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Establishment of Plantation Forests and Development of Sustainable Forestry in Desert Lands of Egypt Using Sewage Water Education and Research

German-Egyptian Collaboration to Afforestation in Desert Lands of Egypt: Information Summary and Description of the Field Experiments

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Sustainable Forestry in Desert Lands of Egypt: Information Summary

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Introduction

Our world is currently facing many challenges that extend from environmental degradation to energy, food and water shortages for an ever-increasing world population. The cause of our problems is mainly man-made. Human beings are resource dependent, but most of our natural resources are finite and non-renewable. Many of the resources, such as minerals, develop very slowly throughout hundreds of millions of years. If resources are not used in a sustainable way they will be depleted, leaving future generations barren and empty handed. At present, human beings are inappropriately managing their resources by achieving a short-term benefit while causing pollution and degradation to the environment.

By utilising the appropriate knowledge and technology currently available to us, we can solve many of the problems the world is facing today through the proper use and use of potential of the available resources in a sustainable way. The following describes the use of available resources which have not yet been effectively utilised for afforestations in arid regions. **Afforestation** is the planting of trees on land formerly used for purposes other than forestry.

Use of available resources for afforestation in arid regions

Arid lands cover an area of nearly one third of the earth's land surface, where over one third of the world's population lives. According to the FAO (1989), arid zones include hyper-arid, arid, and semi-arid regions with 4.2%, 14.6%, and 12.2% of the total land area of the world, respectively. The largest two subtropical deserts are the Sahara (9.1 million km^2) in Northern Africa and the Arabian Desert (2.3 million km^2) in the Arabian Peninsula. Subtropical deserts offer plenty of unutilised lands. Subtropical deserts are characterised by low annual precipitation but, on the other hand, they provide possibilities for trees to grow all-year round and they receive sufficient sunlight, which is essential for the tree growth. Up to a certain extent, the more sunlight available for a tree, the higher the photosynthetic ability and thus the tree production.

Freshwater makes only about 2.5% of the total earth water and 97.5% are saltwater (UNEP, 2008). The usable proportion of freshwater sources accounts for less than 1% of total freshwater and only 0.01% of all water on Earth (UNEP, 2008). Insufficiency of water in many of the arid regions is a serious constraint for human welfare and economic development. Nevertheless, wherever people live, wastewater is generated from municipal, industrial and agricultural activities. Unutilised wastewater represents serious hazards for the human health and environment and in addition is a waste of valuable water resources. Wastewater from municipal activities or sewage water can be partially treated and then used in providing the required water to irrigate trees. Sewage water has high content of the primary plant nutrients "nitrogen" and "phosphorus", which are also essential for tree growth. Furthermore, sludge or solid waste remains after the wastewater treatment can be used for the production of renewable energy (e.g., Biogas) and soil conditioner.

In summary, the potential of the available resources (unutilised desert lands, sunlight, sewage water and nutrients in sewage water) are efficiently used for the establishment of plantation forests in arid regions and, subsequently, the production of renewable resources (e.g., wood, woody-biomass or biofuel). In addition, the potential of the solid waste of the wastewater is also used for the production of renewable energy and fertiliser.

Benefits of afforestation in arid regions

Afforestation has many purposes depending on the establishment goals, whether for production of timber, biomass or biofuel crops, for carbon sequestration or for environmental motivation. Afforestation in arid regions has a multi-functional approach as new established plantations can be of considerable economical, ecological and social benefits such as the below:

- Decreasing pollution as growing trees absorb carbon dioxide from the atmosphere.
- Protection against desertification, sand dune fixation, erosion prevention, and coastal protection.
- Efficient use of the scarce water resources.
- Wood production and biofuel-crop production, as a renewable energy source.
- Human settlement protection from wind and sand.
- Food security for an increasing population through protection of arable and new reclaimed lands from wind and combating desertification. If cultivated areas (e.g., for food production) are protected by forest (greenbelt/windbreak), there will be a considerable reduction in environmental stresses (reducing plant damage by frost, sand deposit and insects, improving the efficiency of irrigation and fertilisation, conserve moisture in plants and soil) and improvement of the microclimate, thus, achieving higher yield of the protected crops.
- Creating new jobs and qualification opportunities.
- Establishing new forest-based and related industries, which will help in promoting employment and national economic development.
- Offering recreational opportunities for residents and tourists due to the attraction of forests in arid regions.

Forestry in Egypt

Egypt offers a great opportunity for large-scale afforestation due to the availability of sufficient sewage water and desert land. After basic treatment, sewage water can be efficiently used as a resource for the production of wood, woody biomass and biofuel crops and for carbon trading.

The cause of the non-existence of forest in Egypt is not only due to the climatic conditions and the scarcity of rainfalls, but also as a result of the urbanisation and the focus on food production for the rapid increasing population. Although the geographical area of Egypt is large, exceeding one million km^2, desert land dominates over 96% of the total country area with little scattered shrub vegetation. Most of the country's vegetation grows in the Nile delta and valley "the most extensive oasis worldwide". The Nile Delta and Valley have a rich variety of tree species, of which some indigenous and some exotic.

Figure 1: Afforestation in the desert lands of Egypt using basic-treated sewage water

At the end of the first centaury, over a thousand years ago during the Fatimids era, Egypt was the first country in the world which established a national forest organisation (Goldmann, 2001). At that time, usage of wood was well managed, mainly in the construction of ships. Thousands of ships with dimensions of 85m in length and 35m abeam were built. Today, less than 0.07% of the country's land area is covered with trees. FAO (2010) estimated for 2009 a total area of 691 km^2 with nearly 74 million standing trees in Egypt. The country has almost no natural forests: Only relic of nature woodlands on the slopes of Gebel Elba (Mountain Elba) in the south of the country and sparse, scattered mangroves along the red sea coast can be found. Forestry in Egypt is mainly based on artificial forests with most common species being Casuarina spp. and Eucalyptus spp. used as windbreaks.

According to FAO (2005), Egypt achieved a 3.3% annual rate of change in forest cover between 1990 and 2000, which was the highest annual increase among the African countries; over the same period the average annual rate of change for the whole African continent was -0.8%. This increase of the forest area was due to the establishment of the "National Programme for the Safe Use of Treated Sewage Water for Afforestation" in the early/mid 1990s. Within the framework of this programme, a pilot project (Figure 1) was conducted on over 4,000 hectares spread over the country to determine the success/failure of afforestation using basic-treated sewage water. The afforestation includes different species, i.e., Acacia (*Acacia nilotica and Acacia saligna*), Casuarina (*Casuarina equisetifolia*), Cupressus (*Cupressus sempervirens*), Eucalyptus

(*Eucalyptus camaldulensis*), African Mahogany (*Khaya senegalensis*), Neem (*Azadirachta indica*), Pine (*Pinus pinea*), in addition to Jatropha (*Jatropha curcas*) and Jojoba (*Simmondsia chinensis*) as biofuel crops. The results of the pilot project clearly revealed that sewage water can be used for the establishment of new plantations in desert lands and showed high potential for afforestation of multipurpose species of socio-economic importance.

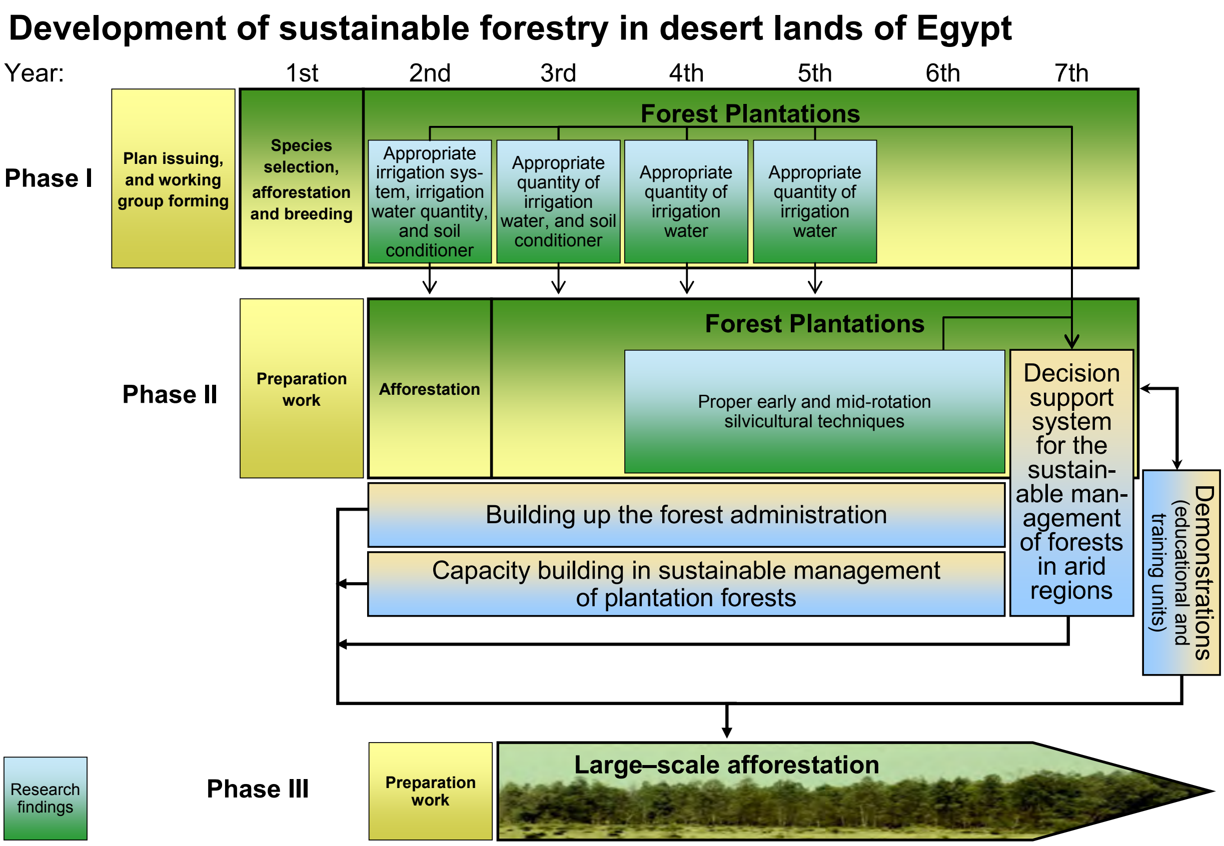

Figure 2: Concept scheme for the establishment of plantation forests in Egypt.

Based on the results of the pilot project and upon a Memorandum of Understanding between the Egyptian Ministry of State for Environmental Affairs and the Institute of Silviculture at the Technische Universität München (TUM) in 2007, the Institute of Silviculture has proposed a concept for the Establishment of Plantation Forests and Development of Sustainable Forestry in Desert Lands of Egypt Using Sewage Water (Figure 2). The concept lays emphasis on the improvement of productivity, quality, technology, cost-effectiveness, and economic returns of the plantation forests. Therefore, an accompanying applied research was proposed with the main objective to develop a decision support system for the sustainable management of plantation forests in arid regions including wastewater management. The supporting scientific work is carried out by highly qualified German and Egyptian scientists including: The Institute of Silviculture, Technische Universität München (TUM); Department of Agricultural Engineering, Ain Shams University; Department of Forestry and Wood Technology, University of Alexandria; Institute of Hydraulic and Water Resources Engineering, TUM;

Institute of Water Quality Control, TUM; Agriculture Research Centre, Ministry of Agriculture and Land Reclamation.

The Bavarian State Government in Germany has expressed support to the afforestation attempts in Egypt by providing technical assistance in the form of technology transfer and support in capacity building. Experts' consultation was provided by the Bavarian State Ministry of Agriculture and Forestry and the Institute of Silviculture at the Technische Universität München (TUM).

In 2012, the German Academic Exchange Service (DAAD) provided funds to support the implementation of a part of the research activities, the assembling of forest-management knowledge at the Egyptian Universities, the optimisation of the afforestation programme, and in addition to strengthen research cooperation in forest and water resource management and scientific exchange through further partnerships between Germany and Egypt.

The media, whether Egyptian or German, has in many contributions reported on TV and newspapers positively about the afforestation project.

Achievements

The scientific team in collaboration with the Under-secretariat for Afforestation and Environment of the Ministry of Agriculture and Land Reclamation could gain important scientific information and attain achievements towards the successful realisation of the afforestation in Egypt.

***Figure 3:** 10-weeks old forest plantations (left: different species, right: Teak) in Sarabium forest near Ismailia.*

Hörl (2012) showed that the potential of forest trees growing in Egypt is high: 134 Forestry-relevant tree-species that are growing in only two parks in Cairo were found. El Kateb and Mosandl (2012) determined the yield of some tree species of the plantations forests in Egypt, which was high, and estimated that the yield achieved in Egypt is approximately attained 4.5 times earlier than in Germany, the leading country in Forestry in Europe. Khalifa, El Kateb & El-Gindy (2013) investigated the feasibility of the afforestation in Egypt using swage water and concluded its environmental, social and economical feasibility. El Kateb, Eger & Walterspacher (2013) estimated an internal rate of return exceeding 12% by afforesting 1,000 ha of desert lands using 14 tree species that were selected on scientific basis by the German and Egyptian scientific team (Figure 3). The species are:

- Precious hardwood species: Gmeline or White Teak (*Gmelina arborea*), African Mahogany (*Khaya senegalensis*), Outeniqua yellowwood (*Podocarpus falcatus*), Teak (*Tectona grandis*)
- Hardwood species: Mangium or Black Wattle (*Acacia mangium*), Neem or Indian Lilac (*Azadirachta indica*), Lemon-scented gum (*Corymbia citriodora*), River Red Gum (*Eucalyptus camaldulensis*)
- Softwood species: Caribean Pine (*Pinus caribbea var. hondurensis*), Canary Island pine (*Pinus canariensis C. Smith*)
- Biofuel crops: Jatropha (Jatropha curcas), Jojoba (Simmondsia chinensis)
- Windbreak species: Orange Wattle (*Acacia saligna*), and Casuarina (*Casuarina equisetifolia*).

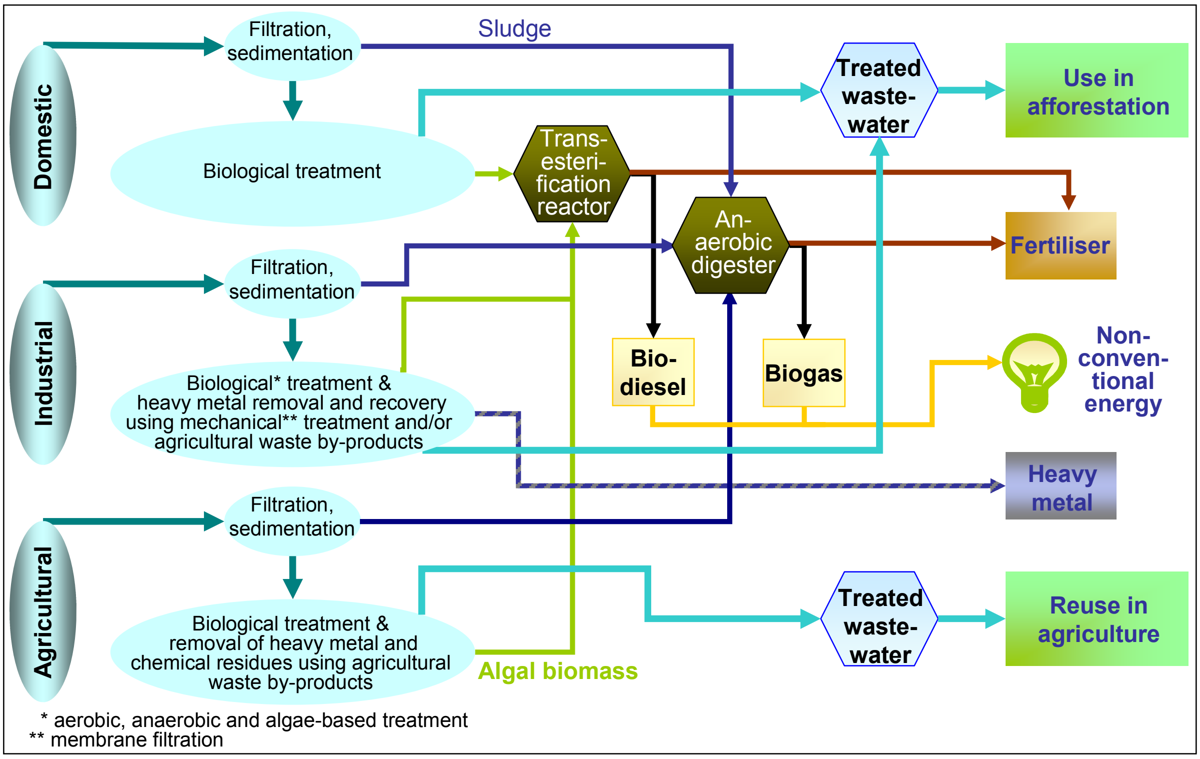

Figure 4: Treatment and use of potential of wastewater.

Within the framework of the Egyptian-German collaboration, many workshops were conducted to deal with the proper **treatment of wastewater**. Emphasis was also laid on the allocation of the available wastewater, the proper use of the potential of the wastewater and on improving its treatment (Figure 4) to ensure the safety and quality of the treated wastewater before reuse.

The Agriculture Faculties at the Egyptian Universities will integrate in their study curricula new study modules for higher agriculture education in plantation forest management and water resource management. The TUM is providing support by conducting study courses, practical training and workshops in Egypt and Germany. A Forest Department will be soon established at the Faculty of Agriculture, Cairo University.

The achievements have awakened the interest of international organisations. Forest Finance Group, Bonn/Germany, a leading organisation in Germany in forest investments and in the development and operation of sustainable forest products, is considerably supporting the development of the afforestation in Egypt in commercial application and forest carbon trading.

Large-scale afforestation in Egypt

Large-scale afforestation in arid regions supports innovative solutions to actual national (Egyptian) and global challenges, such as climate change, renewable energy, food security and management of resources. Afforestation is one of the most effective tools to carbon dioxide fixation. Forest products as wood and biomass are significant sources for renewable energy.

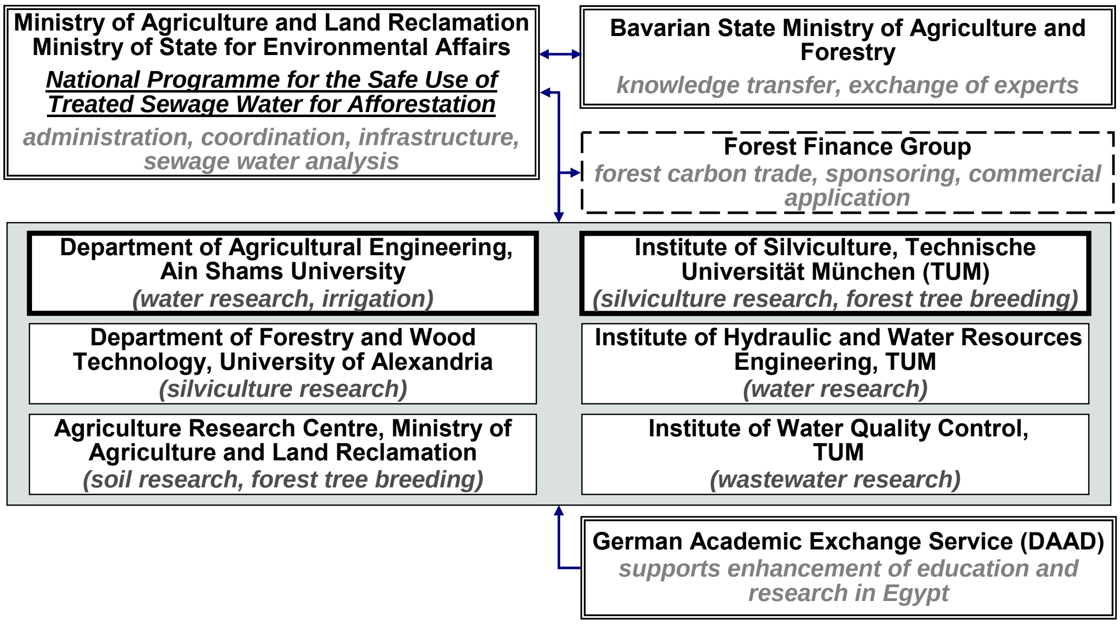

Figure 5: Egyptian-German collaboration

Egypt produces a huge volume of sewage water annually. 5.5 billion m^3 of this sewage water, which equals 10% of Egypt's fixed share of Nile water, is sufficient to afforest over 650,000 hectares of desert lands and store over 25 million tons of CO_2 annually in the new plantation forests (El Kateb and Mosandl, 2012). Large-scale afforestation may stimulate cloud formation and may result in rainfall that the country urgently needs to expand its agricultural production areas (El Kateb and Mosandl, 2012). Their conclusion is supported by a press release of the University of Hohenheim (2012) and a recent study from Becker et al. (2013). Becker et al. (2013) suggest large-scale plantations of *Jatropha curcas* in hot, dry coastal areas to capture carbon dioxide from the atmosphere. The authors had conducted high-resolution simulations using an advanced land-surface–atmosphere model and concluded that large-scale plantations of *Jatropha curcas* (10,000 km^2) could lead to a reduction in mean surface temperature and an onset or increase in rain and dew fall at a regional level.

To ensure sustainability and the ecological and economical success of the large-scale afforestation, emphasis is laid on the Political-Scientific-Economic Collaboration (Figure 5). This is achieved by a viable framework and optimal planning through the political, economic, and scientific environment, respectively, and by gathering the competences, experiences, possibilities and prospects of all the three spheres.

Private sector involvement

The Egyptian Government has expended considerable funds on the development of the infrastructure necessary for the safe use of treated sewage water for afforestation and will set the basis to facilitate the involvement of national and international organisations in order to encourage their investment activities.

References

Becker K., Wulfmeyer V., Berger T., Gebel J. & Münch W. (2013): Carbon farming in hot, dry coastal areas: an option for climate change mitigation. Earth Syst. Dynam., 4, 237–251. http://www.earth-syst-dynam.net/4/237/2013/esd-4-237-2013.pdf. Access: August 14, 2013.

El Kateb H. & Mosandl R. (2012): Aufforstungen in ägyptischen Wüstengebieten. AFZ-Der Wald 67(19): 36-39.

El Kateb H., Eger J. & Walterspacher D. (2013): Financial projections of large-scale afforestation in arid regions - An Example: Egypt. Munich & Bonn. Institute of Silviculture, Technische Universität München, & ForestFinance Group, unpublished, 45 p.

FAO - Food and Agriculture Organization of the United Nations (1989): Arid zone forestry: A guide for field technicians. FAO Conservation Guide 20, Rome, FAO. http://www.fao.org/docrep/T0122E/T0122E00.htm. Access: August 17, 2013.

FAO - Food and Agriculture Organization of the United Nations (2005): State of the World's Forests 2005. Rome, FAO. ftp://ftp.fao.org/docrep/fao/007/y5574e/y5574e00.pdf. Access: August 17, 2013.

FAO - Food and Agriculture Organization of the United Nations (2010): Global Forest Resources Assessment 2010 - Country Report: Egypt. Rome, FAO Forestry Department. http://www.fao.org/countryprofiles/index/en/?subj=5&iso3=EGY#sthash.xNZUTQeY.dpuf. Access: August 18, 2013.

Goldmann G. (2001): Wiege der Forstwirtschaft in Ägypten. Das Fatimiden-Kalifat. AFZ/Der Wald 56(2): 74-75.

Hörl (2012): Potential of growing tree species in Egypt for afforestation. Technische Universität München, Munich. 46 p.

Khalifa S., El Kateb H. & El-Gindy A. (2013): Establishment of forest plantations in Egypt using treated waste water. Ministry of Agriculture and Land Reclamation. Agricultural Magazine vol. 68 (7): 37 – 39.

السيد علي خليفة ، هاني الكاتب وعبد الغني الجندي (2013). زراعة الغابات الشجرية باستخدام مياه الصرف الصحي المعالج بمصر. وزارة الزراعة واستصلاح الاراضي، الصحيفة الزراعية مجلد 68 يوليو ص: 37 –39)

UNEP - United Nations Environment Programme (2008): Vital Water Graphics. An Overview of the State of the World's Fresh and Marine Waters - 2nd Edition. http://www.unep.org/dewa/vitalwater/article1.html. Access: August 20, 2013.

Universität Hohenheim (2012): Plantagen könnten Regen in die Wüste bringen. Press release, 2 p., Text: Weik/Lembens-Schiel. http://idw-online.de/de/news482104. Access: August 16, 2012.

Description of Field Experiments

Hany El Kateb[1], Abdel Ghany El-Gindy[2], Bernd Stimm[1], Ahmed Aamer Settway[3], Haifeng Zhang[1], Ahmed Kherashy Mohamed[4], Amr Abd-Elwaheb[4], Bernhard Felbermeier[1], Hossam Hassan[5], Nashwa Hassan[5], Sara Khamis[3], Manal Abd-Elbaky[3], Michael Weber[1], Mostafa El Hakim[4] and Reinhard Mosandl[1]

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1 Introduction

Egypt, the country with 7,000-year-old record of civilization, has a unique situation in the world due its arid climate, limited arable land (3.6% of the total land's area, which is over 1 million km^2) and limited water resources that is mainly based on only one source "The Nile" (the country has a yearly fixed water share of Nile water amounting 55.5 10^9 m^3). The population is increasing reaching currently over 90 million. The large population produce a huge amount of sewage water. Unused sewage water is a hazard for human health and the environment and at the same time a waste of nutrients, water and energy sources. In the mid 90s, the "National Programme for the Safe Use of Treated Sewage Water for Afforestation" was launched. Within the frame of this programme, a pilot project was conducted to determine the success/failure of afforestation using basic-treated sewage water. Over 4,000 hectares of plantation forests spread over the desert lands of the county were established. The outcomes of this pilot project was very promising, 1) confirming that sewage water can be used for the establishment of new forest plantations, and 2) showing high potential for afforestation of multipurpose species of socio-economic importance in the desert lands of the country. Beside this high potential, Egypt offers a great opportunity for large-scale afforestation due to the availability of huge volume of sewage water and large area of unused desert-lands. However, Egypt lacks experience in the forest sector. The development of sustainable forestry in arid regions must be based on scientific knowledge. An Egyptian-German team of scientists was, therefore, formed to support the establishment of plantation forests and development of sustainable forestry in desert lands of Egypt using sewage water.

2 Scientific approach

Modern silviculture, as a management system of forests, is based on the integration of the ecological, technological, and demographic realities associated with the economic aspects to achieve optimal solutions. There is no only one system to be practiced but many, which depend on the actuality and the desired objectives of establishing new forest plantations. The objectives can vary from environmental motivation, carbon sequestration, protective to productive purposes, whether e.g. for production of timber, biomass or biofuel crops.

The approach is to develop a decision support system for the sustainable management of plantation forests in arid regions. This will endorse the involvement of national and international organisations towards large-scale afforestation over the desert land of the country using sewage water.

The development of such system requires scientific knowledge based on long-term observations. In 2012, the German-Egyptian team started a project supported by the German Academic Exchange Service (DAAD). Different experiments were installed for comprehensive observation to support the realisation of the project objective in developing a decision support system. Information to support the development of the management system will be mainly gained from: long-term observations of different field experiments installed in new established plantations, data and results of the pilot project, assessment of the sewage water situation, acquired ecological and socio-economical information, and the knowledge of the involved working group. A summary of the scientific approach is indicated in Figure 1.

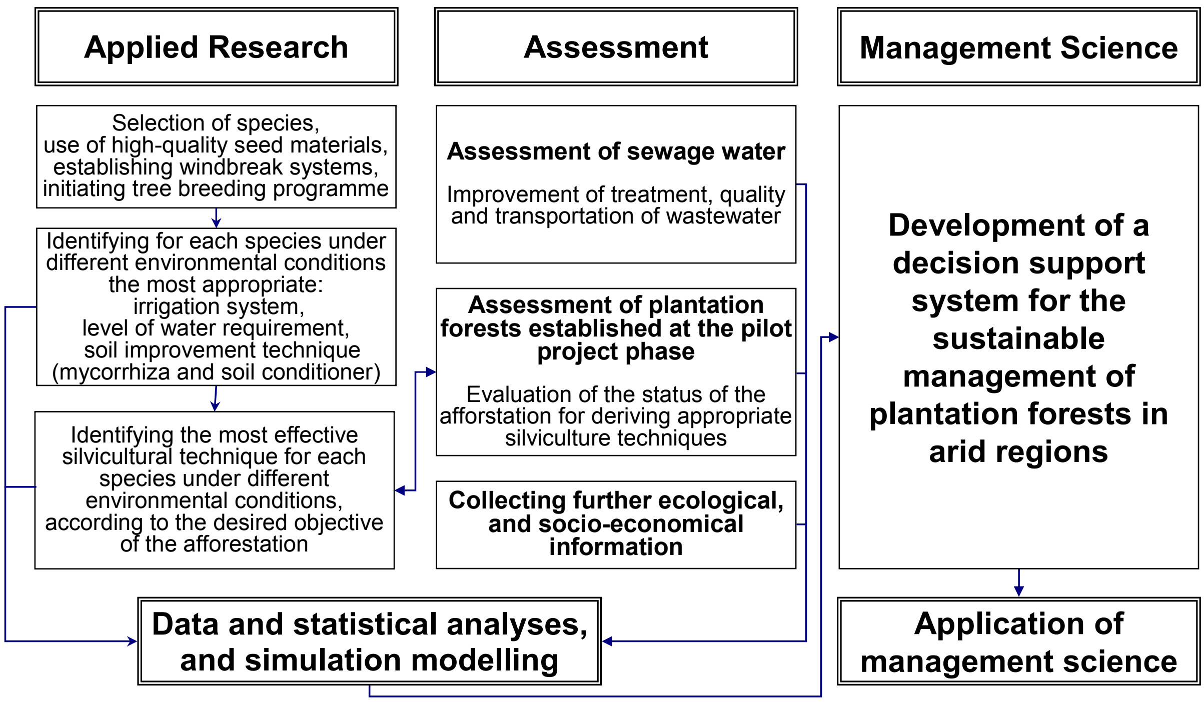


Figure 1: Scientific approach in brief

In the following, the description of the field experiments will be presented. The plots of the experiments are permanently installed. The experiment plots service as units for education, training, and demonstration. A comprehensive long-term observation of eight to ten years is foreseen.

3 Description of activities

The field work is grouped in field activities and experiments (Table 1). Researches are only conducted in the field experiments, while the field activities serve the afforestation.

Table 1: Field activities and experiments within the frame of the project and their size per location in feddan (1 feddan = 4,200 m^2 = 0.42 ha)

Activity	Purpose	Size in feddan
Breeding*	Providing seed materials (not yet installed)	38.83
Windbreak	Protection of the experiments and in general the plantations	
Experiment	**Investigation on**	
Experiment Ia	Water quantity	6.32
Experiment Ib	Irrigation systems and water quantity	3.89
Experiment II	Silvicultural treatments (not yet installed)	74.80
.Experiment IIIa	Soil improvement techniques	6.90
Experiment IIIb	Soil improvement techniques and water quantity	7.80
Experiment IIIc	Mycorrhiza and soil conditioner in a nursery	0.09
Experiment IV	Growth potential of three plantation	

*Breeding is not a part of the funded project, for which funds is expected to be provided by the Egyptian authorities.

3.1 Field activities

Breeding: For the further afforestation attempts, the use of high-quality and certified seeds is a prerequisite to ensure the high-quality of the future forest stands. Therefore, the most suitable seed materials of high-quality will be identified from suppliers around the globe and then purchased for the establishment of the plantation forests. It is recommended to establish at least three stands for each species on at least three different locations in Egypt, one stand in each location. These stands must be used to select mother trees, from which seeds for the future afforestation can be collected. Thus, avoiding purchasing further seeds and ensuring the availability of good-quality seeds for the future activities.

Windbreak: All experiments and forest plantations should be protected by planting a series of windbreaks across the entire plantations in a site. The purpose of a windbreak system is to reduce the wind speed and its impact on the protected area (forest plantations under production) by modifying its microclimate. The windbreaks have the benefits of protecting the forest plantations from damage by wind, reducing plant damage by frost, sand and insects, improving the efficiency of irrigation and fertilisation, conserve moisture in plants and soil and thus support achieving high yield.

The series of the windbreak are placed parallel to each other and at the same time at right angles to the prevailing wind direction or directions. The distance between two windbreaks is depending on the tree height of the windbreaks and should roughly be six to eight times the tree height for reliable protection.

Windbreaks can be installed around all sides of the area to be protected. If only one damaging wind direction is identified, then only one-sided windbreak can be installed, otherwise more than one-sided windbreaks.

Shading of the area to be protected (production area) should be considered: In the short daylight in winter, windbreaks from east to west cause shading to the crops south of the windbreaks. Light demanding species may not be planted south of the east-to-west-windbreaks or may be planted at a larger distance from the windbreak.

The aerodynamic shape of the windbreak is necessary to achieve the protective objective of the windbreak. A sophisticated windbreak may consist of three species in three rows with different heights: Shrubs or the shortest species in the outer rows or the windward side, a tall evergreen species in the middle row and a shorter evergreen species in the interior row

In addition, according to many studies, the permeability of the windbreak should be at 50% to avoid turbulence, This can be achieved by a proper management (e.g. thinning, pruning, trimming) or by selection of appropriate species.

An effective protection by windbreaks depends on design, shape, structure of the windbreaks, etc. Because of irrigation by sewage water, it is not intended to establish multi-propose windbreak systems (for e.g., fruit, fodder), thus high income from the windbreaks is not expected. However, the established windbreaks must be economically viable and a balance between benefits and cost of establishment and management of the windbreaks must be considered.

The arrangement of rows is in a zig-zag order. The distance between rows is 2.7 m and the distance between plants is 2.4 m. Gaps should be avoided within the windbreaks, dead trees should be replaced. Branches and foliages of windbreaks should be managed to roughly reach the ground level.

3.2 Experiments

Experiment I deals with investigations on the effect of irrigation water quantities (Experiment Ia and Ib) and irrigation systems (Experiment Ib) on survival and growth of selected species at two location: Ismailia and Luxor.

The selected species is classified into groups of four species according to their similarity in water consumption. In **Experiment Ia**, each set of species received, according to their average water consumption, five levels of irrigation water quantity with an equidistant difference pattern. In **Experiment Ib**, only three selected species are studied (*Gmelina arborea, Khaya senegalensis, Tectona grandis*), for which three levels of irrigation water quantity with an equidistant difference pattern are investigated for four different irrigation systems. The scheme of separating Experiment I in two studies is favourable, as it keeps the number of the experimental units small and the material cost low and, thus, optimises the cost-benefit relationships of the investigations.

Results of Experiment I will help identifying the proper irrigation system, and the most favourable level of water quantity for each species under different environmental conditions.

Experiment II will make use of the outcomes of Experiment I. For each species, the appropriate irrigation system, and water quantity will be used to serve the appropriate implementation of the afforestation on larger area in Experiment II. Large area is necessary for long-term observations until harvest.

As Experiment I is conducted earlier, results of the most favourable water quantity for a species and site at different plant ages will be used to irrigate the plantations in Experiment II. This scheme will be valid as long as Experiment I under observations. Nonetheless, the proper irrigation system will only be once identified according to the first-year results of Experiment I. However, information on the effect of the different irrigation systems during the rotation period of a species will be further gained over the foreseen observation period of Experiment I. This is planned to be four or five years, depending on species, as over this period no competition between plants is expected to affect the collected data. In addition, over this period most relevant data to crop water consumptions will be collected.

In Experiment II, different techniques aiming at improving quality, yield and the economic value of the plantations will be employed. For each species, different spacing patterns and silvicultural techniques, which include thinning, pruning, and improvement of potential crop trees, will be practiced.

As the choice of inappropriate techniques can considerably reduce quality, yield, and economic values, the outcomes of Experiment II is so imperative to identify the most effective silvicultural practice for each species depending on the desired objective of the afforestation.

Moreover, in Experiment II, observation of the plantations and annual foliage analysis will be frequently made over the rotation period of each species to identify possible nutrient deficiencies and permit immediate application of effective fertiliser.

Experiment III is conducted to test the effect of soil improvement techniques (mycorrhiza and soil conditioner) on germination (Experiment IIIc) and survival and growth (Experiment IIIa and Experiment IIIb) of the different species used in the afforestation. Yet, Egypt lacks experienced forest engineers that can properly managed the afforestation in the many different locations of the afforestation in the country. The objective of this study is to generalise an efficient management option, which can be practiced for the different locations of the afforestation. Experiment III contains three studies: Experiment IIIa, IIIb and IIIc. **Experiment IIIa** and **Experiment IIIb** deal with the impact of soil improvement techniques (mycorrhiza and soil conditioner added to seedlings at the planting time in the field) on seedlings. **Experiment IIIa** involves all species employed at the first phase of the afforestation, while **Experiment IIIb** studies few species (*Gmelina arborea, Khaya senegalensis, Tectona grandis*) in more details using different water quantity. **Experiment IIIc** investigates the effect of soil improvement techniques on seedlings breeding in nurseries.

Experiment IV dealt with assessment of the potential of the different existing plantation forests.

4 Methodology to field experiments

4.1 Study factors

The study factors involved in the field experiments are presented in Table 2.

Table 2: Study factors

Factor/treatment	*Factor levels*	*Description*	*Experiment*
Site (A)	5:	Ismailia, Hurghada, Luxor, Sadaat City, and Alexandria	I, II, III, IV
Species (B)		The used species belong to the list below: *1. Acacia saligna, domestic* *2. Casuarina equisetifolia, domestic* 3. *Jatropha curcas, domestic* *4. Simmondsia chinensis, domestic* *5. Gmelina arborea, imported* *6. Khaya senegalensis, imported* *7. Podocarpus falcatus, imported* *8. Tectona grandis, imported* *9. Swietenia mahagoni, domestic* *10. Acacia mangium, imported* *11. Azadirachta indica, domestic* *110. Azadirachta indica, imported* *12. Corymbia citriodora, domestic* *120. Corymbia citriodora, imported* *13. Eucalyptus camaldulensis, imported* *14. Pongamia pinnata, domestic* *15. Pinus canariensis C. Smith, imported* *16. Pinus caribbea, imported*	I, II, III, IV
Irrigation system (C)	4:	Surface drip, built in (SD), Subsurface drip, built in (SSD), on-line surface drip (OSD), and bubbler (BUB).	Ib
Water quantity (D)	5 & 3	Quantity levels with an equidistant difference pattern. The choice of the levels is depending on water consumption of each group of 4 species. 5 and 3 levels are investigated in Experiment Ia	Ia, Ib, IIIb

Factor/treatment	*Factor levels*	*Description*	*Experiment*
		and Ib, respectively.	
Soil improvement technique (mycorrhiza and soil conditioner) (E)	4	Control, mycorrhiza, soil conditioner, mycorrhiza + soil conditioner.	IIIa, IIIb, IIIc
Spacing of seedlings (F)	3	Depending on objectives and nature of the species, 3 different levels are used from numerous potential spacing levels, as for example: 2.5m x 2.0m (2,000 seedlings/ha, zig-zag) 3.0m x 2.5m (1,333 seedlings/ha, zig-zag) 4.0m x 2.5m (1,000 seedlings/ha, zig-zag) 2.2m x 2.2m (2,025 seedlings/ha) 2.5m x 2.5m (1,600 seedlings/ha) 2.8m x 2.8m (1,225 seedlings/ha)	II
Silvicultural treatment (G)	3	The silvicultural treatment is carried out for each spacing level. It includes 3 levels, which differentiate in intensity, treatment interval, or timing of the treatment implementation (Table 3 shows examples of potential treatment levels). The choice of the treatment level and frequency of treatment depend on the desired objective of the afforestation, nature of the species, and length of the rotation period. Depending on the conditions of a plantation stand, a silvicultural treatment level is carried out once or at intervals applying the same technique, different techniques, or a combination of the techniques. Techniques are for example, thinning, pruning, or crop tree manage-ment (improvement and management of potential crop trees by removing the competitive individuals).	II

Table 3: Possible potential levels of silvicultural treatment (3 of the 4 below levels can be implemented for one species depending on the nature of the species, the length of the rotation period, and the desired objective).

Silvicultural treatment levels	*1st treatment*	*2nd treatment*	*3rd treatment*	*4th treatment*
Control	Non treatment	Non treatment	Non treatment	Non treatment
Late promotion of 250 potential crop individuals/ha	Non treatment	Thinning by removing 50% of the initial individuals	Thinning by removing 50% of the remaining individuals after the first thinning.	Improvement of 250 vigorous and of good-quality potential crop individuals/ ha, and pruning

Silvicultural treatment levels	*1st treatment*	*2nd treatment*	*3rd treatment*	*4th treatment*
Mid-rotation promotion of 250 potential crop individuals/ha	Thinning by removing 50% of the initial individuals	Thinning by removing 50% of the remaining individuals after the first thinning	Improvement of 250 vigorous and of good-quality potential crop individuals/ha, and pruning	Management of the potential crop individuals
Early promotion of 250 potential crop individuals/ha	Thinning by removing 50% of the initial individuals	Improvement of 250 vigorous and of good-quality potential crop individuals/ ha, and pruning	Management of the potential crop individuals	Management of the potential crop individuals

4.2 Layout of the experiments

4.2.1 Experiment Ia

In Experiment Ia, the total number of plots is nqb_i, where n represents the number of the sites, and qb_i the number of the investigated species (plots) within a site. For reliable analysis from the statistical standpoint, the qb_i species are classified into q groups of b_i species within a group. The b_i set of species in a group has similarity in one or more criteria of the followings: water consumption, nature of the species, desired objective of the afforestation or employed silvicultural treatments.

Each plot contains four different species. Depending on how many levels of afforestation materials are used, a plot can also include two species, each of two different afforestation materials, or two species of one afforestation material and a third species of two materials.

b_2	b_1	b_4	b_3
b_4	b_3	b_1	b_2
b_3	b_4	b_2	b_1
b_1	b_2	b_3	b_4

Figure 2a: Layout of a plot in Experiment Ia with 4 species (b1:b4) in a 4x4 Latin Square Design.

Each plot is 7,744 m^2 in size and square in shape (88 m x 88 m). It is subdivided into 16 cells with square formation (22 m x 22 m) in rows and columns. The number of cells in a row or in a column equals the number of the levels of the species. Thus, the design is a 4x4 Latin Square (Figure 2a), in which the levels of the species are randomly assigned to the cells, with the restriction that each level appears only once in a row and once in a column. The random assignment is independently carried out for each plot.

Each row in a plot consists of d (5) irrigation lines, representing the subunit treatments of the water quantity (Figure 2b). The assignment of the d levels to the irrigation lines is at random. The distance between two lines is 4.4 m.

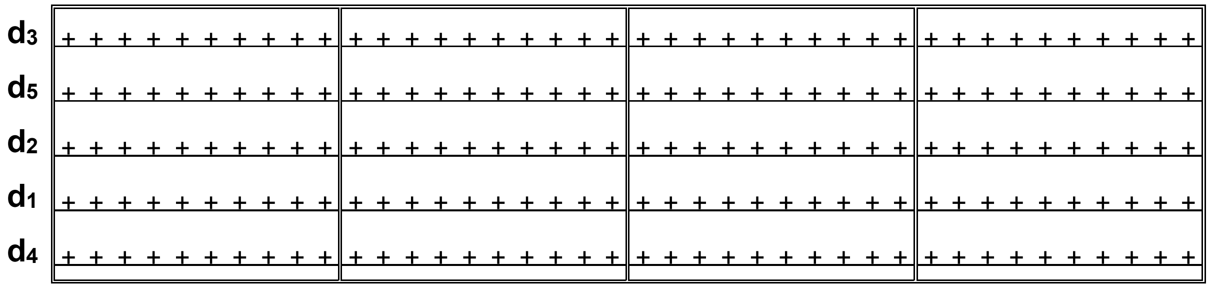


Figure 2b: Layout of a row in the 4x4 Latin Square Design with subunit treatments arranged in strips across each row. Each row with 4 cells consists of 5 irrigation lines representing the water quantity (5 levels: d_1:d_5). Each irrigation line contains 40 (10/cell x 4 cells) samples (+): either seedlings or sample units for the direct seeding.

Each line in a cell irrigates 10 seedlings. The distance between two seedlings or the centre of two sample units is 2.2 m. The number of samples per species having received the same subunit treatment in a plot is 40. The total number of samples for one species and for all species in a plot is 200 and 800, respectively.

4.2.2 Experiment Ib

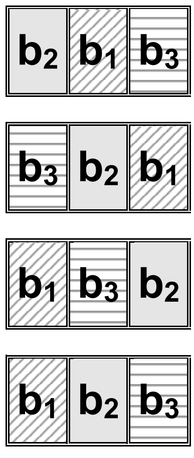


Figure 3a: Layout of the Experiment Ib with 3 species (b_1:b_3) arranged in a Block Randomised Design.

Experiment Ib is separated from Experiment Ia to test the effect of different irrigation systems at different water quantity in a relatively small area size, using only three selected species. The experiment is arranged in a Randomised Block Design with 4 Blocks (Figure 3a). Each block is subdivided into three plots. Each plot contains one species with 120 seedlings. The levels of the species are randomly assigned to the plots. The random assignment is undertaken separately for each block. Each Block contains 12 different levels of the combination “water quantity” and “irrigation system” (Figure 3b), which are randomly assigned to the irrigation lines. The random assignment is independently carried out for each block. The total number of the irrigation lines is 48 (4 blocks x 3 water quantity x 4 irrigation systems), which are arranged in strips across each block. Each line irrigates 30 seedlings (3 plots x 10 seedlings/plot). The total number of seedlings employed in a block and in the experiment is 360 and 1,440, respectively.

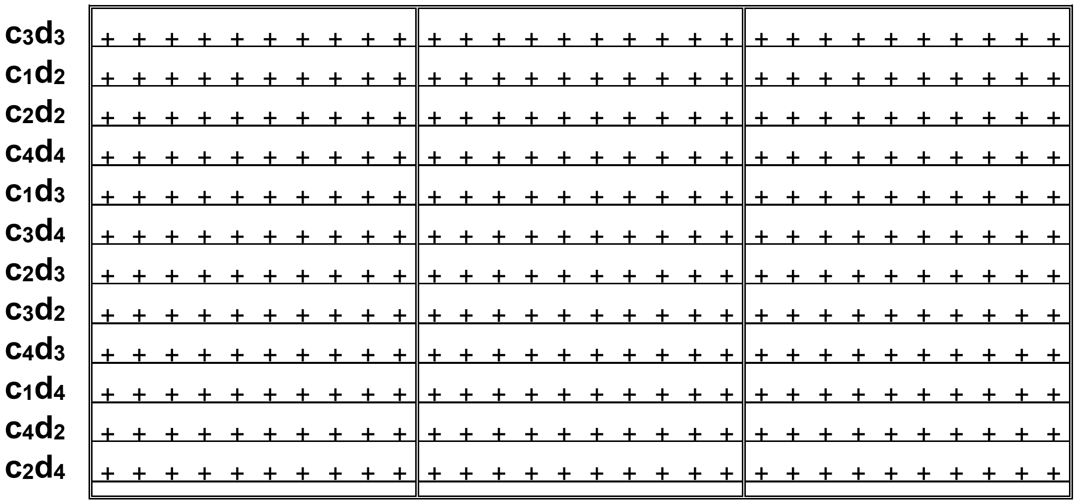


Figure 3b: Layout of a block in the Randomised Block Factorial Design with subunit treatments arranged in strips across each block. Each block with 3 plots consists of 12 irrigation lines representing the combination of irrigation system (4 levels: c_1:c_4) and water quantity (3 levels: d_2:d_4). Each irrigation line contains 30 (10/plot x 3 plots) seedlings (+).

4.2.3 <u>Experiment II</u>

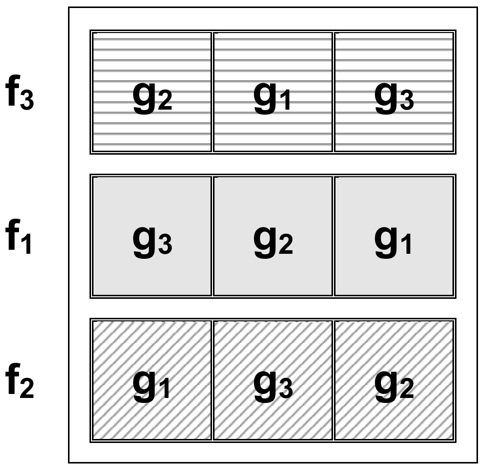


Figure 4a: Layout of a plot in Experiment II. Each plot represents one species with 3 different silvicultural treatment levels (g_1:g_3) arranged in a 3x3 Latin Square Design. The rows represent 3 different levels of spacing (f_1:f_3).

In Experiment II, the total number of plots is np, where n represents the number of the sites, and p the number of the investigated species (plots) within a site.

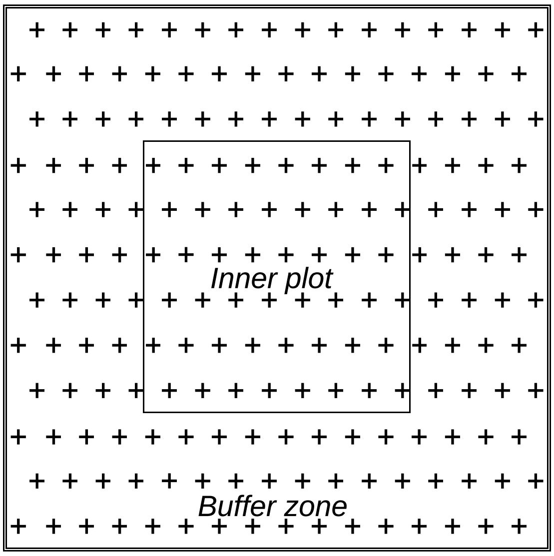


Figure 4b: Layout of a cell in the 3x3 Latin Square Design. The cell contains an inner plot and a buffer zone.

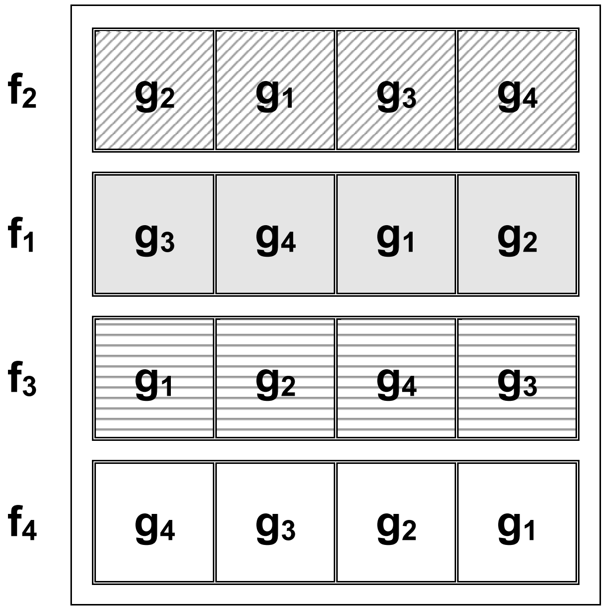


Figure 5: Layout of a plot in Experiment II for those species conducted in only one site. Each plot represents one species with 4 different silvicultural treatment levels (g_1:g_4) arranged in a 4x4 Latin Square Design. The rows represent 4 different levels of spacing (f_1:f_4).

Each plot represents one species and is subdivided into 3 rows. The size of each row is 0,7 ha (145.8 m x 48.6 m). Each row contains 3 cells, making in total 9 (gf) cells per plot. Thus, the arrangement of each plot is a 3 x 3 Latin Square Design (Figure 4a). The plot rows represent the different f spacing levels. The assignment of the spacing levels to the rows is at random for each plot. Each cell in a row randomly receives a silvicultural treatment level, with the restriction that each level appears only once in a row and once in a column. The random assignment of the g silvicultural treatment levels is separately made for each plot.

Each cell in a plot contains r samples (seedlings or installed circular sample-units of 0,5 m^2 in size for direct seeding). The number of the samples r is depending on the spacing level. The cell size is 48.6 m x 48.6 m and contains an inner plot of a size of 24.3 m x 24.3 m and a buffer zone of a width of 12.15 m (Figure 4b). Comprehensive data collection and measurement programmes are conducted on all samples within the inner plots.

Whenever the afforestation of a species is realised in only one site, the arrangement of a plot is a 4x4 Latin Square Design (Figure 5) in order to obtain reliable results.

4.2.4 ***Experiment IIIa***

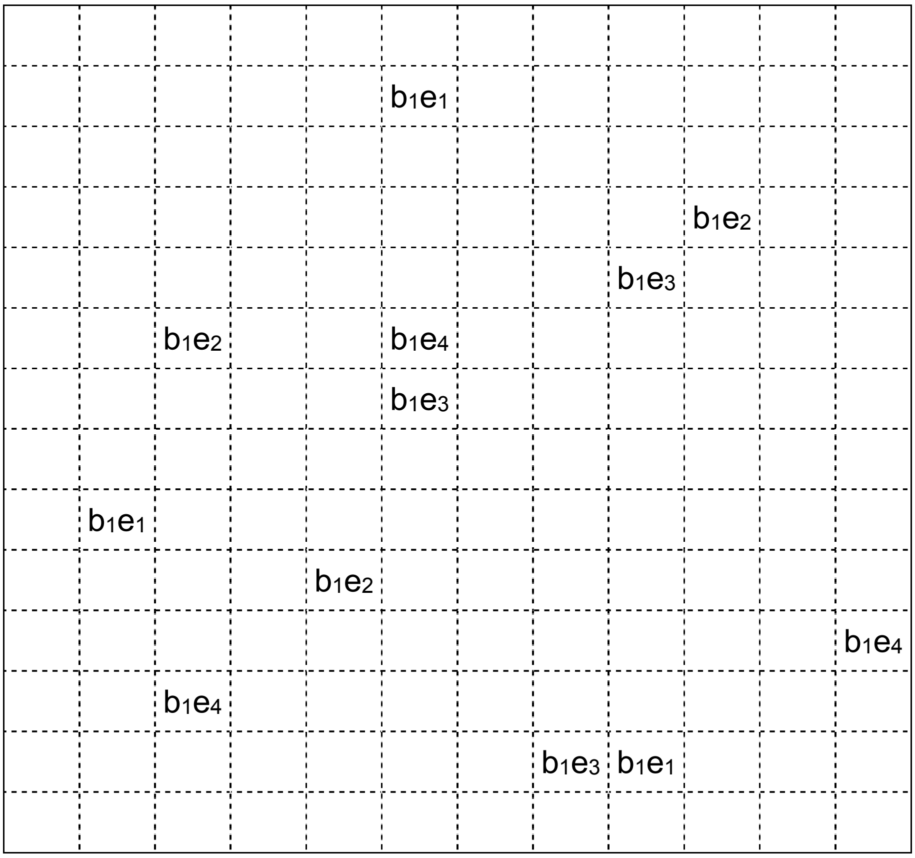


Figure 6: Layout of a plot in Experiment IIIa (Completely Randomised Factorial Design). Each plot is subdivided into rbe experimental units. Each experimental unit represents one of the combination of the species levels (b_1:b_{14}) and the levels of soil improvement technique (e_1:e_4).

In Experiment IIIa, the design for each site is a Completely Randomised Factorial Design (Figure 6). Each site includes one plot. The number of the experimental units in each plot = ber = 14 x 4 x 3 = 168, where

B = Species with j levels, where j = 1, … , b and b = 14 (b_1 to b_{14})

E = Soil improvement technique with k levels, where k = 1, … , e and e = 4 (e_1 = control, e_2 = mycorrhiza, e_3 = soil conditioner, e_4 = mycorrhiza + soil conditioner).

R = Replication with l levels, where l = 1, … , r and r = 3 within a site (3 replications: r_1 to r_3).

Each plot is subdivided into rbe (168) subplots. Each of the rbe subplots receives randomly one of the combination BE, with the restriction that each BE combination is assigned to r (3) experimental units. The random assignment is carried out for each plot separately.

Each experimental unit is 12,5m x 12,5m in size (Figure 7). Each includes 4 x 4 seedlings with a spacing of 2.5m x 2.5m. The distance between two seedlings of different BE combination is 5m.

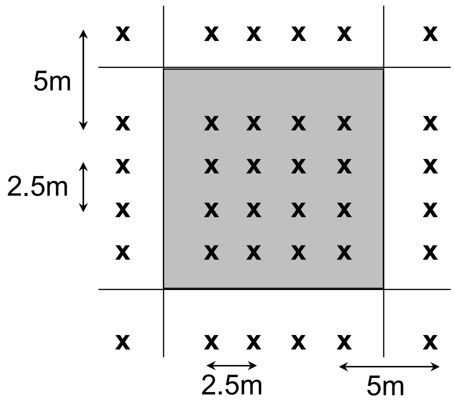


Figure 7: Layout of an experimental unit with 16 seedlings of a size of 12.5m x 12.5m in Experiment IIIa.

4.2.5 Experiment IIIb

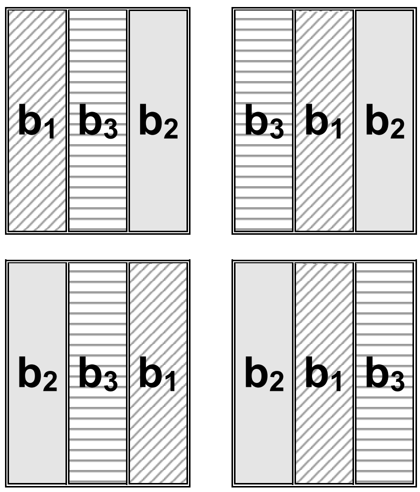


Figure 8a: Layout of the Experiment IIIb with 3 species (b_1:b_3) arranged in a Randomised Block Design.

Experiment IIIb aims at examining the effect of mycorrhiza and soil conditioner on survival, growth and water use of three selected species at different water quantity. The experiment is arranged in a Randomised Block Design with 4

Blocks (Figure 8a). Each block is subdivided into three plots. Each plot contains one species with 120 seedlings. The levels of the species are randomly assigned to the plots. The random assignment is undertaken separately for each block. Each Block contains 12 different levels of the combination “water quantity” and “soil improvement technique” (Figure 8b), which are randomly assigned to the irrigation lines. The random assignment is independently carried out for each block.

e_3d_3	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_1d_2	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_2d_2	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_4d_4	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_1d_3	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_3d_4	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_2d_3	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_3d_2	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_4d_3	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_1d_4	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_4d_2	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +
e_2d_4	+ + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + +

Figure 8b: Layout of a block in the Randomised Block Factorial Design with subunit treatments arranged in strips across each block. Each block with 3 plots consists of 12 irrigation lines representing the combination of soil improvement technique (4 levels: e_1:e_4) and water quantity (3 levels: d_2:d_4). Each irrigation line contains 30 (10/plot x 3 plots) seedlings (+).

The total number of the irrigation lines is 48 (4 blocks x 3 water quantity x 4 soil improvement technique), which are arranged in strips across each block. The distance between two lines or plants in two lines of different combinations is kept large at 8.8 m. Each line irrigates 30 seedlings (3 plots x 10 seedlings/plot). The total number of seedlings employed in a block and in a site is 360 and 1,440, respectively.

4.2.6 <u>Experiment IIIc</u>

Experiment IIIC is conducted in a nursery at the University of Alexandria to investigate the impact of different soil improvement techniques on raising seedlings from seeds. The number of experimental units = ber = 14 x 4 x 4 = 224, where:

B = Species with j levels, where j = 1, … , b and b = 14 (b_1 to b_{14})

E = Treatment with k levels, where k = 1, … , e and e = 4 (e_1 = control, e_2 = mycorrhiza, e_3 = soil conditioner (Revita San), e_4 = mycorrhiza + soil conditioner (Revita San)).

R = Replications with i levels, where i = 1, … , r and r = 4.

The design is a Completely Randomised Factorial Design (Figure 9). The assignment of the be (56) combinations to the ber (224) experimental units is at random, with the restriction that each BE combination is assigned to r (4) experimental units.

												b_1e_4	
						b_1e_1							
										b_1e_2			
		b_1e_2											
	b_1e_1											b_1e_4	
				b_1e_3									
									b_1e_1				
						b_1e_3	b_1e_3						
											b_1e_4		
			B_1e_4			b_1e_2							
					b_1e_2								
		b_1e_1										b_1e_3	

Figure 9: Layout of Experiment IIIc (Completely Randomised Factorial Design). The experiment includes rbe experimental units. Each experimental unit represents one of the combination of the species levels (b_1:b_{14}) and the treatment levels (e_1:e_4).

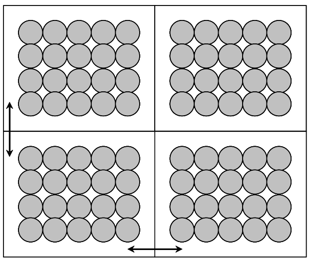


Figure 9: Layout of a 4 experimental units with 20 seeds in Experiment IIIc or layout of a block with all 4 treatment levels (e1:e4) in Split-plot Factorial Design.

The number of the alive seeds used for each species is n = 20 er = 320. They were randomly separated in 16 experimental units (er). In order to secure that the mycorrhiza unit does not affect the other units, sufficient distance is left between each experimental unit. Each experimental unit includes 20 samples (seeds in polyethylene pots) next to each other (Figure 10). The pots has a small diameter but large in length.

4.2.7 Experiment IV

Experiment IV deals with the assessment of the existing plantation forests. Selected forest stands of those tree species that are available at different ages are studied on three different locations: Ismailia, Sadaat City and Luxor. Emphasis is laid on measuring the basal area, crown size, and growth as well as quality parameters of single trees. On the other hand, in Ismailia the above and underground biomass is studied to determine the carbon sequestration of selected tree species. The assessment includes also investigations on the impact of the irrigated forest stand by sewage water on soil in order to identify contamination in soil and in further steps identify more efficient wastewater treatment techniques.

4.3 Hypotheses testing and statistical analyses associated with the experimental designs

4.3.1 Experiment Ia

Table 4: Hypotheses and ANOVA table for the analysis of all sites (each includes a plot of 4 species) in Experiment Ia: 3 (a) 4x4 Latin Squares with 5 (d) subunit treatments arranged in strips across each row (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Total	$ab^2d - 1 =$	239		
Between cells	$ab^2-1 =$	47		
1. A (squares)	a-1 =	2	MS 1/MS 6	H_0: $\mu_{\text{site 1}} = \ldots = \mu_{\text{site a}}$
2. Rows within A	a(l-1) =	9	MS 2/MS 6	H_0: $\mu_{\text{row 1}} = \ldots = \mu_{\text{row l}}$ at each A-level
3. Columns within A	a(m-1) =	9	MS 3/MS 6	H_0: $\mu_{\text{cloumn 1}} = \ldots = \mu_{\text{cloumn m}}$ at each A-level
4. B (species)	b-1 =	3	MS 4/MS 6	H_0: $\mu_{\text{species 1}} = \ldots = \mu_{\text{species b}}$
5. AB	(a-1)(b-1) =	6	MS 5/MS 6	H_0: Interaction effect = 0
6. Error a	***a(b-1) (b-2) =***	***18***		
Within cells	$ab^2(d-1) =$	192		
7. D (water quantity)	d-1 =	4	MS 7/MS 8	H_0: $\mu_{\text{water quantity 1}} = \ldots = \mu_{\text{water quantity d}}$
a. Linear trend		1	MS 7a /MS 8	H_0: linear contrast = 0
b. Quadratic trend		1	MS 7b /MS 8	H_0: quadratic contrast = 0
c. Cubic trends		1	MS 7c /MS 8	H_0: cubic contrast = 0
d. Quartic trend		1	MS 7d /MS 8	H_0: quartic contrast = 0
8. Error b	***(l-1) d-1) =***	**12**		
9. AD	(a-1)(d-1) =	8	MS 9/MS 10	H_0: Interaction effect = 0
a. Linear trend	a-1 =	2	MS 9a /MS 10	H_0: Difference in linear contrast = 0
b. Quadratic trend	a-1 =	2	MS 9b /MS 10	H_0: Difference in quadratic contrast=0
c. Cubic trend	a-1 =	2	MS 9c /MS 10	H_0: Difference in cubic contrast = 0
d. Quartic trend	a-1 =	2	MS 9d /MS 10	H_0: Difference in quartic contrast = 0
10. Error c	***(a-1)(l-1)(d-1) =***	***24***		
11. BD	(b-1)(d-1) =	12	MS 11/MS 12	H_0: Interaction effect = 0
a. Linear trend	b-1 =	3	MS 11a /MS 12	H_0: Difference in linear contrast = 0
b. Quadratic trend	b-1 =	3	MS 11b /MS 12	H_0: Difference in quadratic contras =0
c. Cubic trend	b-1 =	3	MS 11c /MS 12	H_0: Difference in cubic contrast = 0
d. Quartic trend	b-1 =	3	MS 11d /MS 12	H_0: Difference in quartic contrast = 0

Source of variation	Degrees of freedom	F Statistics	Null hypothesis
12. Error d	***(b-1)(l-1)(d-1) = 36***		
13. ABD	(a-1)(b-1)(d-1) = 24	MS 13/MS 14	H_0: Interaction effect = 0
a. Linear trend	(a-1)(b-1) = 8	MS 13a /MS 14	H_0: Difference in linear contrast = 0
b. Quadratic trend	(a-1)(b-1) = 8	MS 13b /MS 14	H_0: Difference in quadratic contrast=0
c. Cubic trend	(a-1)(b-1) = 8	MS 13c /MS 14	H_0: Difference in cubic contrast = 0
d. Quartic trend	(a-1)(b-1) = 8	MS 13d /MS 14	H_0: Difference in quartic contrast = 0
14. Error e	***(a-1)(b-1)(l-1)(d-1) = 72***		

In Experiment Ia, the interest is on examining the response of a group of species on the different sites (Table 4). However, in the event that a group of species is only tested in one site, the statistical analysis can be preformed as indicated in Table 5.

In Experiment Ia, investigations on the effect of fertilisation are studied for only those species that necessitate supplementary fertiliser at the time of establishment. In this event, two plots will be established on each site, one with fertiliser application and the other with non-fertilisation. Assuming that each plot includes 4 species, which all receive the same fertilisation level in a plot, the analysis indicated in Table 6 is the accurate one.

Table 5: Hypotheses and ANOVA table for analysis of one site including a plot of 4 species in Experiment Ia: 4x4 Latin Squares with 5 (d) subunit treatments arranged in strips across each row (MS = Mean Square).

Source of variation	Degrees of freedom	F Statistics	Null hypothesis
Total	b^2d - 1 = 79		
Between cells	b^2-1 = 15		
1. Rows	l-1 = 3	MS 1/MS 4	H_0: $\mu_{\text{row 1}} = \ldots = \mu_{\text{row l}}$
2. Columns	m-1 = 3	MS 2/MS 4	H_0: $\mu_{\text{cloumn 1}} = \ldots = \mu_{\text{cloumn m}}$
3. B (species)	b-1 = 3	MS 3/MS 4	H_0: $\mu_{\text{species 1}} = \ldots = \mu_{\text{species b}}$
4. Error a	***(b-1) (b-2) = 6***		
Within cells	b^2(d-1) = 64		
5. D (water quantity)	d-1 = 4	MS 5/MS 6	H_0: $\mu_{\text{water quantity 1}} = \ldots = \mu_{\text{water quantity d}}$
a. Linear trend	1	MS 5a /MS 6	H_0: linear contrast = 0
b. Quadratic trend	1	MS 5b /MS 6	H_0: quadratic contrast = 0
c. Cubic trends	1	MS 5c /MS 6	H_0: cubic contrast = 0
d. Quartic trend	1	MS 5d /MS 6	H_0: quartic contrast = 0
6. Error b	***(l-1)(d-1) = 12***		
7. BD	(b-1)(d-1) = 12	MS 7/MS 8	H_0: Interaction effect = 0
a. Linear trend	b-1 = 3	MS 7a /MS 8	H_0: Difference in linear contrast = 0
b. Quadratic trend	b-1 = 3	MS 7b /MS 8	H_0: Difference in quadratic contrast=0
c. Cubic trend	b-1 = 3	MS 7c /MS 8	H_0: Difference in cubic contrast = 0
d. Quartic trend	b-1 = 3	MS 7d /MS 8	H_0: Difference in quartic contrast = 0
8. Error c	***(b-1)(l-1)(d-1) = 36***		

Table 6: Hypotheses and ANOVA table for the analysis of all sites, each including 2 plots with 2 different fertilisation levels in Experiment Ia: 3x2 (ae) 4x4 Latin Squares with 5 (d) subunit treatments arranged in strips across each row (MS = Mean Square).

Source of variation	Degrees of freedom	F Statistics	Null hypothesis
Total	aeb^2d - 1 = 479		
Between cells	aeb^2-1 = 95		
Squares	ae-1 = 5		
1. A (site)	a-1 = 2	MS 1/MS 10	H_0: $\mu_{\text{site 1}} = \ldots = \mu_{\text{site a}}$

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
2. E (fertilisation)	e-1 =	1	MS 2/MS 10	H_0: $\mu_{\text{fertilisation } 1} = \ldots = \mu_{\text{fertilisation } e}$
3. AE	(a-1)(e-1) =	2	MS 3/MS 10	H_0: Interaction effect = 0
4. Rows within squares	ae(l-1) =	18	MS 4/MS 10	H_0: $\mu_{\text{row } 1} = \ldots = \mu_{\text{row } l}$ at each AE-level
5. Columns within squares	ae(m-1) =	18	MS 5/MS 10	H_0: $\mu_{\text{column } 1} = \ldots = \mu_{\text{column } m}$ at each AE-level
6. B (species)	b-1 =	3	MS 6/MS 10	H_0: $\mu_{\text{species } 1} = \ldots = \mu_{\text{species } b}$
7. AB	(a-1)(b-1) =	6	MS 7/MS 10	H_0: Interaction effect = 0
8. EB	(e-1)(b-1) =	3	MS 8/MS 10	H_0: Interaction effect = 0
9. AEB	(a-1)(e- 1)(b-1) =	6	MS 9/MS 10	H_0: Interaction effect = 0
10. Error a	***ae(b-1)(b-2) =***	***36***		
Within cells	$aeb^2(d-1)$ =	384		
12. D (water quantity)	d-1 =	4	MS 12/MS 14	H_0: $\mu_{\text{water quantity } 1} = \ldots = \mu_{\text{water quantity } d}$
a. Linear trend		1	MS 12a /MS 14	H_0: linear contrast = 0
b. Quadratic trend		1	MS 12b /MS 14	H_0: quadratic contrast = 0
c. Cubic trends		1	MS 12c /MS 14	H_0: cubic contrast = 0
d. Quartic trend		1	MS 12d /MS 14	H_0: quartic contrast = 0
14. Error b	***(l-1)(d-1) =***	***12***		
16. AD	(a-1)(d-1) =	8	MS 16/MS 18	H_0: Interaction effect = 0
a. Linear trend	a-1 =	2	MS 16a /MS 18	H_0: Difference in linear contrast = 0
b. Quadratic trend	a-1 =	2	MS 16b /MS 18	H_0: Difference in quadratic contrast=0
c. Cubic trend	a-1 =	2	MS 16c /MS 18	H_0: Difference in cubic contrast = 0
d. Quartic trend	a-1 =	2	MS 16d /MS 18	H_0: Difference in quartic contrast = 0
18. Error c	***(a-1)(l-1)(d-1) =***	***24***		
20. ED	(e-1)(d-1) =	4	MS 20/MS 22	H_0: Interaction effect = 0
a. Linear trend	e-1 =	1	MS 20a /MS 22	H_0: Difference in linear contrast = 0
b. Quadratic trend	e-1 =	1	MS 20b /MS 22	H_0: Difference in quadratic contrast=0
c. Cubic trend	e-1 =	1	MS 20c /MS 22	H_0: Difference in cubic contrast = 0
d. Quartic trend	e-1 =	1	MS 20d /MS 22	H_0: Difference in quartic contrast = 0
22. Error d	***(e-1)(l-1)(d-1) =***	***12***		
24. AED	(a-1)(e-1)(d-1) =	8	MS 24/MS 26	H_0: Interaction effect = 0
a. Linear trend	(a-1)(e-1) =	2	MS 24a /MS 26	H_0: Difference in linear contrast = 0
b. Quadratic trend	(a-1)(e-1) =	2	MS 24b /MS 26	H_0: Difference in quadratic contrast=0
c. Cubic trend	(a-1)(e-1) =	2	MS 24c /MS 26	H_0: Difference in cubic contrast = 0
d. Quartic trend	(a-1)(e-1) =	2	MS 24d /MS 26	H_0: Difference in quartic contrast = 0
26. Error e	***(a-1)(e-1)(l-1)(d-1) =***	***24***		
28. BD	(b-1)(d-1) =	12	MS 28/MS 30	H_0: Interaction effect = 0
a. Linear trend	b-1 =	3	MS 28a /MS 30	H_0: Difference in linear contrast = 0
b. Quadratic trend	b-1 =	3	MS 28b /MS 30	H_0: Difference in quadratic contrast=0
c. Cubic trend	b-1 =	3	MS 28c /MS 30	H_0: Difference in cubic contrast = 0
d. Quartic trend	b-1 =	3	MS 28d /MS 30	H_0: Difference in quartic contrast = 0
30. Error f	***(b-1)(l-1)(d-1) =***	***36***		
32. ABD	(a-1)(b-1)(d-1) =	24	MS 32/MS 34	H_0: Interaction effect = 0
a. Linear trend	(a-1)(b-1) =	6	MS 32a /MS 34	H_0: linear contrast = 0
b. Quadratic trend	(a-1)(b-1) =	6	MS 32b /MS 34	H_0: quadratic contrast = 0
c. Cubic trend	(a-1)(b-1) =	6	MS 32c /MS 34	H_0: cubic contrast = 0
d. Quartic trend	(a-1)(b-1) =	6	MS 32d /MS 34	H_0: quartic contrast = 0
34. Error g	***(a-1)(b-1)(l-1)(d-1) =***	***72***		
36. EBD	(e-1)(b-1)(d-1) =	12	MS 36/MS 38	H_0: Interaction effect = 0
a. Linear trend	(e-1)(b-1) =	3	MS 36a /MS 38	H_0: Difference in linear contrast = 0
b. Quadratic trend	(e-1)(b-1) =	3	MS 36b /MS 38	H_0: Difference in quadratic contrast=0
c. Cubic trend	(e-1)(b-1) =	3	MS 36c /MS 38	H_0: Difference in cubic contrast = 0
d. Quartic trend	(e-1)(b-1) =	3	MS 36d /MS 38	H_0: Difference in quartic contrast = 0
38. Error h	***(e-1)(b-1)(l-1)(d-1) =***	***36***		
40. AEBD	(a-1)(e-1)(b-1)(d-1) =	24	MS 40/MS 42	H_0: Interaction effect = 0
a. Linear trend	(a-1)(e-1)(b-1) =	6	MS 40a /MS 42	H_0: Difference in linear contrast = 0
b. Quadratic trend	(a-1)(e-1)(b-1) =	6	MS 40b /MS 42	H_0: Difference in quadratic contrast=0
c. Cubic trend	(a-1)(e-1)(b-1) =	6	MS 40c /MS 42	H_0: Difference in cubic contrast = 0
d. Quartic trend	(a-1)(e-1)(b-1) =	6	MS 40d /MS 42	H_0: Difference in quartic contrast = 0
42. Error i	***(a-1)(e-1)(b-1)(l-1)(d-1)=***	***72***		

4.3.2 Experiment Ib

In Experiment Ib, the response of selected species on different irrigation systems and water quantity is examined on one site. The underlying design is a Randomised Block Factorial Design with subunits treatments arranged in strips across each block (Table 7).

Table 7: Hypotheses and ANOVA table for the analysis of one site in Experiment Ib: 3x4 (bs) Randomised Block Factorial Design with 3x4 (cd) subunit treatments arranged in strips across each block (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Total	sbcd - 1 =	143		
Between cells	sb-1 =	11		
1. B (species)	b-1 =	2	MS 1/MS 2	H_0: $\mu_{\text{species } 1} = \ldots = \mu_{\text{species } b}$
2. Error a	***b(s-1) =***	***9***		
Within cells	sb(cd-1) =	132		
3. C (irrigation system)	c-1 =	3	MS 3/MS 6	H_0: $\mu_{\text{irrigation system } 1} = \mu_{\text{irrigation system } c}$
4. D (water quantity)	d-1 =	2	MS 4/MS 6	H_0: $\mu_{\text{water quantity } 1} = \ldots = \mu_{\text{water quantity } d}$
a. Linear trend		1	MS 4a /MS 6	H_0: linear contrast = 0
b. Quadratic trend		1	MS 4b /MS 6	H_0: quadratic contrast = 0
5. CD	(c-1)(d-1) =	6	MS 5/MS 6	H_0: Interaction effect = 0
a. Linear trend	c-1 =	3	MS 5a /MS 6	H_0: Difference in linear contrast = 0
b. Quadratic trend	c-1 =	3	MS 5b /MS 6	H_0: Difference in quadratic contrast = 0
6. Error b	***(s-1)(cd-1) =***	***33***		
7. BC	(b-1)(c-1) =	6	MS 7/MS 10	H_0: Interaction effect = 0
8. BD	(b-1)(d-1) =	4	MS 8/MS 10	H_0: Interaction effect = 0
a. Linear trend	b-1 =	2	MS 8a /MS 10	H_0: Difference in linear contrast = 0
b. Quadratic trend	b-1 =	2	MS 8b /MS 10	H_0: Difference in quadratic contrast = 0
9. BCD	(b-1)(c-1)(d-1) =	12	MS 9/MS 10	H_0: Interaction effect = 0
a. Linear trend	(b-1)(c-1) =	6	MS 9a /MS 10	H_0: Difference in linear contrast = 0
b. Quadratic trend	(b-1)(c-1) =	6	MS 9b /MS 10	H_0: Difference in quadratic contrast = 0
10. Error d	***(s-1)(b-1)(cd-1) =***	***66***		

4.3.3 <u>Experiment II</u>

Table 8: Hypotheses and ANOVA table for the analysis of all sites, each including 4 species in Experiment II: 3x4 (ab), 3x3 Latin Squares (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Total	abg^2 - 1 =	107		
Squares	ab-1 =	11		
1. A (site)	a-1 =	2	MS 1/MS 10	H_0: $\mu_{\text{site } 1} = \ldots = \mu_{\text{site } a}$
2. B (species)	b-1 =	3	MS 2/MS 10	H_0: $\mu_{\text{species } 1} = \ldots = \mu_{\text{specie } b}$
3. AB	(a-1)(b-1) =	6	MS 3/MS 10	H_0: Interaction effect = 0
4. Columns within squares	ab(l-1) =	24	MS 4/MS 10	H_0: $\mu_{\text{row } 1} = \ldots = \mu_{\text{row } l}$ at each AB-level
5. F (spacing) within squares	ab(f-1) =	24	MS 5/MS 10	H_0: $\mu_{\text{spacing } 1} = \ldots = \mu_{\text{spacing } f}$ at each AB-level
6. G (silvicultural treatment)	g-1 =	2	MS 6/MS 10	H_0: $\mu_{\text{silvicultural treatment } 1} = \ldots = \mu_{\text{silvicultural treatment } g}$
7. AG	(a-1)(g-1) =	4	MS 7/MS 10	H_0: Interaction effect = 0
8. BG	(b-1)(g-1) =	6	MS 8/MS 10	H_0: Interaction effect = 0
9. ABG	(a-1)(b-1)(g-1) =	12	MS 9/MS 10	H_0: Interaction effect = 0
10. Residual	***ab(g-1)(g-2) =***	***24***		

In Experiment II, the interest is on comparing a set of p_i species having shared attributes rather than comparing all investigated species (Table 8 shows an example when $p_i = 4$). When a set of p_i species is studied in only one site, the corresponding analysis is shown in Table 9 for $p_i = 4$. If the interest in testing the effect of the study factors on only one species ($p_i = 1$ species) on the different sites, the analysis can be conducted as shown in Table 10. In the event that the afforestation of a species takes place on only one site, and the arrangement of a plot is a 4 x 4 Latin Square Design (Figure 5), the appropriate analysis would be as indicated in Table 11.

Table 9: Hypotheses and ANOVA table for the analysis of 4 species in one site in Experiment II: 4 (b), 3x3 Latin Squares (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Total	bg^2 - 1 =	35		
1. B (species or squares)	b-1 =	3	MS 1/MS 6	H_0: $\mu_{\text{species } 1} = \ldots = \mu_{\text{specie } b}$
2. Columns within B	b(l-1) =	8	MS 2/MS 6	H_0: $\mu_{\text{row } 1} = \ldots = \mu_{\text{row } l}$ at each B-level
3. F (spacing) within B	b(f-1) =	8	MS 3/MS 6	H_0: $\mu_{\text{spacing } 1} = \ldots = \mu_{\text{spacing } f}$ at each B-level
4. G(silvicultural treatment)	g-1 =	2	MS 4/MS 6	H_0: $\mu_{\text{silvicultural treatment } 1} = \ldots = \mu_{\text{silvicultural treatment } g}$
5. BG	(b-1)(g-1) =	6	MS 5/MS 6	H_0: Interaction effect = 0
6. Residual	***b(g-1)(g-2) =***	***8***		

Table 10: Hypotheses and ANOVA table for the analysis of one species in all sites in Experiment II: 3 (a), 3x3 Latin Squares (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Total	ag^2 - 1 =	26		
1. A (sites or squares)	a-1 =	2	MS 1/MS 6	H_0: $\mu_{\text{site } 1} = \ldots = \mu_{\text{site } a}$
2. Columns within A	a(l-1) =	6	MS 2/MS 6	H_0: $\mu_{\text{row } 1} = \ldots = \mu_{\text{row } l}$ at each A-level
3. F (spacing) within A	a(f-1) =	6	MS 3/MS 6	H_0: $\mu_{\text{spacing } 1} = \ldots = \mu_{\text{spacing } f}$ at each A-level
4. G(silvicultural treatment)	g-1 =	2	MS 4/MS 6	H_0: $\mu_{\text{silvicultural treatment } 1} = \ldots = \mu_{\text{silvicultural treatment } g}$
5. AG	(a-1)(g-1) =	4	MS 5/MS 6	H_0: Interaction effect = 0
6. Residual	***a(g-1)(g-2) =***	***6***		

Table 11: Hypotheses and ANOVA table for the analysis of one species in on site in Experiment II: 4x4 Latin Squares (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Total	g^2 - 1 =	15		
1. Columns	l-1 =	3	MS 1/MS 4	H_0: $\mu_{\text{row } 1} = \ldots = \mu_{\text{row } l}$
2. F (spacing)	f-1 =	3	MS 2/MS 4	H_0: $\mu_{\text{spacing } 1} = \ldots = \mu_{\text{spacing } f}$
3. G(silvicultural treatment)	g-1 =	3	MS 3/MS 4	H_0: $\mu_{\text{silvicultural treatment } 1} = \ldots = \mu_{\text{silvicultural treatment } g}$
4. Residual	***(g-1)(g-2) =***	***6***		

4.3.4 Experiment IIIa

The analysis of Experiment IIIa for one site (Completely Randomised Factorial Design) is indicated in Table 12. Table 13 shows the simultaneous analyses for all sites.

Table 12: Hypotheses and ANOVA table for the analysis of Completely Randomised Factorial Design in on site in Experiment IIIa (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis (Levels of B and E are fixed effects)
Total	ber - 1 =	167		
1. B (species)	b-1 =	13	MS 1/MS 4	H_0: $\mu_{\text{species } 1} = \ldots = \mu_{\text{species } b}$
2. E (soil improvement)	e-1 =	3	MS 2/MS 4	H_0: $\mu_{\text{soil improvement } 1} = \mu_{\text{soil improvement } e}$
3. BE	(b-1)(e-1) =	39	MS 3/MS 4	H_0: Interaction effect = 0
4. Error	***be(r-1)=***	***112***		

Table 13: Hypotheses and ANOVA table for the analysis of Completely Randomised Factorial Design for all sites based on Completely

Randomised Factorial Design in one site in Experiment IIIa (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis (Levels of B, E and A are fixed effects)
Total	aber - 1 =	335		
1. A (site)	a-1 =	1	MS 1/MS 8	H_0: $\mu_{\text{site } 1} = \ldots = \mu_{\text{site } a}$
2. B (species)	b-1 =	13	MS 2/MS 8	H_0: $\mu_{\text{species } 1} = \ldots = \mu_{\text{species } b}$
3. E (soil improvement)	e-1 =	3	MS 3/MS 8	H_0: $\mu_{\text{soil improvement } 1} = \mu_{\text{soil improvement } e}$
4. BE	(b-1)(e-1) =	39	MS 4/MS 8	H_0: Interaction effect = 0
5. AB	(a-1)(b-1) =	13	MS 5/MS 8	H_0: Interaction effect = 0
6. AE	(a-1)(e-1) =	3	MS 6/MS 8	H_0: Interaction effect = 0
7. ABE	(a-1)(b-1)(e-1) =	39	MS 7/MS 8	H_0: Interaction effect = 0
8. Within cells	***abe(r-1)=***	**224**		

4.3.5 Experiment IIIb

In Experiment IIIb, the design is a Randomised Block Factorial Design for one site and the corresponding analysis is indicated in Table 14a. The simultaneous analysis of all sites is shown in Table 14b.

Table 14a: Hypotheses and ANOVA table for the analysis of one site in Experiment IIIb: 3x4 (bs) Randomised Block Factorial Design with 3x4 (ed) subunit treatments arranged in strips across each block (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Total	sbed - 1 =	143		
Between cells	sb-1 =	11		
1. B (species)	b-1 =	2	MS 1/MS 2	H_0: $\mu_{\text{species } 1} = \ldots = \mu_{\text{species } b}$
2. Error a	***b(s-1) =***	***9***		
Within cells	sb(ed-1) =	132		
3. E (soil improvement)	e-1 =	3	MS 3/MS 6	H_0: $\mu_{\text{soil improvement } 1} = \mu_{\text{soil improvement } e}$
4. D (water quantity)	d-1 =	2	MS 4/MS 6	H_0: $\mu_{\text{water quantity } 1} = \ldots = \mu_{\text{water quantity } d}$
a. Linear trend		1	MS 4a /MS 6	H_0: Difference in linear contrast = 0
b. Quadratic trend		1	MS 4b /MS 6	H_0: Difference in quadratic contrast = 0
5. ED	(e-1)(d-1) =	6	MS 5/MS 6	H_0: Interaction effect = 0
a. Linear trend	e-1 =	3	MS 5a /MS 6	H_0: Difference in linear contrast = 0
b. Quadratic trend	e-1 =	3	MS 5b /MS 6	H_0: Difference in quadratic contrast = 0
6. Error b	***(s-1)(cd-1) =***	**33**		
7. BE	(b-1)(e-1) =	6	MS 7/MS 10	H_0: Interaction effect = 0
8. BD	(b-1)(d-1) =	4	MS 8/MS 10	H_0: Interaction effect = 0
a. Linear trend	b-1 =	2	MS 8a /MS 10	H_0: Difference in linear contrast = 0
b. Quadratic trend	b-1 =	2	MS 8b /MS 10	H_0: Difference in quadratic contrast = 0
9. BED	(b-1)(e-1)(d-1) =	12	MS 9/MS 10	H_0: Interaction effect = 0
a. Linear trend	(b-1)(e-1) =	6	MS 9a /MS 10	H_0: Difference in linear contrast = 0
b. Quadratic trend	(b-1)(e-1) =	6	MS 9b /MS 10	H_0: Difference in quadratic contrast = 0
10. Error d	***(s-1)(b-1)(ed-1) =***	**66**		

Table 14b: Hypotheses and ANOVA table for the analysis of all sites in Experiment IIIb: 3x4 (bs) Split- Plot Factorial Design with 3x4 (ed) subunit treatments arranged in strips across each block (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Total	asbed - 1 =	287		
Between A	sa-1 =	7		
1. A (site)	a-1 =	1	MS 1/MS 2	H_0: $\mu_{\text{site } 1} = \ldots = \mu_{\text{site } a}$
2. Error a	***a(s-1) =***	***6***		
Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Within B	sa(b-1) =	16		

3. B (species)	b-1 = 2	MS 3/MS 5	H_0: $\mu_{\text{species 1}} = \ldots = \mu_{\text{species b}}$
4. AB	(a-1)(b-1) = 2	MS 4/MS 5	H_0: Interaction effect = 0
5. Error b	***a(s-1)(b-1) = 12***		
Within ED	sab(ed-1) = 264		
6. E (soil improvement)	e-1 = 3	MS 6/MS 9	H_0: $\mu_{\text{soil improvement 1}} = \mu_{\text{soil improvement e}}$
7. D (water quantity)	d-1 = 2	MS 7/MS 9	H_0: $\mu_{\text{water quantity 1}} = \ldots = \mu_{\text{water quantity d}}$
a. Linear trend	1	MS 7a /MS 9	H_0: linear contrast = 0
b. Quadratic trend	1	MS 7b /MS 9	H_0: quadratic contrast = 0
8. ED	(e-1)(d-1) = 6	MS 8/MS 9	H_0: Interaction effect = 0
a. Linear trend	e-1 = 3	MS 8a /MS 9	H_0: Difference in linear contrast = 0
b. Quadratic trend	e-1 = 3	MS 8b /MS 9	H_0: Difference in quadratic contrast = 0
9. Error c	***(s-1)(cd-1) = 33***		
10. AE	(a-1)(e-1) = 3	MS 10/MS 13	H_0: Interaction effect = 0
11. AD	(a-1)(d-1) = 2	MS 11/MS 13	H_0: Interaction effect = 0
a. Linear trend	a-1 = 2	MS 11a /MS 13	H_0: Difference in linear contrast = 0
b. Quadratic trend	a-1 = 2	MS 1b /MS 13	H_0: Difference in quadratic contrast = 0
12. AED	(a-1)(e-1)(d-1) = 6	MS 12/MS 13	H_0: Interaction effect = 0
a. Linear trend	(a-1)(e-1) = 3	MS 12a /MS 13	H_0: Difference in linear contrast = 0
b. Quadratic trend	(a-1)(e-1) = 3	MS 12b /MS 13	H_0: Difference in quadratic contrast = 0
13. Error d	***(s-1)(a-1)(ed-1) = 33***		
14. BE	(b-1)(e-1) = 6	MS 14/MS 17	H_0: Interaction effect = 0
15. BD	(b-1)(d-1) = 4	MS 15/MS 17	H_0: Interaction effect = 0
a. Linear trend	b-1 = 2	MS 15a /MS 17	H_0: Difference in linear contrast = 0
b. Quadratic trend	b-1 = 2	MS 15b /MS 17	H_0: Difference in quadratic contrast = 0
16. BED	(b-1)(e-1)(d-1) = 12	MS 16/MS 17	H_0: Interaction effect = 0
a. Linear trend	(b-1)(e-1) = 6	MS 16a /MS 17	H_0: Difference in linear contrast = 0
b. Quadratic trend	(b-1)(e-1) = 6	MS 16b /MS 17	H_0: Difference in quadratic contrast = 0
17. Error d	***(s-1)(b-1)(ed-1) = 66***		
18. ABE	(a-1) (b-1)(e-1) = 6	MS 18/MS 21	H_0: Interaction effect = 0
19. ABD	(a-1) (b-1)(d-1) = 4	MS 19/MS 21	H_0: Interaction effect = 0
a. Linear trend	(a-1)(b-1) = 2	MS 19a /MS 21	H_0: Difference in linear contrast = 0
b. Quadratic trend	(a-1)(b-1) = 2	MS 19b /MS 21	H_0: Difference in quadratic contrast = 0
20. ABED	(a-1) (b-1)(e-1)(d-1) = 12	MS 20/MS 21	H_0: Interaction effect = 0
a. Linear trend	(a-1) (b-1)(e-1) = 6	MS 20a /MS 21	H_0: Difference in linear contrast = 0
b. Quadratic trend	(a-1) (b-1)(e-1) = 6	MS 20b /MS 21	H_0: Difference in quadratic contrast = 0
21. Error e	***(s-1)(a-1)(b-1)(ed-1) = 66***		

4.3.6 Experiment IIIc

In Experiment IIIc, the interest is on comparing the impact of soil improvement techniques on germination and early growth of different species. The relevant analysis is shown in Table 15.

Table 15: Hypotheses and ANOVA table for the analysis of Completely Randomised Factorial Design in Experiment IIIc.

Source of variation	Degrees of freedom	F Statistics	Null hypothesis (Levels of B and E are fixed effects)
Total	ber - 1 = 223		
1. B (species)	b-1 = 13	MS 1/MS 4	H_0: $\mu_{\text{species 1}} = \ldots = \mu_{\text{species b}}$
2. E (soil improvement)	e-1 = 3	MS 2/MS 4	H_0: $\mu_{\text{soil improvement 1}} = \mu_{\text{soil improvement e}}$
3. BE	(b-1)(e-1) = 39	MS 3/MS 4	H_0: Interaction effect = 0
4. Error	***be(r-1)= 168***		

4.4 Further statistical analyses in brief

All of the above-mentioned null hypotheses are the simplest ones using a univariate analysis of variance. However, there is an interest in testing multivariate hypotheses and in assessing the changes across the various measurements taken on an individual plant or a species stand over the observation period. Therefore, the above-mentioned hypotheses will be reconstructed according to the statistical analyses performed. These will include univariate and multivariate analyses of variance and covariance as well as repeated-measures analyses of variance. For discrete variables, multivariable analysis of categorical data techniques will be used.

In addition, regression models will be developed to describe, quantify, or predict important relationships between the several study factors and response variables of the different species. Regression analyses will be also preformed to compare regression equations between two response variables for the different combinations of levels of the study factors to precisely quantify differences between these various levels of the study factors. Moreover, collected data during the rotation period will facilitate predicting future development of the plantations until harvest. Finally, an evaluation of all employed treatment levels will be made.

The results of the various analyses will provide reliable information for the composition of recommendations on afforestation in desert lands using sewage water. In addition, data and results will be used in the development of the decision support system for the sustainable management of plantation forests in arid regions with emphasis on the proper application of the sewage water resource.

4.5 Data collection

In order to determine whether the different levels of the treatment combinations have an effect on the development of the new plantations, various response variables of each species (e.g., survival, growth, biomass, vitality, quality, damage) over the rotation period must be studied. Of interest is also the effect of treatments, in particular the application of sewage water, on soil. In addition, there are some experimental conditions, which hardly can be controlled as the initial situation of soil or the topography. These are concomitant variables which will be measured. Table 16 shows the programme for the data collection within the experiments I, II, and III. A part of the data collection for Experiment IV is indicated in Table 17.

Table 16: Data collection in Experiment I, II, and III

Measurement	*Time of measurement*	*Sample*	*Sample size*
Chemical and bacteriological analysis of sewage water	Once monthly in the second year and from the third year onwards 4 times yearly	Site	

Measurement	*Time of measurement*	*Sample*	*Sample size*
Site characteristics:			
Elevation	At the begin of the experiment	Plot	Elevation at the plot centre
Steepness of slope		Plot	5 systematically distributed samples on each plot
Dominating micro relief classes		Subunit treatment in Experiment I and III and cell in Experiment II	1 sample units of 4m^2 in the centre of each subunit treatment and 5 systematically distributed sample units of 4m^2/cell
Soil characteristics including:			
soil type (only at the begin of the experiment),	At the begin of the experiment, at the first year, and then each two years	Plot	1 soil profile/plot
humus form, thickness of AH-horizon, pH,		Subunit treatment in Experiment IIIa and cell in Experiment II	1 sample units in the centre of each subunit treatment and 5 systematically distributed sample units per cell
chemical characterisation		Subunit treatment in Experiment IIIa and cell in Experiment II	One mixed soil sample collected from the above selected samples
Vitality[1], quality[2], damage[3], root development[4], total height, root collar diameter, above-ground and underground biomass	Prior to planting	Species	20 randomly selected seedlings per species
Survival, Vitality[1], quality[2], damage[3], total height, and root collar diameter	Weekly at the start year of Experiment IIIc	Experimental unit in Experiment IIIc	All seedlings/experimental unit in Experiment IIIc
Vitality[1], quality[2], damage[3], total height, root collar diameter, and DBH for those plants higher than 1.3m	At the begin of the experiment	Experimental unit or cell	All seedlings/cell or experimental unit in Experiment I and III all seedlings/inner plot in Experiment II

Measurement	*Time of measurement*	*Sample*	*Sample size*
Number of survived individuals	At the end of each growing season	Experimental unit or cell	All individuals/cell or experimental unit in Experiment I and III, and all individuals/ inner plot in Experiment II
Vitality[1], quality[2], damage[3], total height, height increment, root collar diameter, and DBH	At the end of each growing season till a species attains an average DBH of 5 cm	Experimental unit or cell	All individuals/cell or experimental unit in Experiment I and III, and all individuals/ inner plot in Experiment II
Vitality[1], quality[2], damage[3], total height, annual height increment, root collar diameter, DBH, crown development, root development[4], above-ground and underground biomass on harvested individuals with roots	At the end of the first and second growing season, then at the end of each second growing season till a species attains an average DBH of 5 cm	Harvested individuals with roots	1 randomly selected individual/ cell or experimental unit in Experiment I and III
			5 randomly selected individuals/ buffer zone of a cell in Experiment II
Characterisation of the mature stand: vitality[1], quality[2, 2a], damage[3], social class, and DBH of each individual; height, crown height, crown width of selected individuals; and on the stand level density, basal area, and volume	At the time when a species attains an average DBH greater than 5 cm and at the end of each growing season	Experimental unit or cell	All individuals/cell or experimental unit in Experiment I and III, and all individuals/ inner and selected individuals of the different social classes/ inner plot in Experiment II
Foliage analysis	Once annually in summer or autumn, depending on the nature of species	Foliage from the current seasons growth on secondary branches at the upper third of the crown	2 randomly selected individual/ subunit treatment in each cell in Experiment I
			5 randomly selected individuals/ buffer zone in Experiment II
Biomass of removed individuals from mature stands	During the implementation of the silvicultural treatments on mature stands	Species in Experiment II	9 selected individuals of different social classes/species/ site

Measurement	Time of measurement	Sample	Sample size
Water use efficiency of regeneration plants	Once annually	Subunit treatment in Experiment I, IIIa, IIIb, and IIIc, where IIIc is measured only once, half year after seed germination.	3 randomly selected individual/ subunit treatment in each cell

[1]Three levels of vitality: vigorous (healthy, densely foliated), moderate (reasonably healthy, fairly foliated), and weak (unhealthy or poorly foliated).

[2]Three levels of quality: high (straight trunk, free of fork, and well formed crown), satisfactory (slightly crooked central leader, slightly forked, and/or fairly formed crown), and unsatisfactory (sharply crooked leader, strongly forked, or badly formed crown).

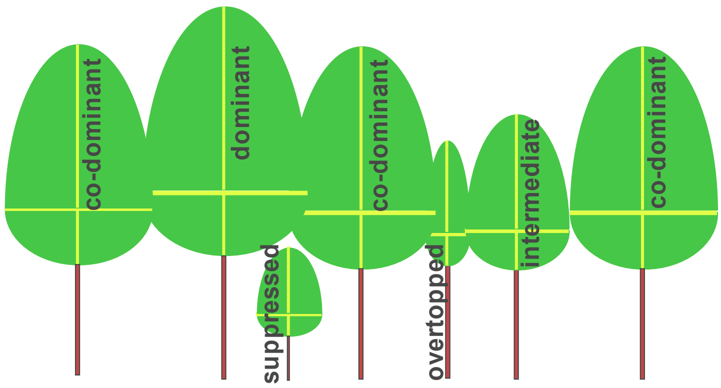
[2a]Beside diameter, height, branch-free bole, crown ratio, and slenderness, the following quality criteria are determined: height and diameter of the thickest live and the thickest dead branches, stem form or crookedness (deviation from the vertical in cm and as an angle), and fork (height and diameter).

[3]Three levels of damage degree: undamaged, slightly damaged, and severely damaged. In addition, damage type is classified in five levels: abiotic, biotic, anthropogenic, unknown, und due to intervention (this is relevant after conducting silvicultural operations). For the mature stand, three categories distinguishing where the damage took place (crown, stem, or root) are determined.

The assessment of the root development will be based on the depth and width of the root crown, the depth of the primary root, the shape of the primary root (straight or bent), and the existence of circling or girdling roots (yes or no), and how well is the root system (well rooted or poorly rooted).

Table 17: Data collection in Experiment IV

Measurement	Description
Site/location	
Species	
Plot No.	
No. of subplot	
Average distance between two rows	
Average distance between two trees in a row	
Age of stand	
Serial tree number	
Previous treatment	Number, date, and type of operations
Bifurcation or number of stems	single tree or tree is bifurcated (set number of stems)
	Fork: the main trunk is split into two or more parts at the lower one third of the tree height, and where the diameter of the fork is at least over 20% of the diameter of the main trunk.
Vitality	vigorous (healthy, densely foliated), moderate (reasonably healthy, fairly foliated), weak (unhealthy or poorly foliated)

Measurement	*Description*
Quality	high (straight trunk, free of fork, and well formed crown); satisfactory (slightly crooked central leader, slightly forked, and/or fairly formed crown); unsatisfactory (sharply crooked leader, strongly forked, or badly formed crown)
Damage degree	undamaged, slightly, severely damaged
Type of damage	abiotic, biotic, anthropogenic, due to intervention, unknown
Location of Damage	crown, stem, root
Stem form or crookedness class	straight, slightly crooked, strongly crooked
	Crookedness: A tree is considered crooked, if a deviation from straight bole form is apparent at the lower tree bole (a bend take place in less than 6 m and lower or at the lower one third of the tree height).
Crown class or social class (Kraft)	dominant, co-dominant, intermediate, overtopped, totally suppressed
Crown overlapping class	0-25%, 25-50%, or ≥50 of the crown is overlapped
DBH	
Diameter at 50% of total height	
Total height	
Crown base (base of the first live branch)	
Base of the largest fork	
Base of the largest crookedness	
Base of the thickest live branch	
Base of the thickest dead branch	
Diameter of the thickest live branch	
Diameter of the thickest dead branch	
Largest deviation from the vertical in a crooked tree	
Crown radius in 8 directions	

5 Outlook

Based on the collected data, the results of all experiments and the gained scientific knowledge, a set of recommendations on afforestation in arid regions using sewage water will be composed and provided to forest officials, managers, consultants, national and international organisations to support them in their decision making in the choice of species, in selecting the appropriate techniques in establishing and managing the plantations towards sustained production of forest produces. Modern information technologies will be employed for the delivery of required information and knowledge as well as the application of decision supporting procedures.

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Notes

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