 49 USD/ha to 3,706 USD/ha. However, direct seeding is "risky and rarely succeeds". In national reforestation programs in Europe in the 1990s, reforestation costs ranged from 1,632/ha USD (with additional cost of 218/ha USD for maintenance over 5 years) for a variety of tree species planted in Spain (Barbero 2000) to 2,718/ha USD for upland planting and 5,434/USD for lowland planting in Britain (Pryor 2000).

There are different cost estimations for reforestation in Lebanon. LRI estimates costs between 4,400 to 12,000 USD/ha at a plantation density of 800 seedlings per ha. The Lebanese Ministry of Environment estimates costs at approximately 7,000 USD for the same density (2014).

New nursery techniques

CHAPTER THREE: Lebanon Planting Trials

3.1 Introduction

The centerpiece of the SRLWR Project was its second objective, testing new techniques of reforestation at pilot sites. None of these techniques had previously been assessed in Lebanon. Three successive sets of trials at 7 different pilot sites were implemented. Each set built on the lessons learned from the previous set. The aim was to develop techniques for use in future large-scale land rehabilitation activities. This is the first era of novel reforestation techniques in Lebanon since the Green Plan effort in the 1960s. due to the fact that the results of those early efforts were not published at the time and/or were mostly lost during the civil war, these new field trials are expected to have an important impact on the improvement of reforestation practices in Lebanon.

3.2 Field Trials on Pilot Sites

3.2.1 Objective: Cost Reduction and Survival Increase

New techniques were tested for their ability to increase seedling survival while minimizing reforestation costs in Lebanon. MoE figures estimate this cost currently at 13,000 LBP (Lebanese Pounds) per seedling (about 8.67 USD) including seedling cost, land preparation, irrigation, and maintenance over 2 years (MoE 2014). Extrapolated to a planting rate of 800 seedlings per hectare the cost is about 7,000 USD/ha, higher than most planting costs/ha reported for other countries.

Through the 3 sets of trials, the Project studied possible ways to decrease planting costs to 1,500 USD/ha by:

- Minimizing irrigation water use (frequency and quantity);
- Using smaller plants (8 months instead of 18 months old);
- Using direct sowing of seeds where possible;
- Evaluating the possibility of no-irrigation reforestation in Lebanon.

Set 1 trials involved *P. pinea* planted at three sites for two growing seasons (from spring 2011 till spring 2013), compared two novel irrigation methods of slow-release water to conventional hose irrigation and no irrigation. They also compared younger (10-months) seedlings and older (12-months) seedlings. This was the available nursery stock at the time of study, although a larger age range would have been preferable. Set 2 was initiated in fall 2011 and lasted till fall 2013 with *C. libani* and *P. pinea* (one species on each of two sites) compared younger or older (8 and 18 months) seedlings versus direct sowing of seeds, as well as conventional irrigation and no irrigation. Set 3 which was initiated in fall 2012 and completed in summer 2014, focused on sowing seeds on two sites (one with *C. libani*, one with *P. pinea*) with hand vs. mechanical soil preparation. For Set 1 and Set 2 sites, soil preparation was done mechanically if labor was not available, so a given site had either hand or mechanical preparation throughout (with the exception of seed sowing treatments for Set 2, which featured no soil preparation at all). On the other hand, soil preparation was the focus of treatment comparison in Set 3.

3.2.2 Site Selection

Sites were selected to represent a diverse range of growing conditions and elevations. *P. pinea* was planted at lower elevations than the sites included in the second and third sets of trials for planting *C. libani* (Table 2). Sites were selected to represent the Mediterranean bioclimatic zone that was most suitable to establish a specific forest species along with abiotic factors (climate, soil, topography) that would encourage seedling survival. Soil depth, texture, and structure were taken into consideration since they impact the development of the seedlings' root and shoot systems and affect soil's water holding and root absorption capacities. These latter factors affect whether a site must be watered, how much and how often during the drought season. In high altitudes, soil aptitude for heating and cooling affects survival of young seedlings, especially those generated from seeds. When the soil surface is heated up by solar radiation, its temperature can exceed ambient air temperature by up to 15-20 °C. Under these conditions the seedling collar being close to the soil can desiccate and consequently cause the death of the seedling (Khouzami 2014).

Project trial site board

Other site-selection criteria included the following:

- Ownership: Sites owned by the government or community were preferred, rather than those privately owned (except Bnabil, a private monastery), to ensure the sustainability of the resulting forest.
- Soil type: Sites were selected according to the soil type requirements for the kinds of trees tested (e.g. preferably sandy for *P. pinea*).
- Location: Sites easily reachable were preferred in order to have easy and safe access for data collection and maintenance activities.

The Project team worked in close coordination with the landowner municipalities and monasteries.

Set 1 sites were clustered in the Bekaa valley and sites in Sets 2 and 3 were more widely distributed along the western slope of the Western Lebanon Mountain Range (Table 2, Figure 1). The Set 1 sites (Kefraya, Aitanit, and Lala) were in the same Mediterranean pre-steppe vegetation zone on the upper slopes of the West Bekaa on the east side of the

Western Mount Lebanon Range.

The exposure of these 3 sites was as follows:

Kefraya: East

Lala: South

Aitanit: Southeast

Soil was nearly identical for Aitanit and Lala sites (silty clay), whereas Kefraya was sandier. Average precipitation was same on Kefraya and Lala, and Aitanit was wetter, presumably because it is closer to the Mount Lebanon range (Figure 1) and near the Qaraoun Lake. Altitudes were all in *P. pinea* habitat: 998 m for Kefraya, 1,035 m for Lala, and 1,147 m for Aitanit (Table 2).

Set 2 trials were conducted on two sites on the western slope of the Western Lebanon Mountain Range: Bkassin (1,032 m of altitude) in the Eumediterranean vegetative zone and Arz-Bcharre (1,968 m of altitude) in the Oromediterranean vegetative zone, for trials on *P. pinea* and *C. libani* respectively (Table 1).

The exposure of these 2 sites was as follows:

Bkassin: Northwest

Arz-Bcharre: Westnorth

Soil was sandy in Bkassin and clayey silt in Arz-Bcharre. Average precipitation was higher in Bkassin than in Arz-Bcharre. Sites were selected near forest stands of the respective species tested.

Set 3 trials were carried out in two sites, Bnabil and Kfarzebian: *P. pinea* and *C. libani* direct seed sowing was assessed in these sites respectively (Figure 1).

Bnabil is located in the Eumediterranean vegetative zone at 1,076 meters of altitude, on the lower western slope of the Western Lebanon Mountain Range.

Kfarzebian is in the Mediterranean mountain zone on the higher northern slopes of Western Lebanon Mountain Range at 2,012 meters of altitude.

The exposure of these 2 sites was as follows:

Bnabil: Southwest

Kfarzebian: Northwest

Soil was sandy in Bnabil and clayey silt in Kfarzebian. Average precipitation was higher in Kfarzebian than in Bnabil.

Table 2: Geographic and climate data for Lebanon planting trials; Arz-Bcharre and Kfarzebian were planted with *Cedrus libani*, and all others with *Pinus pinea*.

Set	Site	Governorate (Mohafaza1)	Vegetation zone	Soil description (color, texture, depth, rock)	Field capacity (cm³ water/cm³ soil)	Soil bulk density (g/cm³)	Slope (%), Aspect	Elevation (m)	Geographic coordinates	Average annual precipitation (mm)	Temperature means Jan & Aug (°C)
1	Kefraya	Bekaa	Mediterranean presteppe	10YR yellowish brown; 38% sand, 30% silt, 32% clay; deep; 10% rock	0.31	1.33	20-30 E	998	33° 40' 38.02" N, 35° 44' 36.90" E	850	2.0, 33.4
1	Aitanit	Bekaa	Mediterranean presteppe	2.5 YR dark red; 10% sand, 56% silt, 34% clay; medium; 40% rock	0.36	1.27	60-65 ES	1147	33° 34' 20.34" N, 35° 40' 18.64" E	1016	1.9, 30.7
1	Lala	Bekaa	Mediterranean presteppe	2.5 YR dark red; 10% sand, 54% silt, 36% clay; shallow; 30-35% rock	0.37	1.26	10-20 S	1035	33° 35' 57.49" N, 35° 44' 55.31" E	850	- 0.4, 28.6
2	Bkassin	South Lebanon	Eumediterranean	7.5YR strong brown; 76% sand, 8% silt, 16% clay; deep; 10% rock	0.2	1.5	40-50 NW	1032	33° 33' 23.53" N, 35° 33' 37.40" E	1250	- 0.5, 31.9
2	Arz-Bcharre	North Lebanon	Oromediterranean	10YR dark yellowish brown; 14% sand, 36% silt, 50% clay; deep; 20% rock	0.44	1.22	5 WN	1968	34° 14' 51.30" N, 36° 03' 27.30" E	970	- 10.6, 27.2
3	Bnabil	Mount Lebanon	Eumediterranean	7.5YR brown; 70% sand, 10% silt, 20% clay; deep; 5% rock	0.22	1.46	35-45 SW	1076	33° 54' 07.39" N, 35° 44' 05.19" E	1270	- 1.0, 32.9
3	Kfarzebian	Mount Lebanon	Mediterranean mountain	43% clay, 36% silt, 21% sand, deep, 40% rock	0.39	1.26	15 NW	2012	34° 01' 09.30" N, 35° 52' 25.89" E	1400	- 6.5, 27.2

1- Lebanon is divided into 8 administrative subdivisions or "Mohafazas"

Figure 1. Trial pilot sites

3.3 Set 1 Trials

3.3.1 Objective

The first set of trials assessed survival rate and reforestation costs with 10 and 12-month-old (10-mo and 12-mo) *P. pinea* seedlings. Four irrigation methods were tested at three sites for two growing seasons (from spring 2011 till spring 2013). Two novel irrigation methods for slow-release solid water were compared with conventional hose irrigation and no irrigation. Different site preparation methods and soil textures were not compared in Set 1 design; however subsequent data analysis involved enough replication from these methods for comparison as "treatments" among sites. This is discussed later in this chapter.

Overview of Kefraya trial site

Although fall or winter planting is more common and desirable, so that seedlings benefit from winter rains, due to the startup time required (to acquire seedlings, obtain necessary field equipment, and order new technologies from overseas suppliers), the seedlings were planted in April 2011. Furthermore, though a larger age range would have been preferable, available nursery stock at the time of initiation of Set 1 trials was mostly 10-mo and 12-mo seedlings planted in plastic bags with a few 8-month-old (8-mo) seedlings in containers, which were the first generation of seedlings prepared according to the recommendations of international nursery experts.

3.3.2 Methods

Each site was laid out as about a half-hectare rectangle. On Kefraya, a backhoe (Poclain) excavator was used to dig the planting holes, whereas on Aitanit and Lala sites a team of workers dug the planting holes with hand tools. The sites had 8 rows of 50 seedlings each, generally planted across slope (each of the 3 sites had one additional row of 25 8-mo seedlings). Seedling planting holes were 50 x 50 cm and 50 cm deep, in both cases of mechanical preparation (MP) and hand tool preparation (HP). Seedlings were spaced approximately 3.5 x 3.5 m apart.

Planting material treatments compared 10-mo and 12-mo seedlings. Water supplement treatments included a control of no irrigation (NIRR), conventional irrigation (IRR) with hose and water tank vehicle, and the two novel water additions described below. The innovative water techniques were discovered by the Project team by researching online. A supplier was found for Rechargeable Solid Water (RSW) in Asia and another for Non-Rechargeable Solid Water (NRSW) in Australia, and materials were ordered and shipped for testing.

The same planting material and water supplement treatments were applied at each of the three sites in successive rows of 50 seedlings per row across slope. Each entire site was considered an “experimental unit” and no within-site experimental design blocking was considered. Seedlings were grown in plastic (nylon) bags of 10 cm in diameter and 20 cm long. It is to note that half (25 seedlings) of the 10-mo NIRR treatment were actually 8-mo seedlings that were grown in containers. These seedlings were given no irrigation treatment on all 3 sites, and were included with the 10-mo seedlings for analysis purposes.

Rechargeable Solid Water (RSW), usually used to save water delivery to garden beds and pots, is a cross-linked polymer in a woven bag with a small amount of clay as an activator. It is biodegradable and nontoxic and contains 98% water when fully charged. The RSW bag gradually releases water for 30 days to 3 months depending on soil types and climate conditions. RSW can be "recharged" while in the ground by adding water or by rain. RSW bags were placed into water for 5-20 minutes to charge them prior to application. A hole was dug next to the root zone of each seedling to be treated deep enough to insert the entire bag underground. Bags were placed on a 45-degree angle in the planting hole along the root zone of the seedlings and covered with soil. The buried RSW bags were recharged with a hose 4 times during the 2-year trial period (during the hot summer season).

Application of RSW

Non-Rechargeable Solid Water (NRSW) is a 97% purified water and 3% cellulose fiber compound. It is designed to decrease evaporation of water molecules into the atmosphere. It has been used effectively in drought conditions to help maintain available water of the soil, raise the surviving rate of tree seedlings, and maintain their normal moisture status and metabolism. The compound remains solid for transport and unfrozen at temperatures from -6 °C and above, and does not melt at up to 100 °C. Once in contact with the soil, microbial action breaks down the cellulose fiber binding water molecules with each other and the liquid water is gradually released directly to the root zone of the plant. For the NRSW treatments, each bag was cut in half. A PVC pipe was buried on each side of each seedling to be treated. Each half of the contents of the NRSW bag was emptied into the pipe so that the gel made contact with the wet soil. A cap was placed over the pipe to avoid soil and particles entering into it. Bags were replaced whenever completely dry, usually after about 1.5-3 months, depending on weather conditions. One initial application (at planting) and 4 replacements of the NRSW were made for each treated seedling throughout the 2-year trial period.

Application of NRSW

Application of NRSW

After initial planting (and watering for all including the NIRR treatments), the water treatments for seedlings on each of the three sites over the 2-year study period included replacement of NRSW bags, recharging of RSW bags, and hose waterings for the conventional treatments. Replacement, recharging, and conventional irrigation were done whenever moisture readings (with a Rapitest Moisture Tester with a rod length of 40 cm and a reading range of 1 to 10) showed a drop of soil moisture to below 2 (equivalent to 20%).

Survival measurements were made monthly for 22 consecutive months beginning in June 2011 and ending in May 2013. Growth measurements were made on subsamples starting the first summer and continuing monthly. Soil moisture and temperature measurements were taken with probe instruments monthly (except for a month or two in winter, depending on snow or rain). Manual weeding was done to clear an area of 1 x 1 m during the growing season, with frequency depending on the site conditions. Kefraya & Aitanit were weeded 4 times each, whereas Lala was weeded twice over the 2-year study period.

Soil moisture meter

Data collection sheet

Chapter 3

3.4 Set 2 Trials

3.4.1 Objective

Set 2 trials, initiated in fall 2011 and lasting until fall 2013, built upon what was learned from the initial results of Set 1 trials. Their objective was to further evaluate reduction of reforestation costs with reduced irrigation (NIRR vs. IRR) while dropping solid water treatments, RSW and NRSW for their overall high costs due to the intensity of the replacements (NRSW) and recharges (RSW) found necessary through the Set 1 trials. A broader test of seedling survivability based on age compared then available 8-mo to much older 18-mo *C. libani* and *P. pinea* seedlings, one species on each of two sites. Two direct seed sowing methods were also compared, having in mind that if direct sowing of seeds or planting younger seedlings resulted in survival comparable to planting of older seedlings, nursery growing time and costs could be reduced. Hand (HP) and mechanical (MP) soil preparation were compared with no preparation (NP). Data were also gathered on the different soil preparation treatments.

Arz-Bcharre trial site covered with snow (winter 2012)

3.4.2 Methods

The provenance of seeds was given great importance to ensure success for the resulting seedlings. For each site, a group of mother trees in the proximity of the trial site was delineated for cone (seed) collection. For Arz-Bcharre, *C. libani* mother trees were selected within the old forest of Arz-Bcharre (Arz El-Rab) and from the Hadath El-Jobbe cedar forest in the same region. For *P. pinea*, some tall vigorous trees within the forest of Bkassin were selected as mother trees. Seeds were collected just prior to planting in late fall 2011. Similarly, seedlings were also produced in small nurseries located near forest stands of the respective species.

The 18-mo seedlings were grown in plastic bags as in Set 1. The 8-mo seedlings were grown in D-27L (L indicates lightweight) containers with 444 ml volume, 6.4 cm diameter, and 17.8 cm depth. The 18-mo seedlings were produced through conventional methods, without any nursery improvements applied, whereas the 8-mo seedlings were the second generation of seedlings produced in containers as per the recommendations of international experts, with better quality than those used in Set 1.

C. libani seedlings and seeds were planted in Arz-Bcharre and *P. pinea* seedlings and seeds planted in Bkassin. Seeds were sown in two different ways:

a) In basins in rows of 3 seeds per basin (SP3), similar to seedlings
b) Broadcast sown (SS200), 200 seeds in an area of around 75 m2 (5 x 15 m)

Seeds sown in small "basins" were expected to retain water when irrigated. The overall design of the seedling trials was still similar to Set 1 with seedlings and the seed SP3-treatment planted in blocks of 50 total per treatment. Blocks of each treatment were moved around sites a bit to accommodate irregular site shape and to include broadcast sowing areas (SS200). For example, the flattest possible terrain was needed for broadcast sowing (SS200) without site soil preparation to prevent seeds being washed away. Bkassin also had existing trees and a hill top area to work with and around. Treatment for each of the two sites still covered about one half-hectare. Holes for seedlings were 50 x 50 cm and 50 cm deep, and were spaced approximately 3.5 x 3.5 m apart. Similarly, sowing in basins (SP3) was done in 70 x 70 cm basins, 2 meters apart from each other. Sown seeds were only slightly covered with soil (1-2 cm). Finally, soil preparation vs. no soil preparation (NP) was tested. Soil preparation was done for seedling and SP3 treatments at each site. MP was used for Bkassin (where hand labor was unavailable/expensive), and HP was used for Arz-Bcharre. Seedlings and seeds were planted in fall 2011 and data was collected throughout 2012 and 2013.

Basins for seed sowing

All groups of seedlings in Bkassin received initial irrigation, whereas none of the groups of seedlings in Arz-Bcharre received any initial irrigation, being planted in snowy conditions. Half of each age group of seedlings at both sites was irrigated during summer/fall dry seasons as needed in 2012 and 2013, while the remaining half was not. Half of the sown seeds (SP3) received irrigation and half did not. The scattered seeds (SS200) received no irrigation at all.

Germination of P. pinea seeds sown (Bkassin)

Germination (seeds), survival, growth, soil moisture, and temperature were measured at each site: 4 times at Bkassin (spring and fall in both 2012 and 2013), and 3 times (spring and fall 2012 and spring 2013) at Arz-Bcharre. Plants receiving irrigation treatment at Bkassin were watered 7 times during the 2-year trial period (4 in summer 2012, 3 in summer 2013). Plants receiving irrigation treatment at Arz-Bcharre were watered 8 times during the 2-year trial period (4 in summer 2012, 4 in summer 2013). Bkassin was weeded twice in spring and summer 2013. Arz-Bcharre was also weeded twice in summer 2012 and spring 2013.

Direct sowing of C. libani seeds (SS200) with soil preparation (Arz-Bcharre)

3.5 Set 3 Trials

3.5.1 Objective

A third set of field trials was initiated in fall 2012 and finalized in summer 2014, with the objective of determining if reforestation costs could be reduced further by eliminating the need for both seedlings and irrigation. These trials focused on selection of planting stocks and timing of planting to imitate nature. The aim was to test the ability of seeds to germinate in the soil and grow deep and extensive root systems quickly during the first fall-winter and to find out whether they would be able to survive without any irrigation, once the root systems of the resulting seedlings reached the underground water table. Unlike Set 1 and Set 2 trials, seedlings were not used. Instead, only seeds of *P. pinea* and *C. libani* were sown, following hand or mechanical soil preparation. Soil texture data were also obtained.

Mechanical Soil preparation

3.5.2 Methods

P. pinea seeds were collected from mother trees in the region of Bnabil. *C. libani* seeds were collected from selected mother trees within the old forest of Arz-Bcharre (Arz El-Rab) and from the Hadath El-Jobbe cedar forest in the same region (same provenance as seeds collected for Set 2 trials).

In Set 3, soil preparation by plowing the site with a tractor (MP) was compared with lighter hand-tool preparation (HP). *P. pinea* was planted at Bnabil and *C. libani* at Kfarzebian. For each of the treatments (MP and HP), seeds were planted in spots (rather than basins as in Set 2) which were not necessarily laid out in rows (due to the site landscape), but were spaced at roughly 2 x 2 m. Spots were used for seed sites (instead of basins) because a key aim of Set 3 trials was to test survival without irrigation and the Set 2 basins were designed for irrigation. For each treatment, 150 spots were planted with 3 seeds per spot (SP3). Seeds sown were covered with 1-2 cm of soil. The Kfarzebian site was prepared and *C. libani* were sown on 30 November 2012. The Bnabil site was prepared and *P. pinea* seeds were sown on 07 January 2013. Seeds were not irrigated.

Both sites were visited fist in March 2013. Some early germination (tiny newly germinated seedlings) was observed at Bnabil while the higher Kfarzebian site was still covered with snow. Weeding was done on Bnabil in April with a first germination count later that month. Root growth was measured in September. Additional weeding was done in December and plant growth, soil moisture, and temperature were recorded in January and August 2014.

Additional growth and abiotic measurement data were collected. Growth data included periodic height measurements of a systematic subsample of all planting material for each treatment (which varied in sample size proportional to survival). Abiotic measurements included soil temperature and soil moisture with a Rapitest Moisture Tester as used in Sets 1 and 2. These data could be of value for further study of seedling survival and germination on a finer time scale for correlating mortality to abiotic factors.

Germination of C. libani seeds (Kfarzebian trial site)

Some early germination was observed in May 2013 on Kfarzebian, but there was still too much snow for an accurate seedling count. Unfortunately, in June 2013 a herd of goats devastated the Kfarzebian site. A few seedlings were counted later in June but then the goats returned and consumed all remaining plants. Because neither initial germination nor survival rate could be assessed, this trial was considered incomplete. Initial design and treatment are included in this report for consistency. This loss was extremely disappointing, particularly as this was an excellent opportunity to evaluate nonirrigated direct seed sowing methods for *C. libani*.

Broken fence in Kfarzebian

3.6 Methodology: Data Analysis

3.6.1 Database Summary

Raw data were compiled, summarized, and visually examined before formal analysis. Also, an additional survival metric was calculated to account for variation in germination rates and to increase replication to boost the power of the statistical analysis.

A database of 1,896 file observations for survival and germination data was constructed. The database was then organized by sets, sites, treatments, and planting point identification (id) with survival and germination data arrayed by month or period of data collection. Measurement period array ranged from initial planting month (date 0) through 22 (date 22) consecutive dates for Set 1 trials and then 4 additional quarterly periods needed for Sets 2 and 3. This placed data from all three sets into a uniform database for analysis.

Treatments for all trials were then harmonized with standardized labeling (Table 3). Assumptions were made to harmonize data as concisely as possible. Seed sowing trials at individual points in Sets 2 and 3 were assumed to be similar treatments (SP3) even though field technique differed slightly as discussed above for basins vs. spots. Any use of mechanical device for soil preparation was grouped (MP) for comparison to hand tools (HP) or no soil preparation (NP). Exact planting dates were matched to the closest month in the date array described above. Seedling age groups were 8-10 months, 12 months and 18 months.

10-mo-old irrigated P. pinea seedling in Lala
3 years after plantation

Soil preparation was not designed as treatment for all trials nor was soil texture, but sufficient replication of these factors allowed examination of them as treatments for statistical analysis. (Set 1 trials had used mechanical or hand tool preparation based on soil conditions and availability and cost of labor at each site.) Soil data had been collected at each site and, based on particle size, grouped into categories of Sandy (Sd) for at least 38% sand and silt-clay (SC). As an interesting artifact, MP was coincident with sandy soil and HP with silt-clay soil for all sites (except the Bnabil site where MP and HP were tested as treatments in field trial Set 3).

Table 3. Background information on Lebanon planting trials treatment definitions

Set	Site	Species planted	Planting date	Ending date	Planting material[1]	Water supplement[2]	Irrigation/ Deployment over 2 years	Soil preparation[3]	Soil texture	Weeding over 2 years
1	Kefraya	*P. pinea*	15-Apr-11	19-May-13	10-mo, 12-mo "bag" seedlings	RSW NRSW IRR NIRR	5 times 5 times 10 times None	MP	Sd	4 times
1	Aitanit	*P. pinea*	20-Apr-11	19-May-13	10-mo, 12-mo "bag" seedlings	RSW NRSW IRR NIRR	5 times 5 times 10 times None	HP	SC	4 times
1	Lala	*P. pinea*	18-Apr-11	19-May-13	10-mo, 12-mo "bag" seedlings	RSW NRSW IRR NIRR	5 times 5 times 10 times None	HP	SC	2 times
2	Bkassin	*P. pinea*	29-Nov-11	28-Nov-13	8-mo container, 18-mo bag seedlings; SP3 SS200 seed sowing	IRR NIRR	8 times None	MP, NP	Sd	2 times
2	Arz – Bcharre	*C. libani*	13-Nov-11	6-Nov-13	8-mo container, 18-mo bag seedlings; SP3 SS200 seed sowing	IRR NIRR	8 times None	HP, NP	SC	2 times
3	Bnabil	*P. pinea*	7-Jan-13	1-Jul-14	SP3 seeds	NIRR	None	MP, HP	Sd	3 times
3	Kfarzebian	*C. libani*	30-Nov-12	Destroyed by goats Jun-13, dropped	SP3 seeds	NRR	None	MP, HP	SC	None

1 - Seedlings were 8, 10, 12 or 18-month-old nursery stock; Seedlings were either grown in plastic bags (10-cm diameter, 20-cm lenght) or containers; SP3 = 3 seeds planted per basin in Set 2, or 3 seeds per spot in Set 3; SS200 = 200 seeds sown in a patch.

2 - NRSW = non rechargeable solid water, RSW = rechargeable solid water, IRR = conventional hose irrigation, NRR = no irrigation.

3 - NP = no preparation, MP = mechanical preparation (backhoe for Sets 1 and 2 and plowed for Set 3), HP = hand tool preparation.

3.6.1.1 Costs

As the primary objective of the trials was to maximize survival and minimize costs, the next step was to compile cost information. Cost data for all the treatments (Table 4) were summarized from itemized categories that included costs for planting material, outplanting labor, irrigation, soil preparation, and maintenance. The total costs were expressed on a per-ha basis by assuming 800 seedlings per ha, without any assumption of the survival rates resulting from each treatment.

10-mo-old NRSW P. pinea seedling in Aitanit 2 years after plantation

As shown by the table 4 below, water supplements increased total costs the most. Highest per-ha costs involved NRSW treatments with total site costs larger than 16,000 USD/ha. Total site costs for treatments with irrigation (IRR) ranged from 2,135 USD/ha per site (for seeds) to 6,218 USD/ha (seedlings) per site. On treatments with RSW, total site cost ranged from 4,068 to 4,881 USD/ha. Nonirrigated treatments (NIRR) added no direct water supplement costs and site totals ranged from 2,284 to 3,907 USD/ha for total seedling treatment costs. Some seeding-only treatments without irrigation cost only a few dollars (ranging from 12 to 965 USD/ha). Planting costs for *P. pinea* seedlings were quite similar regardless of seedling age ranging from 1,200 to 1,400 LPB (0.93 USD) per individual tree. Seedlings costs for the Arz-Bcharre site ranged from 2,000 to 4,000 LPB/tree (1.33 to 2.66 USD/tree), apparently reflecting much higher costs for *C. libani* seedlings. All other sites were planted with *P. pinea*.

10-mo-old RSW P. pinea seedling in Aitanit 2 years after plantation

Figure 2 illustrates the cost per ha distribution for all 42 treatment combinations sorted from most costly to least costly.

Figure 2. Cost of 42 planting treatment combinations

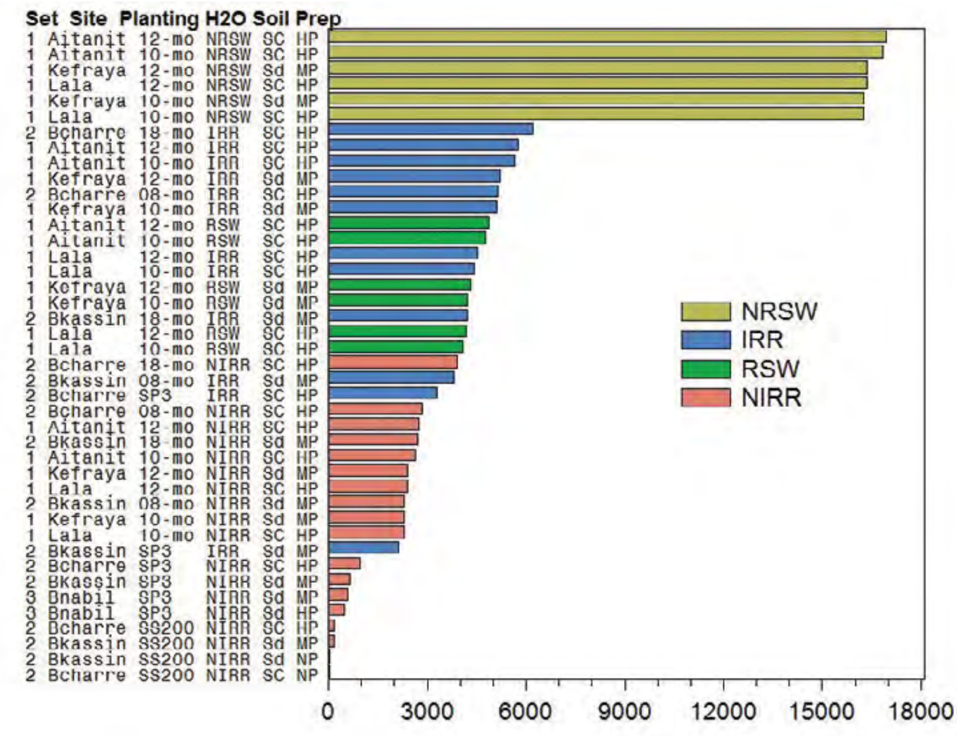


Figure 2. Cost of 42 planting treatment combinations, arrayed from most expensive to least expensive, for all sites in 3 sets of field trials. Treatments (and categories) included planting material (08, 10, 12 and 18-month-old seedlings, SP3 = 3 seeds planted at points, SS200 = 200 seeds sown in patch), water supplement (NRSW = non-rechargeable solid water, RSW = rechargeable solid water, IRR = conventional hose irrigation, NIRR = no irrigation), soil texture (Sd = sandy, SC = silt-clay), and soil preparation (NP = no preparation, MP = mechanical preparation, HP = hand tool preparation).

The trials demonstrated that successful reforestation at costs below 1,500 USD/ha could be achieved at least for certain methods of sowing seeds without irrigation. Further study into impacts of soil types and site preparation should be conducted to determine best methods for achieving higher survival rates with use of seeds and no irrigation.

Germination of P. pinea seeds (SS200) in Bkassin

Table 4. Detailed reforestation costs per tree in Lebanese Pounds (LBP) with summary in USD for planting 800 trees/ha.

Set	Site	Planting method	Water supplement	Site preparation	Cost per individual tree: Planting material	Planting labor	Water supplement	Soil preparation	Maintenance	Cost per ha
					LBP					USD
1	Aitanit	12-mo	NIRR	HP	1400	525	0	1,881	1,350	2,750
1	Aitanit	10-mo	NIRR	HP	1200	525	0	1,881	1,350	2,643
1	Aitanit	12-mo	RSW[1]	HP	1400	525	3,995	1,881	1,350	4,881
1	Aitanit	10-mo	RSW	HP	1200	525	3,995	1,881	1,350	4,774
1	Aitanit	12-mo	NRSW[1]	HP	1400	525	26,600	1,881	1,350	16,937
1	Aitanit	10-mo	NRSW	HP	1200	525	26,600	1,881	1,350	16,830
1	Aitanit	12-mo	IRR	HP	1400	525	5,650	1,881	1,350	5,763
1	Aitanit	10-mo	IRR	HP	1200	525	5,650	1,881	1,350	5,657
1	Kefraya	12-mo	NIRR	MP	1400	562	0	975	1,562	2,399
1	Kefraya	10-mo	NIRR	MP	1200	562	0	975	1,562	2,293
1	Kefraya	12-mo	RSW	MP	1400	562	3,595	975	1,562	4,317
1	Kefraya	10-mo	RSW	MP	1200	562	3,595	975	1,562	4,210
1	Kefraya	12-mo	NRSW	MP	1400	562	26,200	975	1,562	16,373
1	Kefraya	10-mo	NRSW	MP	1200	562	26,200	975	1,562	16,266
1	Kefraya	12-mo	IRR	MP	1400	562	5,250	975	1,562	5,199
1	Kefraya	10-mo	IRR	MP	1200	562	5,250	975	1,562	5,093
1	Lala	12-mo	NIRR	HP	1400	625	0	1,375	1,083	2,391
1	Lala	10-mo	NIRR	HP	1200	625	0	1,375	1,083	2,284
1	Lala	12-mo	RSW	HP	1400	625	3,345	1,375	1,083	4,175
1	Lala	10-mo	RSW	HP	1200	625	3,345	1,375	1,083	4,068
1	Lala	12-mo	NRSW	HP	1400	625	26,200	1,375	1,083	16,364
1	Lala	10-mo	NRSW	HP	1200	625	26,200	1,375	1,083	16,258
1	Lala	12-mo	IRR	HP	1400	625	4,000	1,375	1,083	4,524
1	Lala	10-mo	IRR	HP	1200	625	4,000	1,375	1,083	4,418
2	Arz-Bcharre	18-mo	NIRR	HP	4,000	525	0	1,400	1,400	3,907
2	Arz-Bcharre	08-mo	NIRR	HP	2,000	525	0	1,400	1,400	2,840
2	Arz-Bcharre	18-mo	IRR	HP	4,000	525	4,333	1,400	1,400	6,218
2	Arz-Bcharre	08-mo	IRR	HP	2,000	525	4,333	1,400	1,400	5,151
2	Arz-Bcharre	SP3[2]	IRR	HP	59	50	4,333	300	1,400	3,275
2	Arz-Bcharre	SP3	NIRR	HP	59	50	0	300	1,400	965
2	Arz-Bcharre	SS200	NIRR	HP	19	3	0	300	0	172
2	Arz-Bcharre	SS200	NIRR	NP	19	3	0	0	0	12
2	Bkassin	18-mo	NIRR	MP	2,250	450	0	1,575	800	2,707
2	Bkassin	08-mo	NIRR	MP	1,500	450	0	1,575	800	2,307
2	Bkassin	18-mo	IRR	MP	2,250	450	2,800	1,575	800	4,200
2	Bkassin	08-mo	IRR	MP	1,500	450	2,800	1,575	800	3,800
2	Bkassin	SP3	IRR	MP	68	60	2,800	275	800	2,135
2	Bkassin	SP3	NIRR	MP	68	60	0	275	800	641
2	Bkassin	SS200	NIRR	MP	23	3	0	275	0	160
2	Bkassin	SS200	NIRR	NP	23	3	0	0	0	14
3	Bnabil	SP3	NIRR	HP	68	50	0	250	550	489
3	Bnabil	SP3	NIRR	MP	68	40	0	450	550	591

1 - Costs of NRSW tubes and RSW bags included in irrigation cost
2 - Planting material calculated as 3 seeds per basin

3.6.1.2 Merging Field Survival and Cost Data

A summary of the germination and survival data (1,896 observations) was done for each site and treatment combination and then merged with cost data (from Table 4), resulting in a database consisting of 42 treatment combinations from the 3 sets of trials. Treatment variables were planting material, water supplement, soil preparation, soil texture and species planted (Table 4). Treatment replications for survival and germination were also used to cross-check with other project information previously summarized to edit for possible errors.

Figures 3 (for Set 1) and 4 (for Sets 2 & 3) illustrate the impact of the 42 different treatment combinations, ranking them by survival from highest to lowest for each site. For each treatment combination, the resulting "survival percentage" is actually the total percentage of survival among the 50 seedlings under a given treatment combination on a given site. For example, in Set 1 (Figure 3), 12-mo seedlings on Kefraya in sandy soil with mechanical site preparation and NRSW supplement had the highest survival rate of 85%; 10-mo seedlings on the same site, in sandy soil and with MP but with no irrigation, had just under 70% survival; and all treatment combinations with no irrigation on the other two sites had <10% survival.

Figure 3. Seedling survival for 8 treatment categories of Set 1 trials

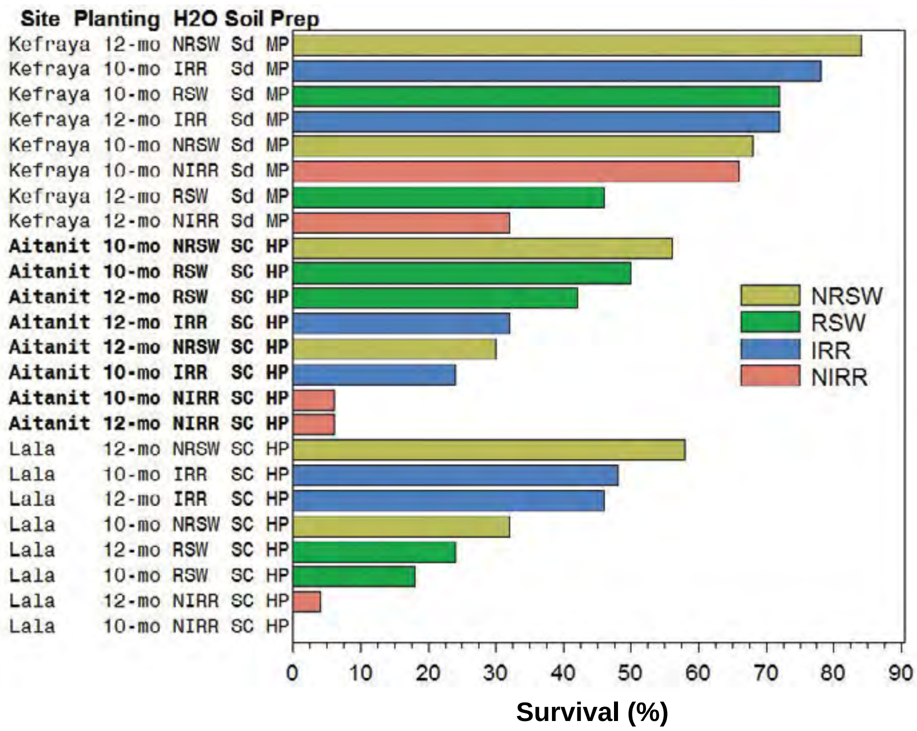


Figure 3. Seedling survival for 8 combinations of treatment categories for each site in Set 1. Sites and treatment combinations within sites are arrayed from best to poorest survival. Survival percentage was calculated from 50 plantings for each of the 24 treatment combinations. Treatments (and categories) included planting material (10 and 12-month-old seedlings), water supplement (NRSW = non-rechargeable solid water, RSW = rechargeable solid water, IRR = conventional hose irrigation, NIRR = no irrigation), soil texture (Sd = sandy, SC = silt-clay), and soil preparation (MP = mechanical preparation, HP = hand tool preparation).

Figure 4 again shows survival for each treatment combination from highest to lowest on each site for the two field trials in Set 2 and the one recorded for Set 3. Interestingly, all treatment combinations on the Bkassin site with seedlings showed fairly similar survival results regardless of seedling age or water supplement (one nonirrigated treatment combination is the highest at nearly 70% survival). Treatment combinations with seed sowing on Bkassin and Bnabil sites all resulted in survival below 25% as did all treatment combinations for both seeds and seedlings on Bcharre.

18-mo-old NIRR P. pinea seedling in Bkassin 2 years after plantation

Figure 4. Seedling and seed survival for 8 treatment categories of Set 2 and Set 3 trials

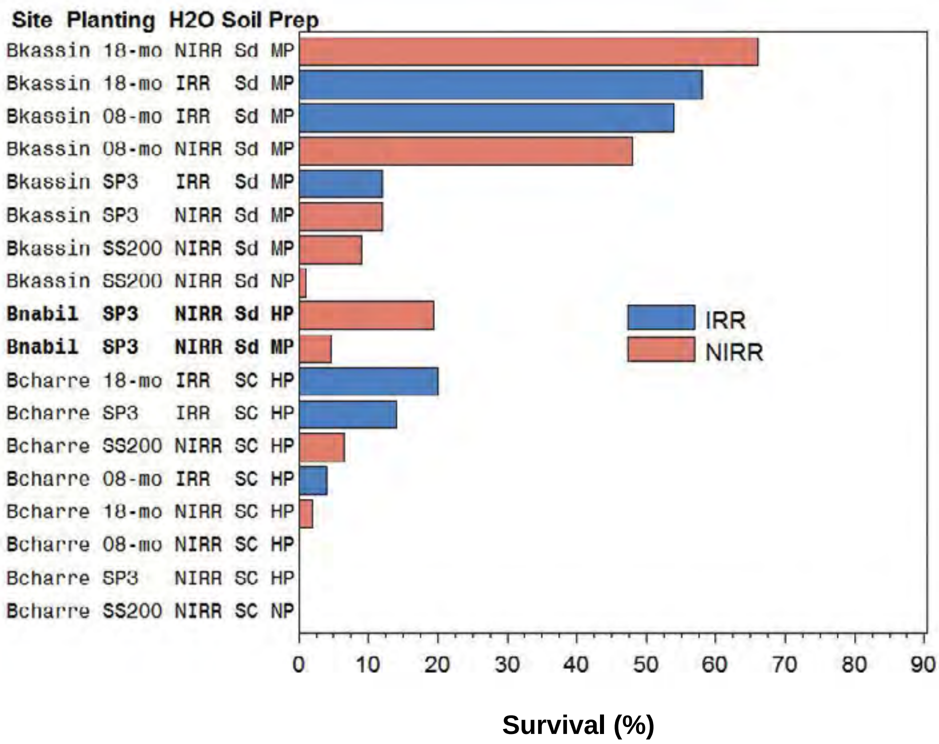


Figure 4. Planting survival for 8 combinations of treatment categories for each site in Set 2 (Bkassin and Arz-Bcharre) and for 2 combinations in Set 3 (Bnabil). Sites and treatment combinations within sites are arrayed from best to poorest survival. For each Set 2 site, survival percentage was calculated from 50 plantings, except that SS200 was based on 200 seeds sown. For Set 3 (Bnabil), survival percentage was calculated based on 200 seeds sown for SS200 and 150 plantings for SP3. Treatments (and categories) included planting material (08 and 18-month-old seedlings, SP3 = 3 seeds planted at points, SS200 = 200 seeds sown in patch), water supplement (IRR = conventional hose irrigation, NIRR = no irrigation), soil texture (Sd = sandy, SC = silt-clay), and soil preparation (NP = no preparation, MP = mechanical preparation, HP = hand tool preparation).

3.6.1.3 Weighted Survival Metric

Calculations in Table 5 below require some explanation. Germination and survival were assessed as follows:

a) Individual-seed sowing treatments in planting points, whether spots or basins (SP3): in case any seed (even only 1 out of the 3 seeds sown per planting point) was found germinated/surviving, the planting point was considered as germinated/surviving. Germination/survival percentage was then calculated by dividing the number of the germinated/surviving planting points by the total number of planting points.

b) Seed sowing (SS200): germinated/surviving seeds were individually counted and germination/survival percentage was then calculated by dividing the total number of seeds germinated or survived by total seeds sown (200).

10-mo-old NIRR P. pinea seedling in Kefraya 3 years after plantation

SP3 IRR C. libani seeds in Arz-Bcharre 2 years after sowing

Treatment combinations were unique and not replicated across the sets of planting trials. Therefore, statistical power to evaluate treatment effects was limited and it was desirable to increase replication by putting treatment combinations with seedlings and seeds on a common basis for comparison. However, to accomplish this, a new metric was necessary that accounted for the interplay of germination and survival.

Methods of calculating germination and survival can complicate assessments of treatment impacts on survival. For example, only a few seeds might germinate but those that germinate survive (low germination, high survival) or many seeds could germinate but only a few survive (high germination, low survival). Either situation could result in the same number of seedlings surviving but the first case represents excellent survival (of those seeds germinated) and indicates that the treatment is “good” for survival while the second case of low survival after high germination indicates that the treatment is “poor” for survival. Ifsurvival rate is calculated on seeds-sown basis only, it appears the same for both situations. Success of germination of seeds in these planting trials could be negatively impacted by rodent or bird predation, or other factors that could not be identified in this study, whereas for outplanted seedlings, regardless of age class, any seed that did not germinate had been already discarded in the nursery.

In order to be able to group seedlings and seeds for comparison of survival under various treatments and to account for highly variable germination rates, an analytical method was devised that was based on a "weighted survival rate." First a germination rate was defined by calculating survival for SP3 (which was to count only 1 of up to 3 seeds germinated at each planting point) and then total seeds survived were divided by total planting points. For seeds sown (SS200), total seeds germinated were divided by 200 seeds sown.

Next "germinated survival" was defined as survival rate divided by germination rate. If "germinated survival" was less than or equal to germination rate, "germinated survival" was used as "weighted survival rate" (i.e., "weighted survival" = "germinated survival"). But if "germinated survival" was greater than germination rate, it was averaged with germination rate [i.e., "weighted survival" = ("germination survival" + germination)/2].

This method essentially "weights" survival to adjust it in proportion to germination rate but also further adjusts for the case of low germination. For example, 100% survival when all survive following a germination rate of 5% is unrealistically high, but a better estimate could be the calculation from the second equation above, or (100 +5)/2 = 53%. Both the "weighted survival" and original unweighted survival are given in Table 5 for comparison for seed planting treatments. The weighted survival metric changed survival for 8 of the 42 total treatments.

SP3 NIRR P. pinea seeds in Bnabil 2 years after sowing

Because this method was specifically developed for this analysis and there are no known references for it, its properties for some combinations of "germinated survival" and germination rate were examined in detail. This was done graphically by plotting weighted survival against germination for all possible values (i.e., 100 by 100 matrix or 10,000 points) showing effects of the "two-part" calculation as described above. This exercise produced reasonable results, supporting addition of the second calculation.

This method may seem odd because "weighted survival" can exceed germination rate—but this is precisely what the metric aimed to accomplish when there was low germination but high survival of seeds germinated. It was developed so that seedling and seed planting could be assessed on a more common basis for the same treatments and so that treatment effects could be more clearly revealed. Hereafter, "weighted survival" is used/assumed for further statistical analysis of seed planting survival results unless stated otherwise.

3.6.1.4 Adjusted Cost Metric

Another cost metric was also devised to account for seedling mortality while still estimating cost of producing 800 seedlings with a given treatment, even if survival was low. The metric simply adjusted cost per ha by dividing by survival expressed as a proportion (i.e., percent survival divided by 100). This metric (termed adjusted cost) presented difficulties when dealing with (a) no estimate for zero survival but the cost, and (b) a large adjusted cost for very low survival.

The second shortcoming was somewhat mitigated for seed sowing treatments by using "survival weighting" as described above when germination was very low. Results of calculations by this method are shown in Table 5, and discussed in Chapter Four: Results and Discussion.

Table 5. The 42 treatments of the Lebanon planting trials summarized for 6 sites.

		Treatments											
Set	Site	Planting method[1]	Water supplement[2]	Site preparation[3]	Soil texture[4]	Species	Germination sample size[5]	Seedling sample size[5]	Germination (%)	Survival (%)	Seeds Weighted Survival[6] (%)	Cost per ha (USD)	Survival adjusted[7] cost per ha (USD)
1	Aitanit	10-mo	IRR	HP	SC	*P. pinea*	NA	50		24		5,657	23,569
1	Aitanit	10-mo	NIRR	HP	SC	*P. pinea*	NA	50		6		2,643	44,053
1	Aitanit	10-mo	NRSW	HP	SC	*P. pinea*	NA	50		56		16,830	30,053
1	Aitanit	10-mo	RSW	HP	SC	*P. pinea*	NA	50		50		4,774	9,548
1	Aitanit	12-mo	IRR	HP	SC	*P. pinea*	NA	50		32		5,763	18,010
1	Aitanit	12-mo	NIRR	HP	SC	*P. pinea*	NA	50		6		2,750	45,831
1	Aitanit	12-mo	NRSW	HP	SC	*P. pinea*	NA	50		30		16,937	56,455
1	Aitanit	12-mo	RSW	HP	SC	*P. pinea*	NA	50		42		4,881	11,620
1	Kefraya	10-mo	IRR	MP	Sd	*P. pinea*	NA	50		78		5,093	6,529
1	Kefraya	10-mo	NIRR	MP	Sd	*P. pinea*	NA	50		66		2,293	3,474
1	Kefraya	10-mo	NRSW	MP	Sd	*P. pinea*	NA	50		68		16,266	23,921
1	Kefraya	10-mo	RSW	MP	Sd	*P. pinea*	NA	50		72		4,210	5,847
1	Kefraya	12-mo	IRR	MP	Sd	*P. pinea*	NA	50		72		5,199	7,221
1	Kefraya	12-mo	NIRR	MP	Sd	*P. pinea*	NA	50		32		2,399	7,498
1	Kefraya	12-mo	NRSW	MP	Sd	*P. pinea*	NA	50		84		16,373	19,491
1	Kefraya	12-mo	RSW	MP	Sd	*P. pinea*	NA	50		46		4,317	9,384
1	Lala	10-mo	IRR	HP	SC	*P. pinea*	NA	50		48		4,418	9,203
1	Lala	10-mo	NIRR	HP	SC	*P. pinea*	NA	50		0		2,284	-
1	Lala	10-mo	NRSW	HP	SC	*P. pinea*	NA	50		32		16,258	50,805
1	Lala	10-mo	RSW	HP	SC	*P. pinea*	NA	50		18		4,068	22,601
1	Lala	12-mo	IRR	HP	SC	*P. pinea*	NA	50		46		4,524	9,835
1	Lala	12-mo	NIRR	HP	SC	*P. pinea*	NA	50		4		2,391	59,773
1	Lala	12-mo	NRSW	HP	SC	*P. pinea*	NA	50		58		16,364	28,214
1	Lala	12-mo	RSW	HP	SC	*P. pinea*	NA	50		24		4,175	17,396

		Treatments											
Set	Site	Planting method[1]	Water supplement[2]	Site preparation[3]	Soil texture[4]	Species	Germination sample size[5]	Seedling sample size[5]	Germination (%)	Survival (%)	Seeds Weighted Survival[6] (%)	Cost per ha (USD)	Survival adjusted[7] cost per ha (USD)
2	Arz-Bcharre	08-mo	IRR	HP	SC	*C. libani*	NA	50		4		5,151	128,773
2	Arz-Bcharre	08-mo	NIRR	HP	SC	*C. libani*	NA	50		0		2,840	-
2	Arz-Bcharre	18-mo	IRR	HP	SC	*C. libani*	NA	50		20		6,218	31,088
2	Arz-Bcharre	18-mo	NIRR	HP	SC	*C. libani*	NA	50		2		3,907	195,333
2	Arz-Bcharre	SP3	IRR	HP	SC	*C. libani*	50	50	74	14	19	3,275	23,396
2	Arz-Bcharre	SP3	NIRR	HP	SC	*C. libani*	50	50	44	0	0	965	-
2	Arz-Bcharre	SS200	NIRR	HP	SC	*C. libani*	200	200	23	7	26	172	2,642
2	Arz-Bcharre	SS200	NIRR	NP	SC	*C. libani*	200	200	3	0	0	12	-
2	Bkassin	08-mo	IRR	MP	Sd	*P. pinea*	NA	50		54		3,800	7,037
2	Bkassin	08-mo	NIRR	MP	Sd	*P. pinea*	NA	50		48		2,307	4,806
2	Bkassin	18-mo	IRR	MP	Sd	*P. pinea*	NA	50		58		4,200	7,241
2	Bkassin	18-mo	NIRR	MP	Sd	*P. pinea*	NA	50		66		2,707	4,101
2	Bkassin	SP3	IRR	MP	Sd	*P. pinea*	50	50	32	12	35	2,135	17,789
2	Bkassin	SP3	NIRR	MP	Sd	*P. pinea*	50	50	38	12	32	641	5,344
2	Bkassin	SS200	NIRR	MP	Sd	*P. pinea*	200	200	9	9	55	160	1,781
2	Bkassin	SS200	NIRR	NP	Sd	*P. pinea*	200	200	3	1	21	14	1,360
3	Bnabil	SP3	NIRR	HP	Sd	*P. pinea*	150	150	53	19	37	489	2,531
3	Bnabil	SP3	NIRR	MP	Sd	*P. pinea*	150	150	9	5	31	591	12,657

1 - Planting methods include 8, 10, 12, 18-month-old seedlings; seeds planted as 3 per basin or spot (SP3); or seed sowing (SS200).
2 - NRSW = non-rechargeable solid water, RSW = rechargeable solid water, IRR = conventional hose irrigation, NIRR = no irrigation.
3 - NP = no preparation, MP = mechanical preparation, HP = hand tool preparation.
4 - Soil with ≥38% sand (Sd), otherwise silt-clay soil (SC).
5 - For SP3, only 1 of 3 counted for each spot or basin regardless of actual germination or survival (i.e., 1 or 0 recorded at each spot or basin).
6 - Weighted survival used in statistical analysis; see text for explanation of how weighted for only those seeds germinated.
7 - This metric (Survival adjusted cost per ha) is the estimate of how much a treatment combination would cost, if as many seedlings were initially planted (or seeds sown) as needed in order to eventually end up with 800 seedlings per ha, according to the survival rates observed for each treatment tested. Survival-adjusted cost per ha of each treatment combination shown in dark purple color is less than the current estimate of 7,000 USD/ha/800 seedlings, while cost shown in light purple color is greater than the 7,000 USD estimate.

3.6.2 Analysis Methodology

Each site was assumed to be an "experimental unit" for statistical analysis. Data assembled in Table 5 include 6 experimental units (6 sites) for analysis to compare treatments. The 6 sites serve as replicates for repeating an experimental treatment so that the variability associated with the phenomenon could be estimated for use in statistical testing. Trials within each of the six sites had insufficient replication for such analysis. Treatments among sites were not balanced (same treatments on all sites) so a more complex method was used instead of a conventional analysis of variance or ANOVA.

Therefore, generalized linear mixed models were used to test for significance of treatment effects among the 6 sites. The treatments are the "fixed effects" tested with this technique but this also accounts for the effect of sites ("random effects") so that treatments across all sites could be assessed equally without confounding because of inherently better survival on better sites. For example, Kefraya and Bkassin (Figure 5) seem to have inherently better survival rates regardless of treatment. Likewise, Arz-Bcharre seems inherently poor. The mixed models analysis accounts for this difference among sites before testing for differences among treatments. A convenient benefit of this analysis was adjustment for species differences because each site was planted with a single species. Hence, Arz-Bcharre - the only *C. libani* site after the loss of the trials initiated in Kfarzebian due to grazing - could be included with the rest of the *P. pinea* sites for treatment assessments.

Mixed models analysis includes a mathematical equation of the model but that is best expressed in matrix algebra and not listed here. Out of the two ways to account for the sites in mixed models using SAS software, the "Repeated" (SAS Institute Inc. 2014) not the "Random" model formulation was selected. This choice was made with help of SAS consultants (SAS Technical Support 2014). Mixed models proved most useful because this technique allowed for statistical analysis among sites despite lack of statistical design for the seedling planting trials.

The field trials also provided other data that could be analyzed to more fully explore impacts of abiotic effects (soil temperature and soil moisture) on survival and germination, and perhaps identify the most critical periods for seedling mortality. Current analysis only considers beginning and ending time periods. Abiotic data could also be summarized and compared with final results. Other data included growth measurement for a small subsample at each site. Tree height measurements were recorded periodically throughout the study. Average root growth was recorded for Set 2 sites. On Arz-Bcharre, root growth was measured in November 2013 (18 months after germination) with average root growth of 24 cm and average growth of green parts of 6.5 cm. At Bnabil, average root growth was measured in September 2013 (6-7 months after germination) with average growth of 14.85 cm for roots and 8.2 cm for green parts of seedlings recorded. A root-to-shoot ratio is the common metric for analyzing such data.

C. libani seed root growth 2 years after sowing (Arz-Bcharre)

Figure 5. Survival of seedlings and weighted survival of seeds for 42 treatment categories of all 3 Sets of trials

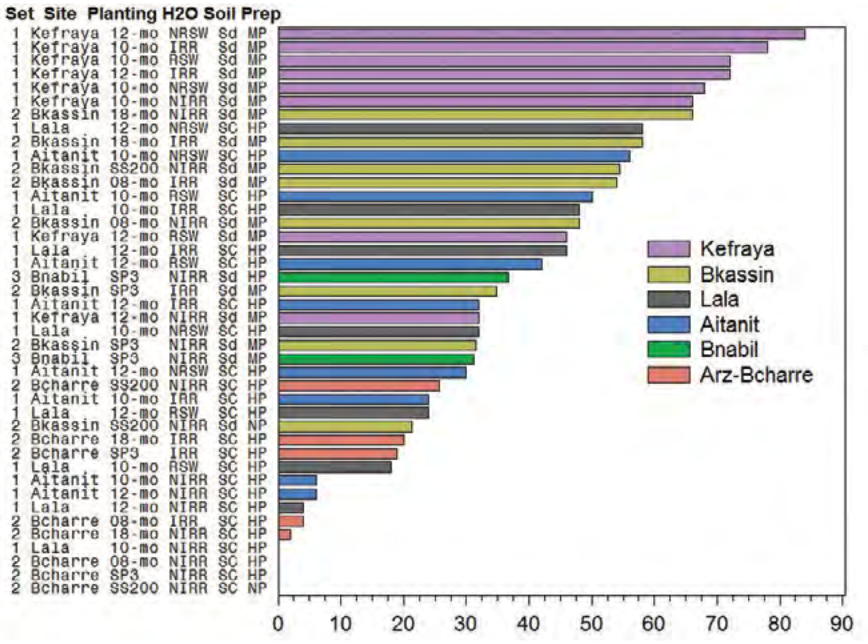


Figure 5. Planting survival (weighted for seed-planting treatments) of 42 planting treatment combinations, arrayed from greatest to least survival, for all sites in 3 sets of field trials. Treatments (and categories) included planting material (08, 10, 12 and 18-month-old seedlings, SP3 = 3 seeds planted at points, SS200 = 200 seeds sown in patch), water supplement (NRSW = non-rechargeable solid water, RSW = rechargeable solid water, IRR = conventional hose irrigation, NIRR = no irrigation), soil texture (Sd = sandy, SC = silt-clay), and soil preparation (NP = no preparation, MP = mechanical preparation, HP = hand tool preparation).

3.7 Large-Scale Field Applications

To apply this new knowledge of cost-effective planting techniques from the field more widely, 8 locations were selected for larger scale reforestation applications. Selection criteria were availability of lands, plot size, adequate soil and climatic conditions, and readiness of the partners to cooperate with the Project. The total area which has been reforested is 25 hectares. Several municipalities, monasteries, local communities, NGOs, universities, schools, and scout associations have assisted the Project with planting and maintenance of these new sites, which had the benefit of the latest technologies being applied in Lebanon. They were generally planted with either 8-month-old seedlings (from the 3rd and latest generation of seedlings grown at local nurseries that have considerably improved practices based on advice from international experts and training) or the direct seed sowing methods described above. Planting of both seedlings and seeds was done at the proper season and time, in autumn or winter 2013–2014 (after the first rains, when the soil moisture was above 20%).

P. pinea seedlings resulting from seeds without irrigation 9 months after sowing in Wadi Al-Karm

Germination of Q. Calliprinos acorns 6 months after sowing in Anjar

8-mo-old P. pinea seedling without irrigation 10 months after plantation in Wadi Al-Karm

8-mo-old C. libani seedling 10 months after plantation in Arz-Bcharre

Most sites were not irrigated at planting or during the dry season. The Project team would have preferred to leave all sites without irrigation for a complete test of these methods. However, some partners decided to irrigate the seedlings at least during the first summer, taking into consideration that fall-winter rainfall & snow in 2013-2014 were exceptionally low and fearing that soil moisture content might not be sufficient to ensure plant survival. All seed sowings have remained without any irrigation.

The species used and the planting methods applied at the 8 large-scale sites were as follows:

Arz-Bcharre:	Seedlings and a small portion of seeds (*C. libani*) – seedlings mostly irrigated with a small plot kept without irrigation for trial purposes. Seeds sown were kept without irrigation.
Anjar:	Seedlings and seeds (*C. libani*, *Pinus pinea*, *Pinus brutia*, *Quercus spp*. and *Juniperus excelsa*) – without irrigation.
Al-Khalleh:	Seedlings and seeds (*Pinus pinea*) – without irrigation.
Wadi Al-Karm:	Seedlings and seeds (*Pinus pinea*) – without irrigation.
Maghdouche:	Seedlings (*Pinus pinea* and *Ceratonia siliqua*) – with irrigation.
Alma Al-Chaab:	Seedlings (*Pinus pinea* and *Ceratonia siliqua*) – with irrigation.
Tebnine:	Seedlings (*Pinus pinea*) – with irrigation.
Kossaibeh:	Seedlings (*Cupressus sempervirens*) – with irrigation.

Although it is too early to record results of a full year growing season, initial results are encouraging. On the Wadi Al-Karm site, reforested in cooperation with the landowner monastery after a fire on more than 10 hectares of pine forests in 2013, initial monitoring after the 2014 dry summer season (20 August 2014) indicated 72% average survival of seeds (seedlings germinated from seeds sown) and 100% survival of 3rd generation 8-month-old seedlings (using a random sample of ten 5-meter circular plots). Because there has been no irrigation on the site, this indicates at least initial success with low-cost no-irrigation planting methods in certain appropriate areas.

CHAPTER FOUR: Results and Discussion

Survival data for the 42 treatment combinations that resulted from consideration of all treatments for all categories across the six planting trial sites were summarized by site (Table 5, Figure 5). However, the data were difficult to interpret in this form, and the survival data had to be compared to treatment costs. Therefore, the mixed-model approach (described in Chapter 3, Analysis Methodology section) was used to condense the 42 treatments and identify statistically nonsignificant treatments that could be grouped before comparing to costs.

Although the generalized linear mixed model is a powerful flexible statistical tool, it must be used with caution. Therefore, statistical graphics were used for many of the comparisons. The mixed-models approach allowed the use of the 6 sites for replication by adjusting for site differences while evaluating significance of treatments.

4.1 Statistical Testing for Survival

Replication was maximized among sites by testing for differences in all sets combined. Four treatments (planting material, water, soil preparation, and soil texture) and 14 treatment categories among sites are listed below:

- Planting material: 8 to 10-mo, 12-mo, and 18-mo seedlings; 3 seeds per planting point (SP3); and sown seeds (SS200)
- Water: no irrigation (NIRR), conventional irrigation (IRR), rechargeable solid water (RSW), and non-rechargeable solid water (NSRW)
- Soil preparation: mechanical (MP), hand tool (HP), and none (NP)
- Soil Texture: sandy (Sd) and silt-clay (SC)

After combining 8 and 10-month-old seedlings, the 42 treatment categories among the 6 sites in the study (Table 5) could be reduced to 29 treatment combinations of 1 to 3 replicates each for statistical analysis. Ideally one would "replicate" each of the 29 treatment categories within and/or among sites 2 or more times each. Survival of planting material was the dependent variable in analysis. As previously mentioned, survival of seed sowing was weighted to account for poor germination.

Overall results from mixed-models analysis were quite insightful. First, the model did describe the data fairly well. Figure 6 shows model fit (labeled as "predicted") was reasonable for most treatment combinations, despite the low replication.

The two significant differences were water and soil texture treatments (P-values 0.007, 0.014 respectively in Table 6: P-value less than 0.05 is considered significant in statistical significance testing.) This indicates that some water treatment and soil texture categories affected planting survival. An equally important finding for the trials was that planting material (seeds or seedling age) and soil preparation (P-values 0.161 and 0.420, respectively) appeared not to be statistically significant. This means that either there was no significant difference among planting material choices or among preparation methods, or that there was insufficient replication to detect such effects.

Figure 6. Comparison of predicted survival to measured survival of the reduced 29 treatment combinations

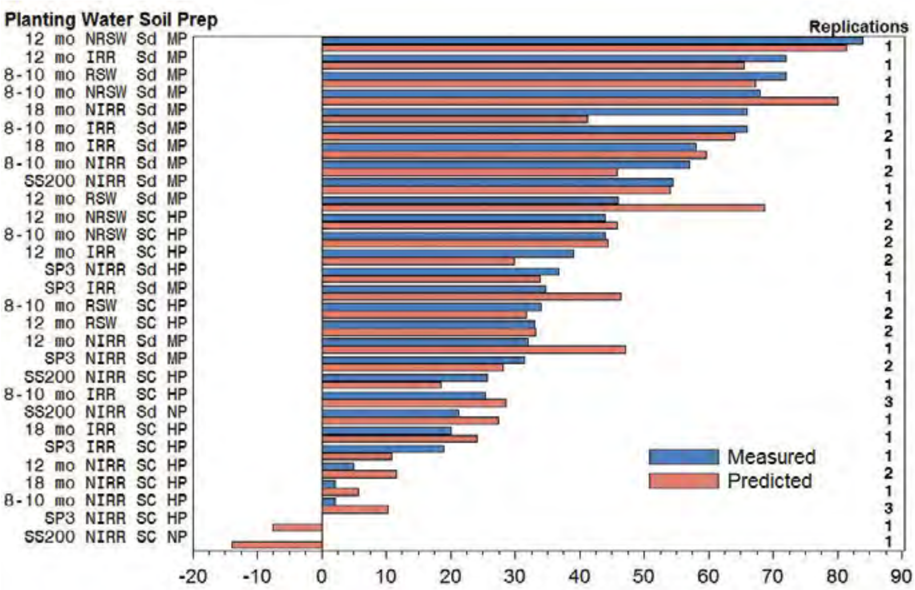


Figure 6. Comparison of predicted survival (weighted for seed-planting treatments) from underlying "mixed-model" analysis—used to test significant treatment effects for all sets combined—to measured survival. Treatments (and categories) included planting material (8-to-10-, 12 and 18-month-old seedlings, SP3 = 3 seeds planted at points, SS200 = 200 seeds sown in patch), water supplement (NRSW = non-rechargeable solid water, RSW = rechargeable solid water, IRR = conventional hose irrigation, NIRR = no irrigation), soil texture (Sd = sandy, SC = silt-clay), and soil preparation (NP = no preparation, MP = mechanical preparation, HP = hand tool preparation).

Table 6. Linear mixed-models statistical tests for 4-fixed treatment effects (while adjusting for 6 "repeated" or random-like site effects) showing significance or nonsignificance.

Fixed effect	Numerator DF	Denominator DF	F-value	Prob > F	
Planting method (seedling age or seeding)	4	5	2.60	0.161	ns
Water supplement	3	8	8.43	0.007	*
Soil texture	1	4	17.71	0.014	*
Soil preparation	2	1	2.34	0.420	ns

* significant at 0.05 probability level / ns nonsignificant

Individual treatment categories were tested with pairwise tests (20 total) to evaluate which categories significantly affected planting material survival (Table 7). Although planting material did not show statistically significant effects overall, in two cases survival for seed sowing (SP3) was marginally significant compared with that for youngest seedlings (P-values 0.044 and 0.035 for comparison with 8-10-mo and 12-mo, respectively) but not significant when compared with that from 18-mo seedlings. On the other hand, none of the seedling age classes significantly affected seedling survival.

Old nursery techniques

Modern nursery for container seedling production in Bcharre

Spiral roots resulting from planting in nylon bags (old method)

8-mo-old C. libani seedling produced in improved nursery

Perhaps effects of planting material were somewhat obscured by seedling quality. During the study period 2011-2013, three generations of container seedlings were produced by Lebanese nurseries. The 2011 seedlings used in Set 1 trials were produced before nurseries implemented improvements recommended by international experts. The 2012 seedlings used in Set 2 trials were of better quality. The highest quality seedlings (3rd generation) became available in 2013 and were used in the large-scale applications, with excellent results and very high survival rates even without any irrigation, as mentioned above. However, Set 3 trials conducted during this time were not testing seedling performance but rather effectiveness of seed planting methods with and without irrigation. Field trials of seedling performance conducted with new improved seedlings might produce different seedling survival results.

Pairwise comparison of the water treatments showed that no irrigation compared with some form of water supplement significantly affected planting material survival (P-values 0.011, 0.002, and 0.018 for comparison of NIRR with IRR, NRSW, and RSW, respectively) but there were no significant differences among kinds of water supplements (although the comparison between IRR and NRSW was close to being significant with a P-value of 0.060). Soilpreparation showed nonsignificance among the 3 categories, but replication was low (only 1 degree of freedom in each test).

In summary, statistical testing for survival showed the following:

- Overall, planting material (whether seedlings or seeds were planted) did not affect weighted survival rate, but finer-scale pairwise tests showed some difference between seeds and younger seedlings. This means that the choice among planting materials can be guided by cost without too much concern about seeds vs. seedlings, except for seed germination, which is an important consideration further discussed below.
- Soil preparation showed no statistical effect on survival, although there was little replication of treatment categories within sites (i.e., low "degrees of freedom" or DF in Tables 5 and 6) to support strong statistical testing of this treatment. This means that these trials should not be used as a basis for strong recommendations for soil preparation.
- No irrigation was statistically different from water supplements. There also were no significant differences among conventional irrigation and novel irrigation techniques tested that affected planting survival. This means that water supplement can be selected on the basis of cost or availability without much concern about survival (as compared to conventional irrigation). All supplements should perform about equally well according to this study.
- Soil texture affected planting survival. Sandy soil was more favorable than silt-clay, although this finding primarily applied to *P. pinea* (*Cedrus libani* was planted on only one poorly performing and compacted silt-clay site so there was no opportunity to compare soil texture impact on this species).

Germination rate was also examined with mixed-models analysis for Sets 2 and 3 treatment categories for water supplement (IRR, NIRR), soil preparation (MP, HP, NP), soil texture (Sd, SC), and seed sowing methods (SP3 or SS200). None of these treatments nor pairwise categories showed significant effects on germination, but with this little replication one would not expect to detect significant effects. (Only one treatment category—"SP3 NIRR Sd MP"—was replicated.) However, the germination data displayed in Table 5 (10 observations) is discussed below together with survival in comparison to cost for evaluating these data; these types of anecdotal observations, based on individual events or examples, can be useful for guiding further testing and research.

Table 7. Linear mixed-models statistical tests (least squares means) for categories within 4 fixed treatment effects.

Fixed effect	Pairwise	comparison	DF	t-value	Prob > |t|	
Planting method (seedling age or seeding)	08-10 mo	12 mo	5	-0.25	0.810	ns
Planting method	08-10 mo	18 mo	5	0.62	0.564	ns
Planting method	08-10 mo	SP3	5	2.67	0.044	*
Planting method	08-10 mo	SS200	5	-0.78	0.469	ns
Planting method	12 mo	18 mo	5	0.82	0.451	ns
Planting method	12 mo	SP3	5	2.87	0.035	*
Planting method	12 mo	SS200	5	-0.66	0.537	ns
Planting method	18 mo	SP3	5	1.45	0.207	ns
Planting method	18 mo	SS200	5	-1.02	0.355	ns
Planting method	SP3	SS200	5	-2.23	0.076	ns
Water supplement	IRR	NIRR	8	3.28	0.011	*
Water supplement	IRR	NRSW	8	-2.19	0.060	ns
Water supplement	IRR	RSW	8	-0.44	0.672	ns
Water supplement	NIRR	NRSW	8	-4.70	0.002	*
Water supplement	NIRR	RSW	8	-2.96	0.018	*
Water supplement	NRSW	RSW	8	1.56	0.158	ns
Soil texture	SC	Sd	4	-4.21	0.014	*
Soil preparation	HP	MP	1	0.56	0.675	ns
Soil preparation	HP	NP	1	2.15	0.277	ns
Soil preparation	MP	NP	1	1.77	0.328	ns

* significant at 0.05 probability level / ns nonsignificant

4.2 Survival Cost Comparison

4.2.1 Categorization by Cost

The field trials were primarily designed to identify techniques to reduce reforestation costs. Therefore, it made sense to further examine and interpret the statistical findings in context of treatment costs. Because the field trials entailed many treatment categories among sites, resulting in fairly small replicate numbers (1 to 4) for any given planting material-water-soil texture-soil preparation combination, the statistical results were mainly used to group treatment combinations for cost comparison. Nonsignificant treatment categories were combined, but only when costs among nonsignificant categories were similar.

The various planting material categories showed no significant differences (Table 7) among seedling ages (8-10 months, 12 months, 18 months), so it was statistically reasonable to combine all seedling ages. However, 18-mo seedlings were much more costly than younger seedlings so they were kept separate while all younger seedlings (8-12 months) were combined. Additionally, pairwise comparison showed some statistical significance between the spot seed sowing method (SP3) and both seedlings aged 8-10 months and seedlings aged 12 months so this spot seed sowing method (SP3) was kept separate. Although SP3 and SS200 treatments did not show statistical differences for weighted survival, they were kept separate from each other because there was marginal significance (P-value = 0.076, Table 7) and planting cost differences. The net result of condensing plant material was reduction of the 42 treatment categories to 21.

Further reduction was done by dropping the NRSW treatment combinations from group analysis because NRSW was so much more costly than the other water treatments (Figure 2) that it was discussed separately. Also, the Arz-Bcharre *C. libani* site was analyzed separately because it was the only *C. libani* site and it seemed unwise to combine it with *P. pinea*, in addition to the fact that *C. libani* establishment appears much more costly than for *P. pinea*, particularly due to the cost of 18-mo seedlings (Table 4). These reductions resulted in 13 treatment-category combinations of 28 survival observations for comparison to cost. This meant the 13 reduced treatments included from 1 to 4 replications each.

Additional reduction from the statistical perspective could be done by combining RSW and IRR water treatments and combining all soil preparation categories, but there would have been little practical gain from doing so (i.e., reducing the 13 to 10).
As mentioned earlier, cost was a factor in selecting combinations. Effort was made to avoid combining treatment categories with dissimilar planting costs. To check this, variation of the cost within each treatment category was calculated (from standard error divided by mean) and found to be less than 10% for all 13 groups.

4.2.2 Survival (not Weighted) vs. Cost in *Pinus pinea*

Figure 7 summarizes cost per ha of the 13 treatment combinations mentioned above for establishment and maintenance for 2 years, and compares actual survival (not weighted) to cost. Replication is small in general, but in some cases it reached up to four replications, which is good for survival. On the other hand, cost had to be averaged for the replications and it was desirable to not combine costs that varied greatly among replications.
Only 4 seeding treatments met the Project's target cost criterion of less than 1,500 USD per ha (Figure 7, part B). These were all treatments with no irrigation (NIRR) on sandy soil (Sd) and with all combinations of soil preparation. Survival of these seed plantings ranged from 1% to about 20% and germination was generally poor at about 25% or much less except for one treatment just over 50%. Also, it can be seen that survival of seed plantings is generally much less than survival of the much more costly (2,000 to 4,500+ USD per ha) seedling plantings.

Figure 7. *Pinus pinea* survival and germination (A) compared to cost (B)

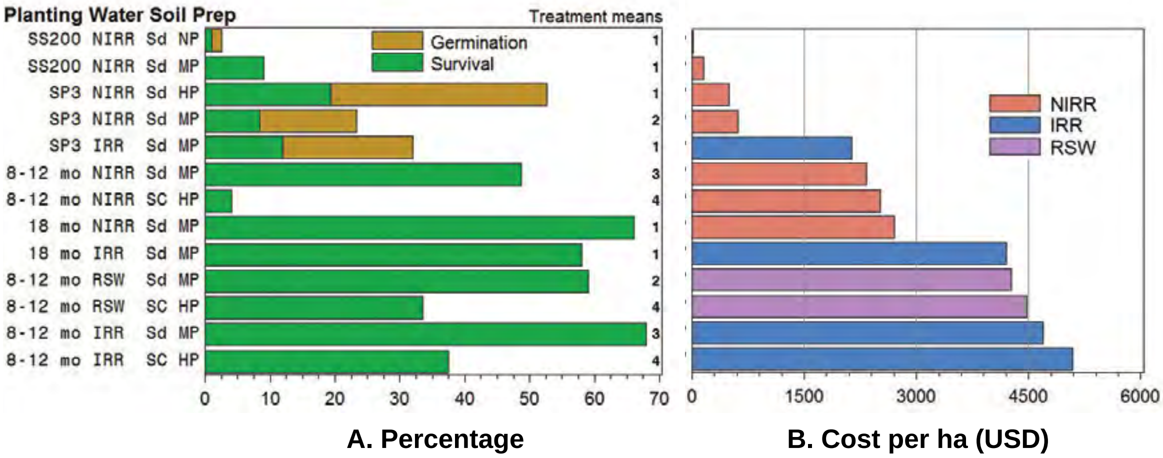


Figure 7. *Pinus pinea* percent survival and germination (A) compared to cost in U.S. dollars (B) for establishment and 2 years' maintenance. Treatments included planting material (8 to 12 and 18-month-old seedlings, SP3 = 3 seeds planted at points, SS200 = 200 seeds sown in patch), water supplement (RSW = rechargeable solid water, IRR = conventional hose irrigation, NIRR = no irrigation), soil texture (Sd = sandy, SC = silt-clay), and soil preparation (NP = no preparation, MP = mechanical preparation, HP = hand tool preparation). Replications > 1 indicate survival and germination and cost estimate values were averaged. Survival (green) overlays germination (brown); e.g., germination on treatment category SS200 NIRR Sd MP is not visible, because it is identical to survival; both are 9%.

4.2.3 Survival (Weighted) vs. Cost in *Pinus pinea*

Using weighted survival for seed plantings (Figure 8) allows comparison on similar basis for treatment combinations that worked equally well for seedlings and those seed plantings that germinated. As mentioned in the Weighted Survival Metric section of this report (3.6.1.3), this new metric was developed to account for the interplay of germination and survival and had two purposes:

The first was to put seeds and seedlings on a common basis to increase treatment replication and enable statistical analysis. (This statistical analysis was done as an "after-the-fact" guide for data interpretation, aiming at looking for trends, not determining absolute survival rates or strictly significant/nonsignificant findings).

Second, weighted survival helped to account for variable germination rates. For example, treatment combination "SS200 NIRR Sd MP" had low germination (9%) but all the seeds that germinated survived this treatment for 2 years. Using the weighted survival metric gives a net result of 55% rather than 100%, allowing some credit both for low germination but high survival . Figure 7 shows *Pinus pinea* germination and survival of both seeds and seedlings (with unweighted seed survival). Unless read carefully, this figure obscures the fact that there was excellent survival from poor germination—the germination bar is overlaid by the survival bar, because 9% germinated and 9% survived. Figure 8 (weighted seed survival) indicates the 55% survival for the treatment and also the low 9% germination.

Figure 7 showed 4 seed-planting treatment combinations that cost less than 1,500 USD per ha (over 2 years) but unweighted survival was rather low because germination was also quite low. In Figure 8, some of these 4 treatments look comparable to seedling survival and actually exceed seedling survival. Of course the purpose here is to look at trends and not to make an absolute comparison of weighted survival numbers between seed plantings and seedlings.

Figure 8. *Pinus pinea* survival (weighted for seed plantings) and germination (A) compared to cost (B)

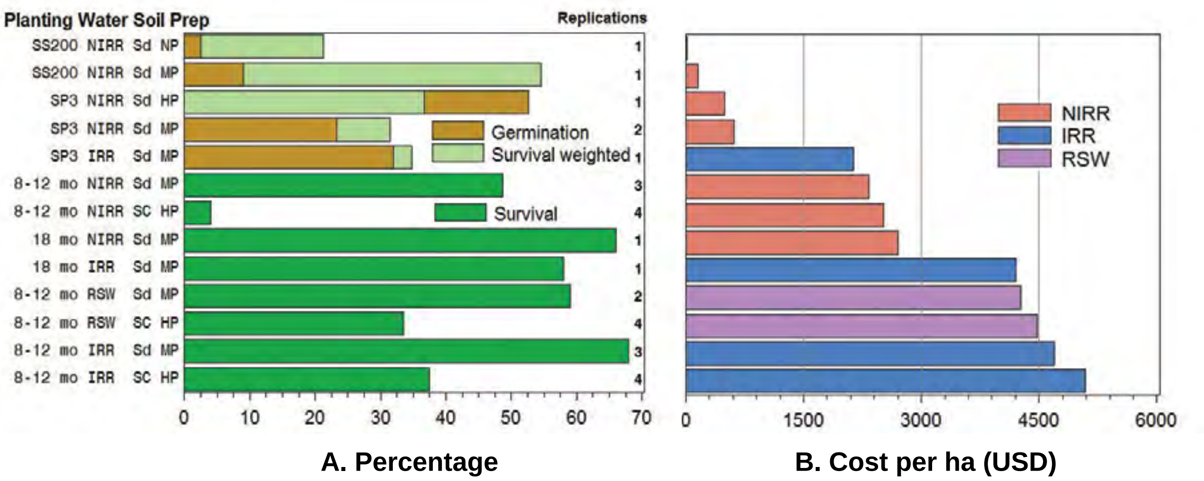


Figure 8. *Pinus pinea* percent survival and germination (A) compared to cost in U.S. dollars (B) for establishment and 2 years' maintenance; survival was weighted for seed plantings SS200 and SP3 to account for germination. Treatments include planting material (08 to 12 and 18-month-old seedlings, SS200 = 200 seeds sown in patch, SP3 = 3 seeds planted at points), water supplement (RSW = rechargeable solid water, IRR = conventional hose irrigation, NIRR = no irrigation), soil texture (Sd = sandy, SC = silt-clay), and soil preparation (NP = no preparation, MP = mechanical preparation, HP = hand tool preparation). Replications > 1 indicate survival and germination and cost estimate values were averaged. Cost for SS200 NIRR Sd NP is 14 USD (barely visible). Weighted survival (light green) overlays germination (brown); e.g., survival for SP3 NIRR Sd HP is 37% and germination is about 53%.

4.3 Poor or Ineffective Treatments

Results indicated that several treatment combinations for *P. pinea* should be avoided:

- Even though seed sowing (SS200) with no irrigation and no site preparation is very inexpensive (< 15 USD per ha), seeds germinated poorly. This problem must be seriously considered and reasons for poor seed germination should be better understood before making final recommendations on the large scale adoption of this method. This finding is also consistent with literature statements that seeding is not often successful (Bainbridge 2007). However, due to the very low cost of this technique, it might be recommended where low cost seeds are available abundantly. It is also very interesting that seedlings resulting from seeds in treatment SS200

NIRR Sd MP survived so well from what little germinated. This might be attributed to the sandy nature of the soil which well suits *Pinus pinea*. Also, perhaps the mechanical soil preparation (MP) is critical for rapid root development. This could be a similar finding to that from soil preparation method tests in Spain (Querejeta et al. 2001) where mechanical terracing increased soil water storage more effectively than manual terracing and apparently allowed more seedling access to water stored in deeper soil layers.

- Likewise, 8–12 month seedlings (8-12 mo NIRR SC HP) should not be planted on silt-clay soils with hand-tool soil preparation and without irrigation, until there is further study of the effects of silt-clay soils. Since there were no plantings of 18-month-old seedlings, nor use of mechanical soil preparation on nonirrigated silt-clay sites, it is not known whether use of these treatment categories could improve survival. However, other treatments on silt-clay showed that irrigation improved survival.
- Although water supplement improved seedling survival on silt-clay soils over no irrigation (8-12 mo RSW SC HP, 8-12 mo IRR SC HP), these treatments produced only half the survival on clay soil as compared with similar treatments on sandy soil (8-12 mo RSW Sd MP, 8-12 mo IRR Sd MP).Mechanical preparation might also improve survival on sandy sites.However, the trials were not designed to compare this treatment effect on sandy versus silt-clay sites. MP simply was not used on silt-clay sites to avoid soil compaction. Therefore, additional seedling trials or at least predesigned monitoring (to test survival improvement ideas) should be done to sort out negative impacts of silt-clay soil on seedling survival.
- The most interesting counter-intuitive finding was that seed sowing with irrigation (SP3 IRR Sd MP) offered no better survival than the same treatment combination without irrigation, when sown at the right time. This suggests that irrigation of seed sown on sandy soils should be avoided because it adds cost with for no survival benefit. Instead, proper timing of the sowing operation is recommended (autumn-fall, after the first rains, when soil moisture is above 20%).

4.4 Cost-effective Treatments

With 6 of 13 treatment combinations eliminated, 7 were left for serious consideration for *P. pinea* planting material. It is clear from Figure 8 (and previously observed from Figure 7) that seed sowing with no irrigation is the cheapest.

1) Because seed sowing (SS200) treatments were already eliminated for poor germination, this leaves two seed planting (SP3) treatment combinations:SP3 NIRR Sd HP and SP3 NIRR Sd MP.

SP3 NIRR C. libani seeds in Arz- Bcharre 7 months after sowing

The main difference between these was apparently a better germination rate with hand-tool soil preparation, but statistical analysis did not support this difference (as previously mentioned, germination analysis included too few replications to establish any significant results). To further complicate choice between these two treatment combinations, results also showed that seeds on MP sites, once germinated, survived better than those germinated on the HP sites.

Therefore, for sandy soils, seed sowing for about 500 to 600 USD per ha looks most promising, but germination practices need further study. Due to the knowledge gap for seed planting of *P. pinea* on silt-clay soils, no overall best treatment recommendation can be made for establishing *P. pinea* at less than 1,500 USD cost per ha for all soils.

2) The next most cost-effective treatment (after seed sowing) was selected from the five remaining seedling treatments, all from sandy soils with similar survival from about 50% to 70%. The main distinguishing difference among these five was that no irrigation (NIRR) was one-third to one-half of the cost of water supplements (IRR, RSW). Cost for 10 to 12-month-old seedlings without irrigation was about 2,300 USD compared with about 2,700 USD for 18-month-old seedlings without irrigation: although it was not a statistically significant difference, the 18-month-old seedlings showed about 20% greater survival than 8-12-month-old seedlings.

Therefore, nonirrigated seedlings are the second most cost-effective treatment with costs between 2,300 and 3,900 USD per ha (Refer to table 5). Similar to seed sowing, this is only recommended for sandy soils as data show survival reduced to 50% for silt-clay.

Water supplements are not recommended for establishing seedlings because added survival does not outweigh added cost, despite the significant differences in effects of water treatments and NIRR shown by statistical tests.

10-mo NIRR P. pinea seedling in Kefraya

There is little survival difference between conventional irrigation and rechargeable solid water (as indicated in statistical findings and confirmed in Figure 8), but RSW cost less, due to the high costs of water and labor needed for conventional irrigation.

As previously mentioned, NRSW treatment combinations (for 8-12 month old seedlings) were left out of the above analysis, because they were too costly for serious consideration (over 16,000 USD per ha). Information from these combinations offered no additional insight into survival, as results were nearly identical to similar water supplement treatments (IRR and RSW) for 8-12 month seedlings at lower costs. There was about a 30% reduction in survival for sandy versus silt-clay soil texture (76% vs. 44%).

4.5 Cost analysis for Cedrus libani

As previously mentioned, a separate cost analysis was done for *C. libani* (Figure 9) because data were only available from one site and could not be compared to *Pinus pinea* treatments. There were only three treatment categories that cost less than 1,500 USD, all seed sowings without irrigation: SS200 NIRR SC NP, SS200 NIRR SC HP, and SP3 NIRR SC HP. Survival of these was low; only SS200 NIRR SC HP had weighted survival greater than zero, at about 25%. Like that of *P. pinea*, seedling survival was no better than that of seed plantings. The most interesting finding was that germination of spot sowing or 3-seeds sowing per spot (SP3) was about 50-75%, but survival of these was poor. Hence there is anecdotal evidence that *C. libani* may germinate well on silt-clay. Overall, there were too little data (only 1 site) and survival was too poor for *C. libani* to make planting recommendations. But if survival could somehow be increased without much additional cost, the trial showed that it would be feasible to establish *C. libani* for less than 1,500 USD per ha. In summary, anecdotal results corroborated with *P. pinea* findings in that:

a) Seed planting looks more promising than seedlings for keeping costs below 1,500 USD per ha.
b) Silt-clay soils need more study to better determine what factors are inhibiting survival (after germination) on these sites.

Figure 9. *Cedrus libani* germination and survival (A) compared to cost (B)

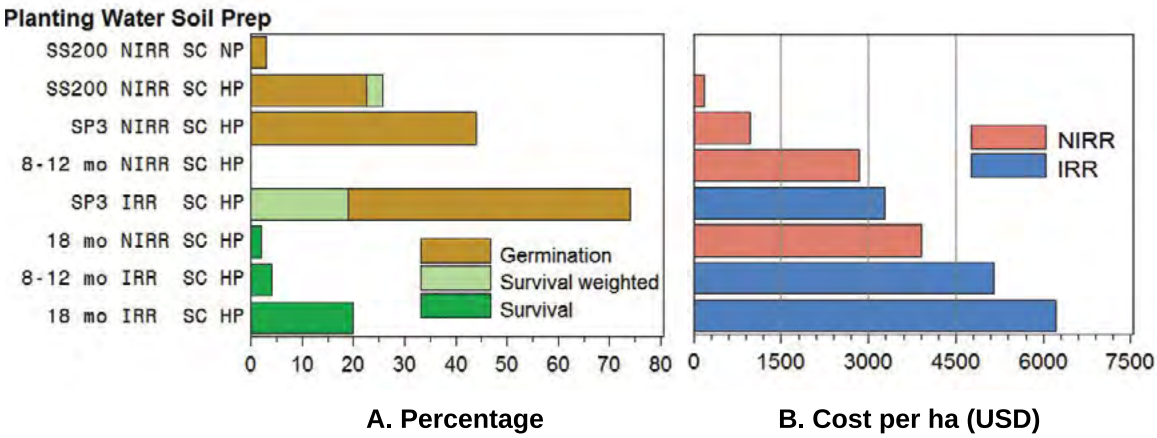


Figure 9. *Cedrus libani* percent germination and survival (A) compared to cost in U.S. dollars (B) for establishing and maintaining plantings for 2 years. Treatments include planting material (8 and 18-month-old seedlings [8-12 mo category only includes 8-mo for this site], SP3 = 3 seeds planted at points, SS200 = 200 seeds sown in patch), water supplement (IRR = conventional hose irrigation, NIRR = no irrigation), soil texture (SC = silt-clay), and soil preparation (NP = no preparation, HP = hand tool preparation). Weighted survival (light green) overlays germination (brown); e.g., no survival for SP3 NIRR SC HP and weighted survival for SS200 NIRR SC HP is 26% and germination is 23%. These data included only Arz-Bcharre site so there was no replication.

4.6 Adjusted Cost Metric

Figure 10 returns to observed or "unweighted" survival from seeds (Figure 7) for comparison to cost per ha adjusted for survival for *P. pinea* (no similar figure was done for *C. libani* for comparison to Figure 9 although data to do so are in Table 5). This adjusted cost metric, previously described in Chapter 3, was initially devised for possible additional interpretation of planting trial results. It was devised is useful to estimate how much a treatment combination would cost if as many seedlings were initially planted (or seeds sown) as needed in order to eventually end up with the needed 800 seedlings per ha, according to the survival rates observed for each treatment tested. Although, this metric assumes the additional seeds planted would survive at same rate as in this study (which from biological perspective may or may not happen) it is still useful for roughly judging cost for over-planting to make up for expected mortality. Figure 10 should be viewed as additional information to Figure 7 for assessing cost of *P. pinea* planting trials.

SS200 P. pinea seeds with soil preparation in Bkassin 8 months after sowing

On the other hand, adjusted cost is a ratio-defined metric that can give erratic results for low survival. For example, the two most effective seed sowing treatment combinations SP3 NIRR Sd HP and SP3 NIRR Sd MP for *P. pinea* shown in Figure 8 differ widely in costs (in Figure 10) because SP3 NIRR Sd MP adjusted cost is an average for two very different survival rates (12% and 5% from table 5) that disproportionately affect adjusted cost (12% for 5,344 USD and 5% for 12,657 USD from table 5). Further discussion of the adjusted cost metric would require a different statistical analysis than the one used which was beyond time available for this report. Interested readers can use adjusted cost values given in Table 5 for further consideration.

Figure 10. *Pinus pinea* weighted survival and germination (A) compared to survival-adjusted cost (B)

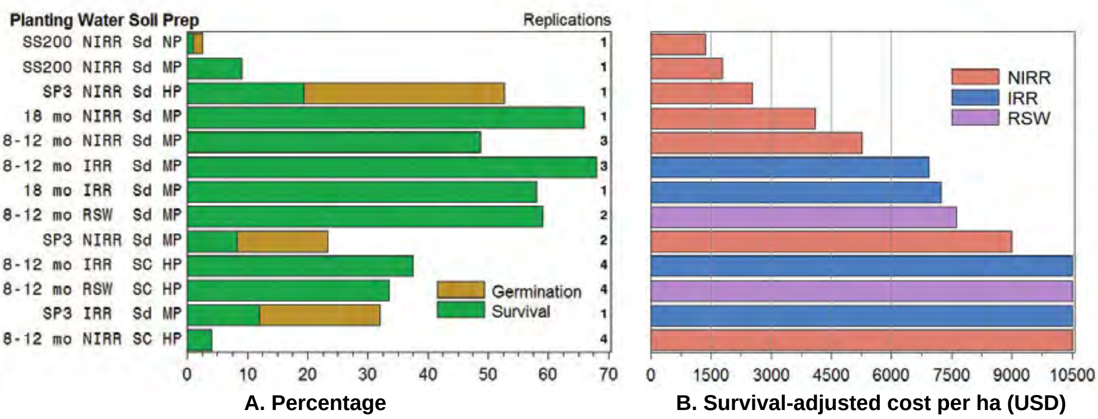


Figure 10. Same as Figure 7 for *P. pinea* except cost comparison (B) is adjusted for survival (see text for definition of survival-adjusted cost). The x-axis is truncated for costs over $10,500 up to $50,000.

4.7 Summary

- Three seeds sown in a spot or basin (SP3) without irrigation is the most promising low-cost technique (< 1,500 USD per ha) for both *P. pinea* and *C. libani*, but only *P. pinea* were replicated with sufficient data to make planting recommendations from these trials. For *P. pinea* this recommendation is valid only for sowing on sandy soils.

- The next best technique is planting seedlings on sandy soils without irrigation for costs currently ranging from 2,300 to 3,900 USD.

- There was no significant survival difference between 08-10-month-old, 12-month-old and 18-month old seedlings. The performance of these 3 age groups of seedlings was quite similar.

- Despite of the overall significant difference between irrigated and nonirrigated seedlings, fairly similar results in terms of survival were observed in many sites. Furthermore, nonirrigated treatment combinations sometimes performed even better than irrigated ones, reaching up to the highest survival at site of around 70%.

- Germination needs further study before making firm recommendations from these trials. Statistical analysis of germination showed no significant differences among any treatment combinations but this may be due to little replication of germination treatment combinations. Germination was not tested for *P. pinea* on silt-clay soils. *C. libani* did germinate adequately on silt-clay, although it survived poorly.

- Overall, tree survival was better on sandy soils than on silt-clay for the same treatment combinations. Planting on silt-clay should be studied further before making recommendations for this soil type, which is likely widely distributed in Lebanon. This applies to both *P. pinea* and *C. libani*. From this study, silt-clay was defined as all soil textures with less than 38% sand.

SP3 IRR P. pinea seeds in Bkassin

18-mo-old NIRR P. pinea seedling in Bkassin 2 years after plantation

Mechanical Soil preparation in Kfarzebian

- There was a significant difference in survival for irrigated and nonirrigated (NIRR) seedlings. However all treatments involving irrigation cost more than the 1,500 USD/ha (the field trials aimed at treatments costing below this figure) so they were not explored in depth. Interestingly, some NIRR treatment combinations performed better than irrigated ones, with survival near 70% on two sites. Irrigation effects were probably correlated with other factors. But these were difficult to evaluate because there was such low replication among the multiple treatments.

- There was no significant survival difference among conventional irrigation (IRR) and novel water supplements (NRSW and RSW). From a cost perspective, NRSW was too expensive (more than 16,000 USD per ha) for serious consideration but RSW was comparable in cost to conventional irrigation, in fact, even a little cheaper (Figure 8). It would be interesting to do an additional follow up study on the RSW treatment. It appeared to be effective in saving water as it required fewer applications than treatments with conventional irrigation.

10-mo-old RSW P. pinea seedling in Kefraya
3 years after plantation

CHAPTER FIVE: Recommendations

The SRLWR Project aimed at developing new, successful and cost effective techniques for their possible use in future large-scale land rehabilitation activities. The ultimate goal was to increase seedling survival while reducing reforestation cost in Lebanon by optimizing seedling quality, minimizing, minimizing irrigation water use, using younger seedlings, sowing seeds directly, and assessing the possibility of successful reforestation without any irrigation, as performed in most countries of the world and the region. The trials advanced the potential for no-irrigation reforestation, minimal water use, and seed sowing. Some gaps still prevail in knowledge about seed sowing on silt-clay soils and seed germination. The comparison of seedling ages gave inconclusive results, but in general, nonirrigation of seedlings was just as effective for survival as using water supplements.

A number of conclusions were offered in Chapter 4 (Results and Discussion) about success and cost-effectiveness of some seed sowing methods. These were made on the basis of observations from the field trials as well as the statistical analysis outlined in Chapters 3 and 4 that aimed to improve replication and reliability, ensuring that results observed from the trials could be reasonably assumed to predict similar results under similar conditions. Without repeating conclusions from Chapter 4 we conclude the report here with a number of recommendations to best capture results of the SRLWRP to benefit long term reforestation practices in Lebanon.

5.1 Direct sowing of seeds:

- Planting 3 seeds per spot or basin (SP3) without irrigation is the most cost-effective reforestation practice (about 500 to 1,000 USD per ha, 500-600 USD/ha for *P. pinea* in sandy soils only) and the most promising for at least survival of seeds that germinated. Germination is a weak link with rates ranging from about 10% to 50%. However, once *P. pinea* is germinated, survival can be reasonable (about 33%). *C. libani*, on the other hand, did not survive without irrigation (in Set 2 trials). However, results were limited to only one site. Unfortunately, the second site of Set 3 trials (Kfarzebian) where *C. libani* seed sowing was being tested produced promising initial germination but results were destroyed by grazing before they could be included in the study. Therefore, SP3 without irrigation is recommended as the most cost-effective reforestation method. Further details need to be resolved before broad-scale use. Germination needs more study and there is an information gap about the effects of silt-clay soils. *P. pinea* was tested only on sandy soil (at least 38% sand) and *C. libani* did not survive on the only silt-clay site where SP3 without irrigation was tested.

C. libani SP3 IRR seeds in Arz-Bcharre 2 years after sowing

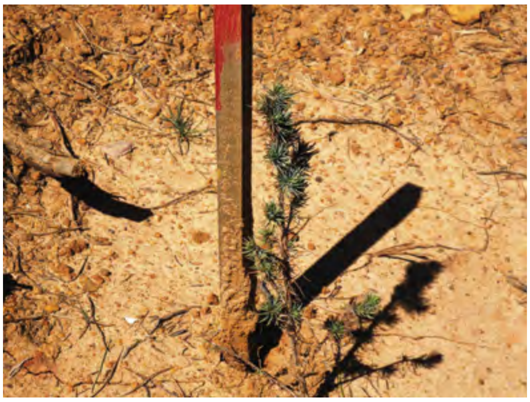
- Generally, low germination and resulting low survival rates were reached with direct sowing of seeds (SS200) without irrigation. However, this was found to be the least expensive reforestation method (<175 USD per ha) out of all treatment combinations tested. Therefore, it remains one of the possible techniques worth adopting. Further study of the germination/survival interaction for seed sowing is recommended in order to reach higher germination/survival rates.

P. pinea SS200 NIRR seeds in Bkassine 1year after sowing

5.2 Planting seedlings:

- For seedling planting, cost exceeded the target cost of 1,500 USD per ha, ranging from 2,300 to 3,900 USD for no irrigation (NIRR) treatment combinations, and increasing when water supplements were added. It is to note however, that this cost remains much lower than the current estimations of around 7,000 USD per ha and thus seedling planting with no irrigation remains one of the recommended practices for Lebanon.

- Results showed that choice of seedling age (08-10-month-old, 12-month-old and 18-month old) is not statistically significant for survival. Therefore, the recommendation is to plant the least expensive seedling stock available from reasonable nursery practices. Usually younger container seedlings are less expensive. It also would be advisable to monitor survival of seedlings planted on the recently established eight large-scale reforestation projects (described in Chapter 3) because these represent the newest generation of seedlings from improved nursery practices which have not yet been tested for results in terms of survival.



8-mo-old 1st generation P. pinea seedling without irrigation 2 years after plantation

8-mo-old 3rd generation P. pinea seedling without irrigation 10 months after plantation

5.3 Irrigation and water supplements:

- Although there is an overall significant difference between irrigated and nonirrigated seedlings in terms of survival, is not always justified due to high irrigation costs. irrigating for reaching to reach additional survival has not been shown to be was not cost effective in some most instances. Therefore, survival/irrigation cost interactions should must be seriously thoroughly studied. Minimizing of irrigation need and no-irrigation reforestation can be reached with use of high quality seedlings and seeds, proper site selection, adequate soil preparation and good plantation timing.

- Water supplement treatments were found to be statistically different from no irrigation. However, similar to the case of seedlings' irrigation, the additional costs of the water supplements resulted in increasing total costs dramatically, far beyond the desired 1,500 USD per ha threshold (ranging from 3,800 to over 16,000 USD per ha). In some cases RSW performed better than conventional irrigation and this method is worth additional study. Findings were quite interesting in that water supplements roughly doubled survival for seedling treatment combinations but had little effect on seed sowing treatment combinations.

12-mo-old P. pinea seedling (RSW) in Lala 3 years after plantation

- Whereas *Quercus spp*. and *Pinus brutia* present a high probability of natural regeneration following forest fires, *Pinus pinea* does not have this potential due to the overexploitation of its seeds. In this case, carrying out reforestation activities during the next fall following the fire is recommended through seedling plantation and/or direct sowing of seeds without any irrigation. Due to the absence of both predators and competition for water by any existing vegetation, high survival rates can be expected.

- The fact that irrigation did not increase seed germination and survival considerably, confirms the earlier statement on that direct seed sowing without irrigation can be recommended as an effective and low cost method, with high quality seeds and proper timing and site selection.

5.4 Soil texture:

- Although soil texture was not designed as a treatment for testing in the planting trials, it was coincidently replicated among sites and found to be very important (statistically significant) for reforestation. For example, *P. pinea* seedling survival on silt-clay sites was about half that produced with the same water treatments on sandy soils, and was reduced even more with no irrigation. *C. libani* was only tested on a silt-clay site and performed poorly for both seed and seedling plantings. *P. pinea* seed sowing was not studied on silt-clay sites, which is a potential knowledge gap for this recommended reforestation technique. Therefore, more study of silt-clay soil, particularly focused on soil-plant-moisture relationships, is recommended. Existing but unanalyzed data fromthis Project could also be evaluated to learn more about plant-soil-water relationships in sandy soil. The field trials and statistical analysis affirmed conventional knowledge that planting in sandy soils is best for *P. pinea* survival. Some of the monthly data on soil moisture might offer some clues on the relationship of soil physics and water availability in this soil type.

5.5 Soil preparation:

- Like soil texture, soil preparation was not designed as a treatment for all trials but was replicated enough among sites for statistical testing and found to be nonsignificant. However, some anecdotal effects of soil preparation on survival were observed. More importantly, soil texture could have been confounded with soil preparation in statistical testing because they were the same on many sites. If soil texture is studied further, trials should be designed to study effects of soil preparation separately to identify which or both are important for seedling survival.

Soil preparation in Kefraya

5.6 Follow up on Project data and findings:

- The Project also collected a wealth of additional data such as individual tree survival and growth, as well as environmental parameters (relative soil temperature and moisture) over monthly or larger time intervals. These data could be important to help address and explain some of the issues raised above regarding poorer survival on silt-clay vs. sandy soils and ineffective water supplements for seed plantings, and to compare results with other findings. For example, examination of mortality over time in comparison to environmental factors could further illuminate and explain why some treatment combinations performed better or worse. Therefore, it is recommended that these existing data be considered for more careful study before any further field trials or studies are planned.

- Funding limitations and political instability may inhibit the prospect for further study of details and gaps as suggested in recommendations above and reforestation in Lebanon may have to continue based solely on results from this study along with ongoing practices. In this case, it is strongly recommended that all future plantings include a small subsample of representative trees that are monitored for survival at least annually. If possible, future planting designs could be developed to address issues raised in this study such as silt-clay soil, germination, and water delivery efficiency. For example, on the Wadi Al-Karm reforestation after a 2013 fire on more than 10 hectares of *P. pinea* (mentioned at end of Chapter 3) 10 monitoring plots have been established to track survival of seeds sown and seedlings planted.

So far, after about one year survival rate for nonirrigated seeds sown is 72% and survival for seedlings planted is 100%. It seems reasonable that faculty or students from universities or some other entities might be funded to carefully design and conduct a small-scale reforestation monitoring effort to adaptively improve practices if future study of gaps identified in this report is not possible.

- Finally, Reforestation is essential to the environmental, economic and symbolic recovery of Lebanon and it is also a challenging and daunting arena of trying to restore a priceless forest resource on lands greatly impacted and changed by human interaction over thousands of years. The capacity-building efforts and planting trials of the Safeguarding and Restoring Lebanon's Woodland Resources Project have advanced knowledge of reforestation practices in Lebanon and potentially for other water-scarce areas around the world. Although these findings cannot offer a detailed "cookbook" set of instructions for an area as complex as reforestation, they offer intriguing options for low-cost sowing and planting methods that emulate nature and suggest what to monitor as reforestation efforts continue throughout the country.

100% survival of P. pinea seedlings in Wadi Al-Karm after 1 year WITHOUT IRRIGATION

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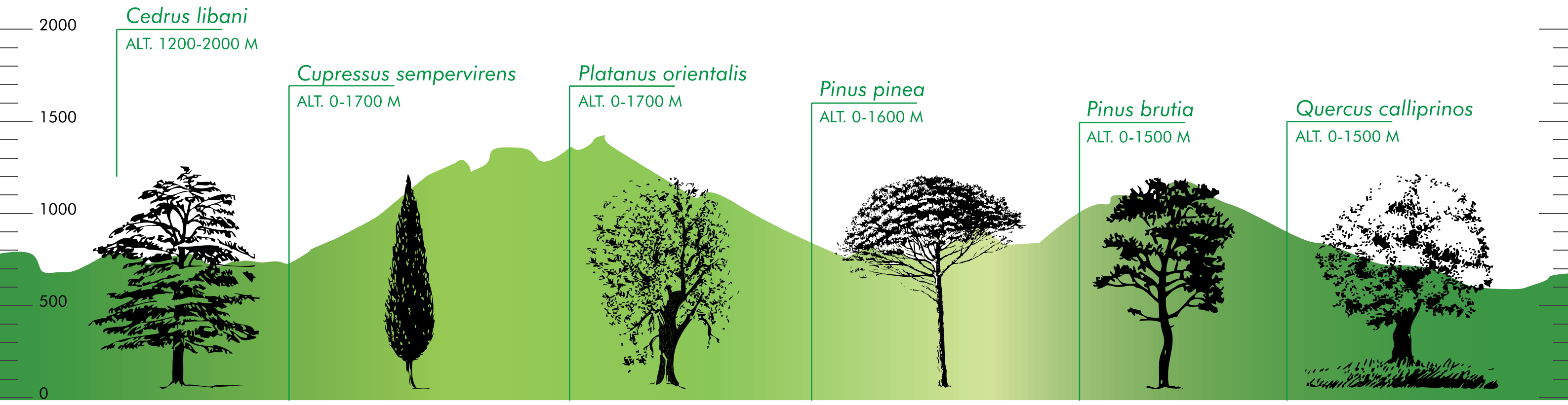
The Cedar forest in Arz-Bcharre back in 2005

The Cedar forest in Arz-Bcharre in 2014
after remarkable reforestation efforts


2000
1500
1000
500
0
Cedrus libani
ALT. 1200-2000 M
Cupressus sempervirens
ALT. 0-1700 M
Platanus orientalis
ALT. 0-1700 M
Pinus pinea
ALT. 0-1600 M
Pinus brutia
ALT. 0-1500 M
Quercus calliprinos
ALT. 0-1500 M

Beirut, Lebanon
December 2014