Technische Universität München
TUM School of Life Sciences

Silvicultural Experiments on Afforestation

Examples from Germany, China and Egypt

Hany A. M. El Kateb

Vollständiger Abdruck der von der TUM School of Life Sciences der Technischen Universität München zur Erlangung des akademischen Grades eines

Doktors der Forstwissenschaften (Dr. rer. silv.)

genehmigten Dissertation.

Vorsitzender: Prof. Dr. Rupert Seidl

Prüfer der Dissertation:

1. Prof. Dr. Dr. Reinhard Mosandl
2. Prof. Dr. Thomas Knoke

Die Dissertation wurde am 24.03.2022 bei der Technischen Universität München eingereicht und durch die TUM School of Life Sciences am 08.07.2022 angenommen.

Scientific Publications

The cumulative study is based on the below publications at different locations:

I. An example from the Ore Mountains, Germany: El Kateb H., Benabdellah B., Ammer Ch., Mosandl R. (2004). Reforestation with native tree species using site preparation techniques for the restoration of woodlands degraded by air pollution in the Erzgebirge, Germany. Eur. J. Forest Res. 123, 117-126.

II. Examples from Southern Shaanxi Province, China

IIa. El Kateb H., Felbermeier B., Zhang P., Peng H., Zhang H., Summa J., Wang X., Mosandl R. (2009). Rehabilitation of degraded land ecosystems in Southern Shaanxi Province: An introduction to a Sino-German project (pp. 202-214). ERSEC Conference Proceeding, Sustainable Land Use and Water Management, International Conference, Beijing.

IIb. El Kateb H., Zhang Hf., Zhang Pc., Mosandl R. (2013). Soil erosion and surface runoff on different vegetation covers and slope gradients: A field experiment in Southern Shaanxi Province, China. Catena, 105, 1-10.

IIc. Summa J., El Kateb H., Felbermeier B., Zhang P., Mosandl R. (2010). Introduction to a Study on Afforestation by Native Tree Species in the Southern Shaanxi Province. Journal of Yangtze River Scientific Research Institute, 27(11), 75-80.

III. Examples from desert lands, Egypt

IIIa. El Kateb H., El-Gindy A., Stimm B., Settawy A., Zhang H., Abd-Elwaheb A., Felbermeier B., Hassan H., Hassan N., Khamis S., Abd-Elbaky M., Weber M., El Hakim M., Mosandl R. (2015). German-Egyptian Collaboration to Afforestation in Desert Lands of Egypt: Information Summary and Description of the Field Experiments. In Mosandl R., Felbermeier B., El Kateb H. (Eds.). Silvicultural Experiments, No. 4 (pp. 1-36), Karl Gayer Institute.

IIIb. El Kateb H., Zhang H., Abdallah Z. (2022). Volume, biomass, carbon sequestration and potential of desert lands' afforestation irrigated by wastewater on examples of three species. Forest Ecology and Management, 504, Article 119827.

The cornerstone of the cumulative study is on the three publications in bold, for which a more detailed description is given in the present study. The author's contribution to the publications was in the project conception and construction of the experimental designs, in supervision of field work and data collection, in the data and statistical analyses and in the compilation, writing, and revising the manuscripts for the publications. These apply to all publications mentioned above with the exception of Publ. I (El Kateb et al. 2004), in which the author did not participate in the project conception and construction of the experimental design. A detailed description of the contribution of each author to the core publications is presented below.

Contributions of authors in the core publications

Brief description of the publication and its *contribution to the dissertation*	Contribution of each author
I: El Kateb H., Benabdellah B., Ammer Ch., Mosandl R. (2004). Reforestation with native tree species using site preparation techniques for the restoration of woodlands degraded by air pollution in the Erzgebirge, Germany. Eur. J. Forest Res. 123, 117-126.	
Due to large-scale deforestation caused by severe air pollution in the Ore Mountains, a silvicultural experiment was conducted to assess the success of reforestation with native tree species. In a split-plot factorial design, three species were studied under two levels of protection against game browsing and eight levels of site preparation techniques including control and seven amelioration techniques (soil cultivation, weed control, liming, and their combinations). Repeated-measures analysis of variance was performed to examine the development of the young plantations over an observation period of seven years. *This silvicultural experiment demonstrated the advantages of long-term observation in assessing the development of young plantations and the importance of scientifically testing the adequacy of techniques before large-scale application*.	*El Kateb*: Data analyses, statistical analyses, as well as compilation, writing and revising the manuscript. *Benabdellah*: Field work and data collection. *Ammer*: Field work, data collection, and revising the manuscript. *Mosandl*: Project conception, supervision of field work and data collection, revising the manuscript, preparation and submission of the project application.
IIb. El Kateb H., Zhang Hf., Zhang Pc., Mosandl R. (2013). Soil erosion and surface runoff on different vegetation covers and slope gradients: A field experiment in Southern Shaanxi Province, China. Catena, 105, 1-10.	
Due to deforestation and inappropriate land use over decades, the south of the Shaanxi Province suffered from high soil loss and rising natural disasters with considerably shorter intervals. An erosion experiment was carried out to determine and compare soil loss and surface runoff generated from the dominating five rural land-uses at three different levels of slope gradient. Small erosion plots of 7 m^2 in size were used for the collection of the runoff and soil loss after each rainfall event on 33 randomly selected experimental units of the combination “land use and slope gradient”. *This experiment showed that forestlands are the most effective rural land-use to reduce soil erosion. Even at steep slops, forestlands generate negligible amount of soil loss. These results may lead to increased efforts to encourage afforestation activities.*	*El Kateb*: Project conception, construction of the experimental designs, identification and selection of the experimental units, supervision of field work and data collection, data analyses, statistical analyses, compilation, writing and revising the manuscript, significant contribution to the preparation of the project application, organisational and project management activities, conducting and participating in international workshops in Germany and abroad. *Zhang H.*: Field work, data collection, support in literature survey, revising the manuscript, and support in organisational and project management activities. *Zhang Pc.*: Chinese project partner that makes access to research area possible. *Mosandl*: Revising the manuscript, submission of project application, and leading the organisational and project management activities
IIIb. El Kateb H., Zhang H., Abdallah Z. (2022). Volume, biomass, carbon sequestration and potential of desert lands’ afforestation irrigated by wastewater on examples of three species. Forest Ecology and Management, 504, Article 119827.	
An experiment was carried out to estimate the potential of young forest plantations afforested in desert lands and irrigated by primary-treated sewage water. Trees of three different species were felled to determine the form factor and stem volume, as well as the biomass and carbon sequestration of stem, crown and root of the individual trees. In addition, a scenario for the development of un-thinned stands up to the age of 35 years was constructed. *This experiment demonstrated that afforestation in desert lands presents a unique situation in forestry, as growth is stimulated by sufficient sunlight and nutrient-rich waste-water. Competition for water and nutrients is strongly diminished. Tree maturity span is curtailed. These open new possibilities for different forest management and practices towards resilient forest-based mitigation of climate change. This in turn shows the importance of promoting such afforestation activities in desert lands for its unexpected role as an effective mitigation measure.*	*El Kateb*: Project conception, construction of the experimental designs, supervision of field work and data collection, data analyses, statistical analyses, compilation, writing and revising the manuscript, significant contribution to the preparation of the project application, leading the organisational and project management activities, conducting and participating in international workshops in Germany and abroad. *Zhang*: Field work, data collection, and revising the manuscript. *Abdallah*: Field work and data collection.

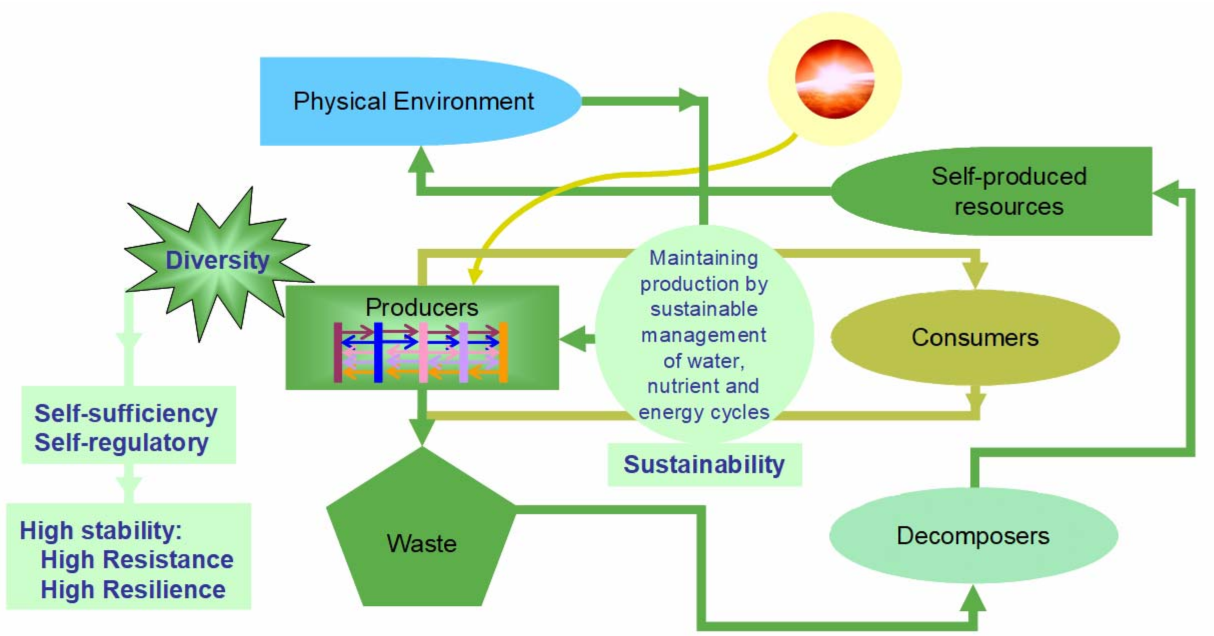
All of the above mentioned silvicultural experiments laid emphases on gaining reliable information to provide recommendations based on scientific knowledge. These help to minimise risks associated with afforestation initiatives and thus the success of such initiatives.

Table of contents

Foreword

Our world is facing many challenges that extend from Climate change and decline in biodiversity to food, water and energy shortages for an ever-increasing world population.

The cause of our problems is mainly man-made. Although human beings are resource dependent, they are inappropriately managing their resources in emissions-intensive economy by achieving a short-term benefit while causing pollution and degradation to the environment.



Through photosynthesis and take up inorganic nutrients, biomass is produced by the producers [plant community] under a specific physical environment [climate, soil, topography, water supply], providing food for consumers [herbivores, their predators]. Organic nutrients is generated by mortality [producers and consumers], while inorganic nutrients by mineralisation [decomposers (microbes (bacteria, fungi), microfauna, mesofauna, macrofauna) and consumers].¶

Figure 1: Management of resources in an agro-ecosystem, simplified

In contrast, nature manages itself in a sustainable way in diverse ecosystems (e.g., desert, savannah, forest, marine or wetland). An ecosystem is simply an environment in a particular area, which embraces the physical elements, living organisms (flora und fauna), and non-living organisms. An ecosystem is almost self-sufficient. The different elements of an ecosystem interact with each other, and at the same time each organism has its role in supporting another. The intake or consumption of an organism is associated with “waste” production that is consumed by another organism. Ecosystems without a negative anthropogenic impact are characterised by high stability in terms of resistance (e.g., weather, pest, and disease resistance) and resilience (recoverability after disturbance or elasticity to disturbance). In an ecosystem (cf. Figure 1), nature follows a strategy based on retaining the quality of the physical elements and the biodiversity of the flora and fauna, while maintaining the production by managing the energy, water, and nutrient cycles. Although ecosystems are dynamic, as the living organisms grow over time and die, while the non-living elements change, they remain stable and are self-regulatory.

Human beings are a relatively new element to the ecosystems. For thousands of years and in many cultures, people were able to be a part of the ecosystem, following nature's rules. With the industrial revolution, the rate of consumption of the resources has dramatically increased whereas human beings became less aware of nature's rules.

Due to the problems the world is facing today, human beings are obliged to find solutions. One crucial solution is to return to nature and understand it. Having the appropriate knowledge and technology, we can imitate Nature. Taking the rainforest as a paradigm, we can establish systems with high species diversity that are stable, and to a large extent self-sufficient and self-regulatory. The objective of such systems is to manage the resources in a sustainable way using environment friendly techniques. These are of high significance for the establishment of new forests through afforestation and reforestation activities. Forests are carbon sinks. Afforestation and reforestation can reduce the impact of the climate change. Climate change should be an opportunity for afforestation initiatives that build new plantation forests having high stability in terms of high resistance and high resilience. This poses a challenge for the forest scientists, who should establish examples for the afforestation that demonstrate suitable solutions to tackle challenges.

Acknowledgements

It is my pleasure to express my apperception to Prof. Dr. Dr. Reinhard Mosandl for his suggestions and thoughtful comments. I am indebted to Prof. Dr. Thomas Knoke for his valuable support. I am also very grateful to many colleagues and students for their helpful comments and intensive field works inside and outside Germany.

1. Introduction

Gayer (1891) stated that „*Alles waldbauliche Wirken muss auf naturgesetzliches Denken begründet sein" [*All silvicultural activities must be based on thinking of laws of nature (translation by the author)]."

Burschel & Huss (1997) described the task of silviculture as follow: „*Aufgabe des Waldbaus ist es, die Pflanzenformation Wald so zu gestalten, dass ihre biologischen Eigenarten erhalten bleiben, aber dem Menschen auf nachhaltige Weise nutzbar werden. Das gilt insbesondere für die Fähigkeit des Waldes zur Produktion großer und wertvoller Holzmengen. Der Waldbau hat eine naturwissenschaftliche Grundlage, ist aber ein Fach, das seinem Sinn aus der Anwendung zieht*". [The task of the Silviculture is to arrange the formations of plants in a way that maintains their biological characteristics, but can be provided to human beings for sustained use. This is especially true for the forest's ability to produce large volume and valuable timber. Silviculture has a natural scientific basis, but is a subject that draws its meaning from the application (translation by the author)].

According to Smith et al. (1996), "Silviculture is designed to create and maintain the kind of forest that will best fulfil the objectives of the owner and the governing society."

Mosandl et al. (2003) understand silviculture "As a modern forest ecological management-system that requires the integration of the following components in science and practice. On the basis of the ecological conditions and according to the technological possibilities, forest ecological systems must be managed in such a way that the various requirements of the society are best achieved in compliance with the economic principles. These elements must be considered everywhere in the world, if it concerns to develop appropriate forest management-systems. Likewise, for the determination of the effect of silvicultural measures in scientific researches, world-wide, the assumptions associated with the experiments and with the statistical analyses must be fulfilled. Only so, reliable information can in rational way be gained and precise statements about the complex mechanisms of forests be made."

The presented publications deal with afforestation under special and difficult environment: In the severe air-polluted Ore Mountains, Germany, in degraded lands characterised by high soil erosion in the Southern Shaanxi Province, China and in arid climate in the desert lands of Egypt where water resources are scarce. For all the three locations there was no sufficient knowledge that is based on scientific researches to support the execution of appropriate measures. The presented publications are at different geographical locations, but all are based on the description of silviculture by Mosandl et al. (2003), where emphases were laid on gaining reliable information that supports achieving the objectives of the studies.

The presented examples deal with the afforestation and reforestation, as deforestation, which is contributing to the production of greenhouse gas emissions and loss of biodiversity, is ongoing. The increase of the atmospheric carbon dioxide (CO_2) above the pre-industrial levels in 1750 from 277 ppm to 407.38±0.1 ppm in 2018 was, primarily caused by the release of carbon to the atmosphere from deforestation and other land use change activities (Friedlingstein et al. 2019). According to FAO and UNEP (2020), “The net loss of forest area has decreased substantially since 1990, but deforestation and forest degradation continue to take place at alarming rates resulting in significant loss of biodiversity. … Between 2015 and 2020, the rate of deforestation was estimated at 10 million hectares per year, down from 16 million hectares per year in the 1990s. The area of primary forest worldwide has decreased by over 80 million hectares since 1990.”

“Afforestation, reforestation and avoidance of deforestation are recognized as methods for reducing anthropogenic global warming by the United Nations Framework Convention on Climate Change” (Betts 2011). According to Mildrexler et al. (2020) “Forest carbon accumulation is crucial for mitigating ongoing climatic change”. “Forests present a significant global carbon stock accumulated through growth of trees and an increase in soil carbon” (UNFCCC 2019). According to Betts (2011) “Forests affect climate not only by taking up carbon, but also by absorbing solar radiation and enhancing evaporation. In the tropics, the climate benefit of afforestation may be nearly double that expected from carbon budgets alone”. Based on 91 publications covering different countries and climate zones, Guo et al. (2021) reveal that the afforestation significantly increased soil organic carbon and total nitrogen stocks in soils.

According to Bastin et al. (2019), “photosynthetic carbon capture by trees is likely to be among our most effective strategies to limit the rise of CO_2 concentrations across the globe”. Kreidenweis et al. (2016) confirm that afforestation offers a high potential for carbon dioxide removal and that it is a comparatively low-cost option to sequester carbon. In addition to the important role of the afforestation in the climate change mitigation, there are also economic benefits of the other ecosystem services provided by the afforestation (e.g., wood, food and fodder production, enhancing air quality, water purification, erosion control, raising biodiversity, recreation and aesthetic value).

2. I. An example from the Ore Mountains, Germany

The below description is based on the publication of El Kateb et al. (2004).

2.1. Introduction

Large-scale deforestation has been caused by severe air pollution in the Erzgebirge ('Ore Mountains') in the eastern part of Germany. According to Šrámek et al. (2008), "Sulphur dioxide, produced mainly by coal power plants and the chemical industry, caused extensive decay of forests in the upper part of the Ore Mountains during the 1970s and 1980s. Dying trees were felled on more than 40,000 ha. Stands of mainly substitute tree species, considered to be more resistant to air pollution, were established on these locations. With the desulphurization of the main pollution sources and the decrease in industrial production, pollution significantly diminished during the 1990s. Nevertheless, even in the second half of the 1990s, distinctive damage to substitute forests was observed." A research project was established (cf. Mosandl et al. 1994) to contribute to the derivation of a scientifically founded strategy for rehabilitation of the degraded forest conversion. The overall objective of this project is to assess the success of the reforestation with native tree species by 1) examining whether the young native species plantations have been changed in size over an investigation period of seven years and 2) whether these changes were depending on the experimental factors including protection against game browsing and various amelioration techniques (soil cultivation, liming, weed control, and their combinations).

2.2. Methodology

The study site is located near Altenberg (Saxony, south-east Germany) 880 m above sea level. The annual precipitation averages 1,100 mm and the mean annual temperature is 4.5°C. Winds and storms are frequent. Soils can be classified as skeletal rhyolite-podsols, underlying the natural forest association of Calamagrostio-villosae-Piceetum (Oberdorfer 1992). The pH- (KCl) increases with increasing depth (3.2 at the top 10 cm depth and 4.1 at 30-60 cm depth).

In 1994 an experiment was initiated to investigate the success of reforestation of the deforested woodlands in the Erzgebirge. Three species were employed: The dominant native species Norway spruce (Picea abies [L.] Karst) and two typical species for the early successional phase: Rowanberry (Sorbus aucuparia L.) and Birch (Betula pendula Roth).

The layout of the experiment is a split-plot factorial design with the sub-subunit levels of treatment arranged in strips. The experiment contained two blocks. Each block is divided into two levels of protection against game browsing in a fenced and an unfenced plot. Each plot (Figure 2.1) was subdivided into three subplots, representing the three species. Eight levels of treatment (amelioration techniques) were arranged in strips (Table 2.1 and Figure 2.1) across each subplot in eight sub-subplots. Each sub-subplot has a size of 100 m^2, on which 75 individuals were planted in the spring of 1994. The seedlings were five, two and one year old for Norway spruce, rowanberry and birch, respectively. They had an average initial height of 37, 84, and 32 cm, and an initial root collar diameter of 7, 8, and 3 mm for spruce, rowanberry, and birch, respectively.

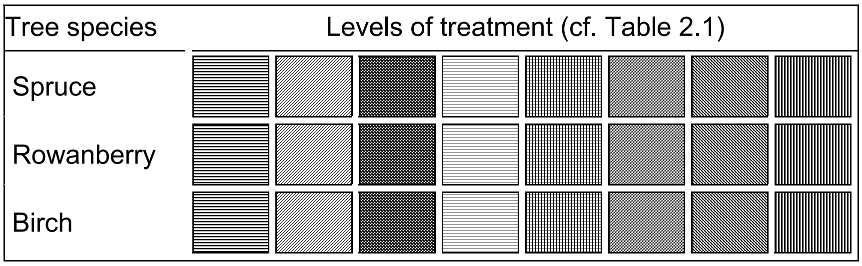


Figure 2.1: Design of a plot showing the strip arrangement

Table 2.1: Levels of the treatment (amelioration techniques) in the eight sub-subplots

Levels of treatment	Description
a) Control	no treatment
b) Soil cultivation	Furrow ploughed every 2 m
c) Liming	liming with $CaMg(CO_3)_2$: 3,000 kg/ha per sub-subplot and an additional 500 g per seedling
d) Weed control	between 1994 and 1997, yearly scything between seedlings
e) Soil cultivation + liming	combination of the treatment levels b and c
f) Soil cultivation + weed control	combination of the treatment levels b and d
g) Liming + weed control	combination of the treatment levels c and d
h) Soil cultivation + liming + weed control	combination of the treatment levels b, c and d

Data for each individual including survival, total height (cm), and root collar diameter (mm) was collected at the end of the growing seasons 1994, 1995, 1996, 1997, and 2000. Volume index (root collar diameter^2 x total height) for each individual was calculated. The sum of the volume index for all individuals within a sub-subplot (m^3 ha^{-1}) were estimated as an expression of the aboveground biomass and will subsequently be designated as a production index. At the end of the seventh growing season in 2000, the vitality status was registered for each surviving seedling.

Repeated-measures analyses of variance (Bortz 1985, Kirk 1995, Littell et al. 1991) were performed to (i) examine the changes in the survival rate, arithmetic mean of the total height, arithmetic mean of the root collar diameter, and production index over the observation period, and (ii) to test if these changes depend on the experimental factors (time (1994-2000), fencing, tree species, treatment, and their interactions). Both univariate and multivariate repeated-measures analyses of variance were conducted. For univariate tests of hypotheses for the within-groups effects, the sphericity condition (cf. Kirk 1995) was examined and accordingly adjusted (cf. Littell et al. 1991 and Huynh and Feldt 1970 in SAS Institute Inc. 1989). In order to minimise correlation between means and variances of the data, the following transformations were undertaken: Inverse sine transformation for the survival rate ($2 \sin^{-1} \text{survival rate}^{1/2}$), and logarithmic transformation for the production index.

Based on the results of the repeated-measures analyses, polynomial curves (cf. Figure 2.2) indicating the arithmetic means of the sub-subplot over the observation period were plotted. Not every level of treatment was plotted separately. For simplicity, one polynomial curve was plotted for all levels of treatment that were not significantly different from the control group at 5% level of significance. Otherwise, a curve that obviously deviated from the course of the others was plotted separately, even if there was no indication from the test of hypothesis that the effect of the associated treatment level was significant.

2.3. Results

Results of the univariate tests of hypotheses according to the repeated-measures analysis of variance (Table 2.2) showed that the time factor was significant ($p < 0.0001$), indicating that survival, growth, and production had changed during the observation period (Figure 2.2). These changes were mainly dependent on the tree species factor ($p < 0.0001$) and to a lesser degree on the treatment factor and the interaction tree species*treatment.

Table 2.2: Summary of results of the univariate tests of hypotheses according to repeated-measures analysis of variance (the probabilities for the total height and root collar diameter are adjusted).

Source of variation	Degrees of freedom (df)	Probability > F			
		Survival rate	Total height	Root collar diameter	Production index
Total	384				
Time	4	0.0001***	0.0001***	0.0001***	0.0001***
time*block	4	0.5438	0.8908	0.7405	0.7007
time*fencing	4	0.7165	0.8500	0.9764	0.9756
time*block*fencing (error a)	4				
time*tree species	8	0.0001***	0.0001***	0.0001***	0.0001***
time*contrast a [contrast a= spruce vs rowan and birch]	4	0.0001***	0.0001***	0.0001***	0.0001***
time*contrast b [contrast b= rowan vs birch]	4	0.0007***	0.0001***	0.0001***	0.0001***
time*block*tree species (error b)	8				
time*fencing*tree species	8	0.1573	0.9771	0.7711	0.7100
time*block*fencing*tree species (error c)	8				
time*treatment	28	0.0003***	0.0002***	0.0008***	0.0008***
time*block*treatment (error d)	28				
time*fencing*treatment	28	0.3668	0.4163	0.5702	0.8121
time*block*fencing*treatment (error e)	28				
time*tree species*treatment	56	0.0005***	0.0001***	0.0002***	0.0001***
time*block*tree species*treatment (error f)	56				
time*fencing*tree species*treatment	56	0.0902	0.3303	0.8356	0.3865
time*block*fencing*tree species*treatment (error g)	56				

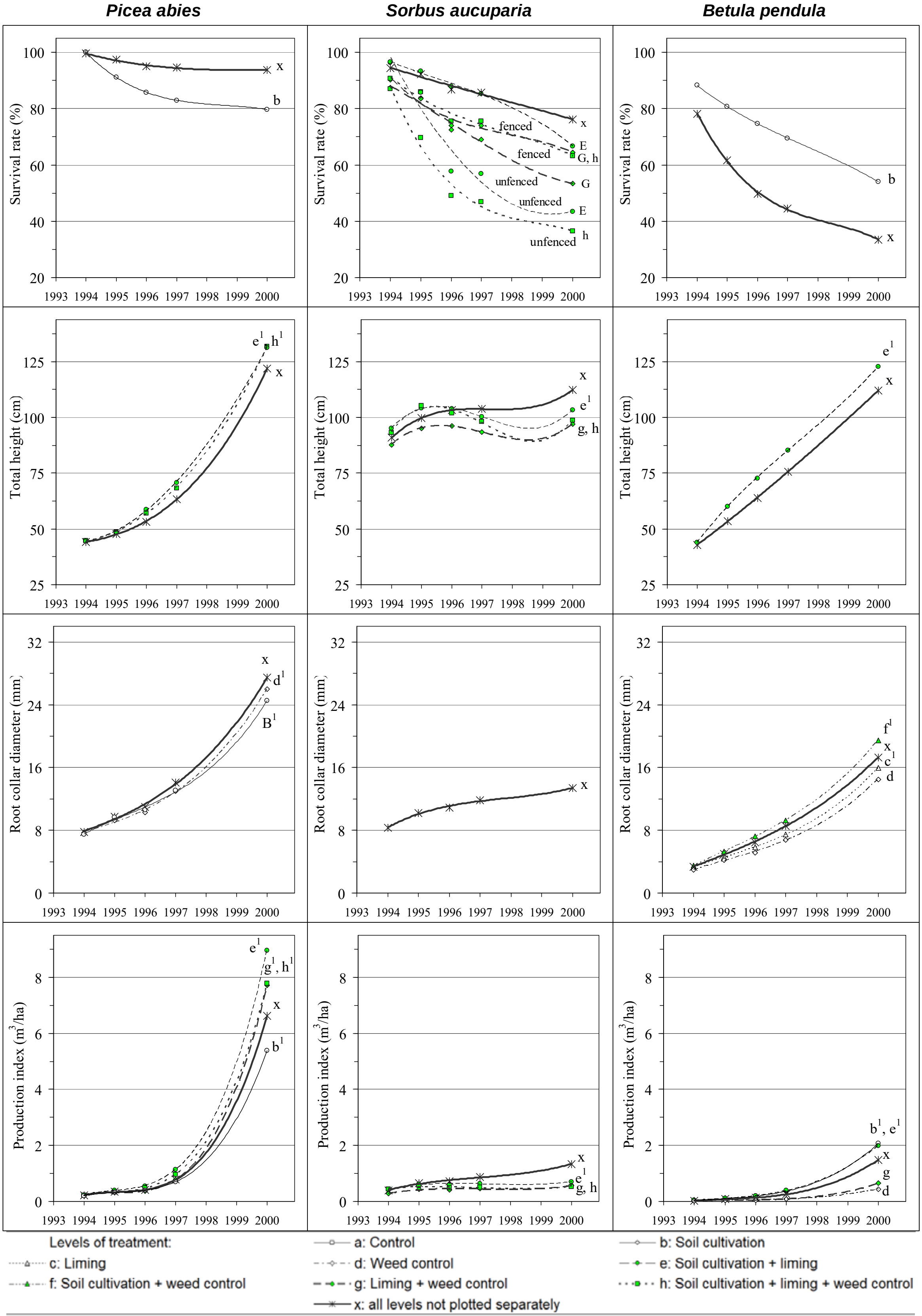


Figure 2.2: Development of spruce, rowanberry, and birch within the observation period 1994-2000. [1] Denotes a treatment level that had an effect on only a part of the units of a block and fencing combination. Capital letter indicates that the effect of a treatment level was not statistically significant.

Fencing had no significant effect on any of the investigated variables: All source of variations that take account of fencing in the multivariate analyses were statistically insignificant.

After seven years of observation, spruce showed high survival rate and reasonable growth and biomass production (Figure 2.2). Birch responded similar to spruce but with less survival rate. Rowan, on the other hand, showed low survival rate and unsatisfactory growth as well as production capacity.

The effect of the amelioration techniques was contrasting. Negative effects on all tree species were only indicated when techniques including weed control were employed. Furthermore, soil cultivation increased the mortality rate of spruce and negatively influenced the production capacity. On the other hand, positive effects were only detected for spruce and birch: Techniques, which include liming, had a positive effect on the height growth of spruce, and those include soil cultivation had a positive effect on birch. These effects were particularly obvious for the production index (Figure 2.2).

Table 2.3: Status of vitality of surviving individuals after seven growing seasons (V1 = vigorous (healthy, densely foliated, and not, or only slightly damaged), V2 = moderate vitality (reasonably healthy, fairly foliated, and/or moderately damaged), V3 = weak (unhealthy, poorly foliated, and/or severely damaged))

Fencing and Treatment	Spruce				Rowanberry				Birch			
	N	Vitality status in %			N	Vitality status in %			N	Vitality status in %		
Fencing		V1	V2	V3		V1	V2	V3		V1	V2	V3
Fenced (Total)	1,039	63	25	12	734	9	21	70	414	57	21	22
Unfenced (Total)	1,029	46	36	18	658	5	18	77	417	49	28	23
Treatment		V1	V2	V3		V1	V2	V3		V1	V2	V3
Control	277	57	33	10	187	12	22	66	103	61	14	25
soil cultivation	229	44	31	25	189	12	27	61	162	51	34	15
Liming	272	52	35	13	189	6	14	80	102	41	29	30
weed control (weed)	278	57	34	9	208	2	21	77	54	43	24	33
soil cultivation + liming	274	58	24	18	137	7	13	80	148	53	21	26
soil cultivation + weed	228	54	26	20	219	9	26	65	96	57	28	15
liming + weed control	260	54	34	12	131	3	12	85	60	57	25	18
soil culti. + liming + weed	250	59	25	16	132	4	14	82	106	57	20	23
Total	2,068	55	30	15	1,392	7	19	74	831	53	25	22

The vitality status after seven growing seasons is illustrated in Table 2.3. None of the treatment levels (amelioration techniques) improved the vitality of the seedlings in comparison to the control group. Rowanberry with 7%, had the lowest percentage of vigorous individuals compared, to over 50% for spruce and birch. There was no evidence that fencing affected the vitality of the plants.

2.4. Discussion

Repeated measure analysis was performed to achieve the objectives of the study: Assessing the success of reforestation of severe air polluted area after seven years of observations using different amelioration techniques. However the experiment was laid out with insufficient number of replications, which did not support testing all possible multivariate hypotheses of interest. Fortunately, performing both the univariate as well as the multivariate repeated-measures analyses of variance could help interpreting the results. In addition, the layout of the experiment in strip arrangement was favourable in reducing the cost of the experiment. On the other hand, the design sacrifices precision on the main effects and provide higher precision on the interactions (Cochran and Cox 1992). In general, such a design can not be recommended, as it requires separate estimates of the error variances for each main factor and each interaction leading to small degrees of freedom for estimating the error variances of the main factors.

Results suggest that native species can be used in restoring woodlands formerly damaged by air pollution. Spruce, the dominant native tree species of the former stands, showed seven years after planting sound growth development and good individual vitality under the given environmental conditions in the study site. This was also valid for birch, as this tree species is able to colonise clear-felled areas quickly and effectively (Ellenberg 1982). According to Fiedler et al. (1973), this early successional species has proven to grow on anthropogenic altered soils, due to its low nutrient demands. The high mortality rate of birch was most probably attributed to the small initial size of the one-year-old seedlings, which had been at severe competition with the lush ground vegetation. Distinctly different from spruce and birch, the growth of rowanberry on the cleared area was completely hindered by severe mouse damage. Since a large mouse population is very common on cleared areas (Binder 1994), afforestation of such areas known to be susceptible to rodent damage is only recommended, if the rodent population is strictly controlled.

Results of the repeated measure analysis showed that protecting regeneration against game browsing by fencing in the study site was insignificant. Different from many other studies (e.g., Ammer 1996, Gill 1992, Gill and Beardall 2001), the density of game population was obviously not high to hinder the regeneration development. Nevertheless, the mortality rate of the rowanberry was higher in the unfenced than in the fenced plots (Figure 2.2). However, game browsing was not the main reason for the continuous disturbance of the development of rowan. This was due to the mice damage during the winters that was recognised by the debarked shoots at ground level (cf. Schwenke 1981). Whether in the fenced or unfenced plots, rowan shoots, which protruded above the snow cover, were clipped. This severely impeded the growth in height and diameter of rowanberry (Figure 2.2).

As damage to rowanberry was not only caused by game animals but rather by mice, only slight differences between the fenced and unfenced plots in the three vitality categories could be detected (Table 2.3). Differences between the fenced and the unfenced plots were more obvious for the vigorous seedlings of spruce and birch. However, this was not so dramatic as to be of any practical usefulness.

Results clearly revealed that none of the amelioration techniques had a substantial effect on survival, growth, production, or vitality of the three species under observation. Accordingly, a specific site preparation technique cannot be recommended in the study area for any of the three tree species. However, there was a strong indication that the production index, as an expression of the aboveground biomass, was improved when liming was employed for spruce, and soil cultivation for birch. The increased biomass of spruce due to liming could be a result of the improved base cation supply and increased mineralisation by an enhanced microbial activity (cf. Kreutzer 1995). Soil cultivation and weed control were employed to ameliorate the conditions for survival and early growth of the plantings through, inter alia, the control of competing ground vegetation: At the beginning of the experiment, the ground vegetation covered 95% of the study area with 30 species; *Calamagrostis villosa* dominated with 50% cover, followed by *Avenella flexuosa* with 31%. Ground vegetation affects the competitive ability of seedlings (Wagner and Radosevich 1991). Many studies reported that competition by ground vegetation, mainly grasses, reduces survival and diminishes growth of seedlings (Cole and Newton 1987, Elliott and White 1987, Kolb and Steiner 1990, Caldwell et al. 1995). Soil cultivation considerably decreased the cover of competing ground vegetation (two years after planting, the cover of ground vegetation reached an average of 96% in the non-cultivated sub-subplots compared to 71% in the cultivated sub-subplots; the reduction of coverage particularly affected *Avenella flexuosa* and *Vaccinium myrtillus*). This explains the positive response of the initially small birch seedlings on techniques including soil cultivation. On the other hand, partial water logging occurred in the cultivated plots due to soil compaction through machinery tyres. Where this took place, the condition proved to be unfavourable for the survival of spruce. Schmidt-Vogt (1986) pointed out that water logging causes an extremely shallow-rooting behaviour of Norway spruce, which results in a high susceptibility to drought (cf. Puhe 2003).

It can be concluded that all the applied amelioration techniques, which were very costly, did not advance the establishment or early growth of the seedlings, and were therefore absolutely unnecessary. This shows how it is important to scientifically study such expensive techniques prior to transforming them into practice.

Finally, the results support the conclusion that deforested woodlands can be reforested by planting tree species of the former forest ecosystem provided appropriate seedling materials are available and the young plantations adequately protected.

3. II. Examples from Southern Shaanxi Provice, China

3.1. An overview of the experiments (Publ. IIa)

The below information is based on the publication of El Kateb et al. (2009).

The examples from the Southern Shaanxi Provice are a part of the Sino-German Project "Rehabilitation of Degraded Land Ecosystems in Southern Shaanxi Province" (El Kateb et al. 2009). The project is located in the Qinling mountainous region in Shangnan County in the south of Shaanxi Province. Due to hundreds of years intensive land utilisation and cultivation, natural forests are degraded and the forest area drastically decreased (He et al. 2008), resulting in widespread erosion occurrence (Xi et al. 1997), connected with increased surface discharge of polluted water and a raise in natural catastrophes such as floods and landslides at significant shorter intervals (Wang et al. 2003, Xi et al. 1997, Zou and Ren 2008). In brief, the land ecosystems in southern Shaanxi Province are degraded (Figure 3.1) and have lost their natural potential functions, both protective and productive.

Figure 3.1: Degradation of land ecosystems in the south of the Shaanxi Province

According to El Kateb et al. (2013), "the Qinling mountainous region in southern Shaanxi province has been considered as soil water conservation area since 1981 (Wang 1981; Liu et al. 1996). With the approval of the plan for "South to North Water Diversion Project" by the Chinese central government in the mid 1990s, southern Shaanxi Province became the headstream area for supplying water to the capital city Beijing and its surrounding industrialised regions (Zhu et al. 2008). Therefore, highest priority was given to improve the situation in southern Shaanxi Province". The Chinese government exerted numerous efforts to combat degradation of the land ecosystems. These include measures such as banning tillage on steep slope lands, protecting natural forest, and even relocating residents to localities out of areas that become protected (Hu 2004; Wang and Ma 2008).

To support the rehabilitation of the degraded lands in the south of Shaanxi Province, the presented Sino-German project was initiated with the overall objective to develop a "land-use planning system" towards sustainable land use. Sustained land use systems can be achieved by several selective measures such as, rehabilitation of degraded lands, afforestation of areas susceptible to erosion, sustainable management of forests, agroforestry, and/or organic farming or integrated agriculture. A land use planning system will provide a range of prospective possibilities to improve the soil and water conservation in the region.

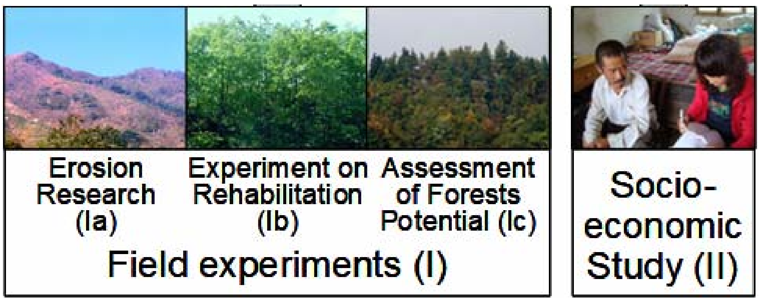


Figure 3.2: Project tasks of developing a land use planning system

Information to support the development of the planning system is based on an integrative research approach that comprises two main tasks (Figure 3.2). Task I includes an experimental component of three different field experiments [Ia) erosion (El Kateb et al. 2013), Ib) afforestation (Summa et al. 2010, Summa 2013), and Ic) assessment of forest resources (Wang et al. 2012, Wang 2013)]. Task II involves a socioeconomic survey in the study area (Wang 2013, Wang et al. 2015). Both tasks (I and II) are associated with a system-analysis component on modelling and development of a reliable planning system.

The research questions related to Task I and Task II are shown in Table 3.1. Figure 3.3 lists in brief the data collection, data and statistical analyses and outcomes of the four different tasks mentioned-above (cf. El Kateb et al. 2009).

Table 3.1: Research questions related to Task I

Task Ia:	What is the degree of erosion and surface run off on the different vegetative covers?
Task Ib:	Is afforestation necessary for the rehabilitation of abandoned farmlands?
Task Ib:	Which degree of success/failure, on the short and medium-term, does each of the investigated tree species have in the afforestation of abandoned farmlands?
Task Ib:	Under which site conditions can a successful afforestation be practiced on abandoned farmlands?
Task Ib:	Which short and medium-term impacts does afforestation have on soil and vegetation on abandoned farmlands?
Task Ib:	Which site preparation techniques for each cultivated tree species is ecologically and economically feasible and can be practised on abandoned farm lands on a large scale?
Task Ic:	What is the potential of wood in mass and regeneration in quantity and quality in the high forest?
Task Ic:	What is the potential of the forest resources to support the reduction of excess atmospheric carbon dioxide and of poverty?
Task II	What is the degree of acceptance of the local inhabitants to changing the conventional land use in the study area?
Task II	Which impacts of land use changes on socioeconomic conditions can be expected?

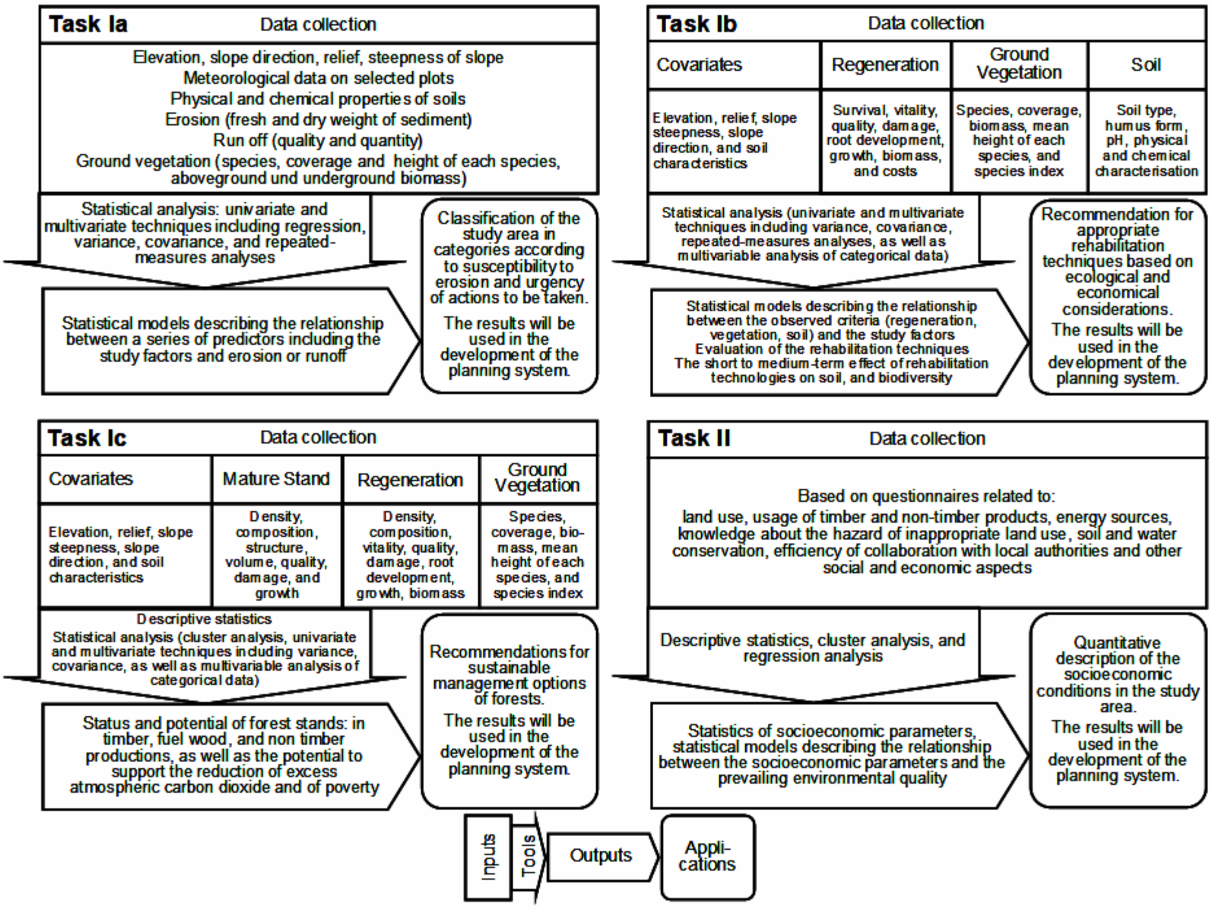


Figure 3.3: Inputs, tools, outputs and applications of results of the research activities in Southern Shaanxi Province to support the development of a land use planning system.

In the following, only Task 1a and Task Ib are discussed. As the prevailing erosion situation was a decisive factor for further measures to be taken, Chapter 3.2 elaborates Task 1a (Publ. IIb: El Kateb et al. 2013). Task 1a has the objective to determine the degree of soil erosion and surface runoff on different vegetation covers and slope gradients. Task 1b (Publ. IIc: Summa et al. 2010), which deals with afforestation of abandoned farmlands with native tree species, is briefly presented in Chapter 3.3.

3.2. The soil-erosion experiment (Publ. IIb)

The below description is based on the publication of El Kateb et al. (2013).

3.21. Introduction

The project is located in the south of Shaanxi province. According to El Kateb et al. (2009), "the southern Shaanxi province is of special interest due to its role in diverting water to Beijing within the frame of the South-to-North Water Diversion Project. However, soil loss in the south of the Shaanxi Province is estimated at annual 4,000-7,000 t km^{-2} (Wang et al. 2003) and soil erosion increased rapidly over the last decades (Xi et al. 1997). The consequence is raising natural disasters of landslides and floods with considerably shorter intervals of an average of a 5-years since the middle of the 20th century, compared to an average interval of a 28-year before this time (Wang et al. 2003). The main reasons for this deterioration are deforestation, and inappropriate land use (Xi et al. 1997). The former ecosystem in the region embraced 246 woody species from 60 families. Over the last century, the natural forests have been strongly degraded or deforested (Zhang 1986, Jia 1984). The forest coverage decreased from 64 percent to 46 percent compared to the 1950s. Most of the remaining forests are of poor quality or were turned to coppices, bushes, and even grasslands."

Highest priority was given to improve the situation in southern Shaanxi Province by the Chinese government. To support policy-making processes, evidence based on scientific research is required. The Sino-German research project on rehabilitation of degraded land ecosystems was initiated in southern Shaanxi Province (El Kateb et al. 2009). Within the frame of this project, a research on erosion was conducted, with the objective to determine the degree of soil erosion and surface runoff on the dominating vegetation covers and slope gradients.

3.22. Methodology

The field experiment was carried out in Suo Yu He valley, Shangnan County, which is located in the Qinling mountainous region at the eastern part of southern Shaanxi Province. The area is characterised by hilly topography at low altitudes (350 m to 700 m above sea level). According to the Agricultural Planning Committee of Shangnan County (1984) annual total sunshine is 1,900 hours, frostless period is 199 to 230 days, annual temperature ranges between 12.7°C and 15.0°C, and the dominated soil type in the study area is slight acidic, yellow-brown soil developed from granitic gneiss. The study area is at the edge of the subtropical humid climatic zone with 700 mm to 850 mm annual precipitation, which according to Zhang et al. (2000) mainly falls during May to October, mostly as storm with high intensity.

The landscape in the study area is highly fragmented as a result of the practiced traditional land-use over many decades. The major vegetation covers are forestlands, farmlands (agriculture and horticulture), and abandoned farmlands developed to grasslands. All vegetation types, except the forestlands which reach few hectares in size, have very small area size, which mostly does not exceed a quarter hectare.

Table 3.2: Description of the levels of the study factors

Study factor	Description
Vegetation cover	
Agriculture land (summer maize)	Farmlands with winter wheat and maize during summer
Horticulture land (tea plantation)	Farmlands under tea cultivation in rows having a distance of 40 cm between each two rows. The age of the tea plantations varied between 8 and 10 years. Under the tea, peanut was cultivated as an intercrop within rows (seeding during the last two weeks of April and harvesting during the last two weeks of September). The peanuts plants covered in average of all plots during its growing season 35% of the soil surface between two rows of tea.
Grassland	Abandoned farmlands that developed to grasslands with the dominating species being *Imperata cylindrical*, *Bidens pilosa*, and *Erigeron annuus*
Low forestland (oak coppice)	*Quercus variabilis* forests under traditional coppicing (regular cut back of trees to the ground level)
High forestland (pine plantation)	Forest plantations at an average age of 35 years with the dominant species being *Pinus tabuliformis*
Slope gradient	
Slight slope	>10° - ≤20°
Moderate slope	>20° - ≤30°
Steep slope	>30° - ≤40°

The study deals with the dominating vegetation covers and slope gradients in the study area. Table 3.2 shows the investigated levels of the study factors, for both the vegetation cover and slope gradient. The experiment was carried out on the dominating yellow-brown soil in the study area (a sandy-loam soil with 60, 25 and 15% sand, silt and clay, respectively). Based on land use and contour maps, a map was constructed to facilitate the identification of the location of the different vegetation covers and their slope gradient. In the field, a re-check of the location and slope gradient of the identified vegetation covers were made. Only those vegetation covers which had had uniform slope-form were listed. From the combinations of the vegetation cover and slope gradient, a selection of the experimental units was made at random. As the dominant slope class was the moderate, three experimental units from each vegetation cover level were selected at random. For the other two slope classes (slight and steep), only two units were randomly selected from each level of the vegetation cover (Figure 3.4). However, as agriculture activities had been ceased at steep slopes, agriculture lands with slopes exceeding 30° could not be found. In total 33 experimental units were selected.

The underlying experimental design is a Completely Randomised Factorial Design with unequal number of replicates.

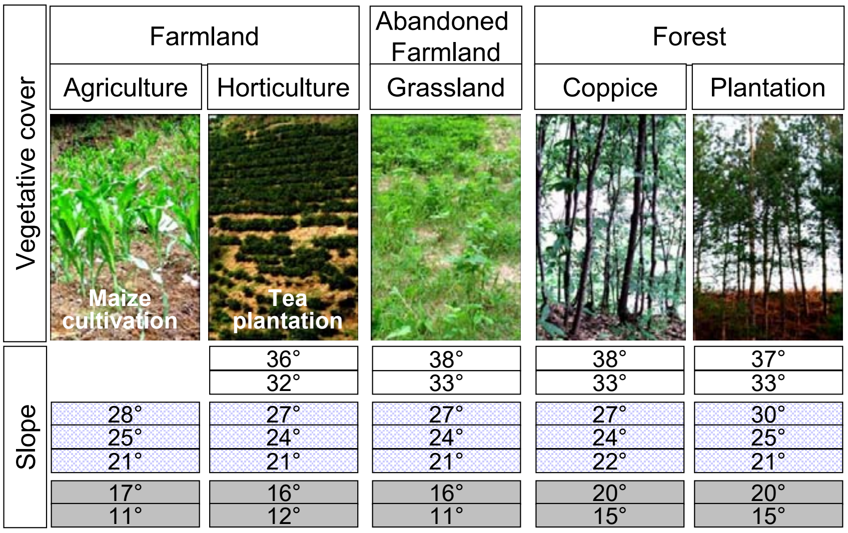


Figure 3.4: Schematic layout of the experiment

In each experimental unit, an erosion plot (Figure 3.5) was installed. Each plot is 7 m^2 in size (2 m in width and 3.28 m in length). The plots were laid out in such a way that the runoff and sediment can be collected in a plastic barrel without any loss. During the installation, as much care was taken as possible not to cause remaining disturbance to the surface soil or vegetation within the plots.

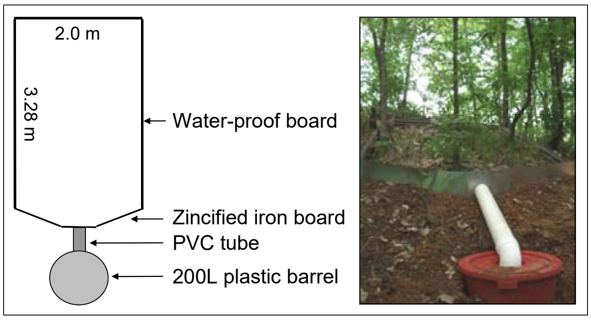


Figure 3.5: Layout of an erosion plot

A pluviometer was installed in the study area to collect data about the duration and amount of each rainfall event over the rainy season in 2008 (May 15th to October 30th). After each rainfall event, the plastic barrel installed in each plot was checked. In the event that the precipitation was not sufficient enough to generate measurable runoff in at least one of the 33 plots, the rainfall was considered as “non-erosive”. In this case, the runoff and sediment were zero. So, soil loss and runoff discharge were only recorded after each “erosive rainfall”. An erosive rainfall event means that a measurable runoff was generated in at least one of the 33 plots. The runoff volume inside the barrel was determined using a measuring cylinder. In addition, sediment was collected from the bottom of the barrel in each plot and stored in bottles for transportation to the laboratory. After the collection of data and materials, the barrel in each plot was cleaned up for the record of the following rainfall event. At the laboratory, the fresh sediment was dried (105°C for 48 hours) and weighed.

Analyses of variance were performed to describe the relationship between the study factors (vegetation cover, slope gradient, and their interactions) and the dependant variables (surface runoff and soil loss). As agriculture activity is ceased at slopes higher than 30°, agriculture plots were non-existence at the steep-slope gradient. Therefore, two different analyses were conducted. The first excludes the steep-slope level but includes all the five levels of the vegetation cover. The second excludes the agriculture land but includes all the three levels of the slope gradient. The null hypotheses for the contrasts tested in the two different analyses are indicated in Table 3.3. The logarithmic transformation for both criteria (runoff and soil loss) was appropriate to minimise correlation between means and variances of the data and, subsequently, to fulfil the assumptions of the ANOVA (Kirk 1995). All statistical analyses were performed using SAS for Windows, version 9.2 (SAS Institute, Cary, NC).

Table 3.3: Null hypotheses for the contrasts tested in the two different analyses

Contrast		Null hypothesis
1st analysis: steep slope category is excluded from the analysis		
V1:	Maize & tea versus grassland, low and high forest	H_0: $(\mu_{maize} + \mu_{tea})/2 = (\mu_{grassland} + \mu_{low\ forest} + \mu_{high\ forest})/3$
V2:	Maize versus tea	H_0: $\mu_{maize} = \mu_{tea}$
S1a:	Slight slope (>10°-≤20°) versus moderate slope (>20°-≤30°)	H_0: $\mu_{slight\ slope\ (maize\ +\ tea\ +\ grassland\ +\ low\ forest\ +\ high\ forest)} = \mu_{moderate\ slope\ (maize\ +\ tea\ +\ grassland\ +\ low\ forest\ +\ high\ forest)}$
I11:	Interaction V1 x S1a	H_0: Interaction effect = 0
I21:	Interaction V2 X S1a	H_0: Interaction effect = 0
2nd analysis: maize is excluded from the analysis		
V3:	Tea versus grassland, low and high forest	H_0: $\mu_{tea} = (\mu_{grassland} + \mu_{low\ forest} + \mu_{high\ forest})/3$
V4:	Grassland versus low and high forest	H_0: $\mu_{grassland} = (\mu_{low\ forest} + \mu_{high\ forest})/2$
V5:	Low forest versus high forest	H_0: $\mu_{low\ forest} = \mu_{high\ forest}$
S1b:	Slight slope (>10°-≤20°) versus moderate slope (>20°-≤30°)	H_0: $\mu_{slight\ slope\ (tea\ +\ grassland\ +\ low\ forest\ +\ high\ forest)} = \mu_{moderate\ slope\ (tea\ +\ grassland\ +\ low\ forest\ +\ high\ forest)}$
S2:	Slight & moderate slopes (>10°-≤30°) versus steep slope (>30°-≤40°)	H_0: $(\mu_{slight\ slope\ (tea\ +\ grassland\ +\ low\ forest\ +\ high\ forest)} + \mu_{moderate\ slope\ (tea\ +\ grassland\ +\ low\ forest\ +\ high\ forest)})/2 = \mu_{steep\ slope\ (tea\ +\ grassland\ +\ low\ forest\ +\ high\ forest)}$
I31:	Interaction V3 x S1b	H_0: Interaction effect = 0
I41:	Interaction V4 x S1b	H_0: Interaction effect = 0
I51:	Interaction V5 x S1b	H_0: Interaction effect = 0
I32:	Interaction V3 x S2	H_0: Interaction effect = 0
I42:	Interaction V4 x S2	H_0: Interaction effect = 0
I52:	Interaction V5 x S2	H_0: Interaction effect = 0

3.23. Results

In total, 35 rainfall events were recorded over the rainy season in 2008 between May 15th and October 30th. The rainfall was classified into non-erosive and erosive events. Each was in turn grouped in two categories according to the rainfall intensity (Figure 3.6). The non-erosive events did not exceed an intensity of 2.75 mm h^{-1} with the categories: ≤0.75 mm ha^{-1} and >0.75 & ≤2.75 mm ha^{-1}. The two erosive rainfall categories had, as expected, higher intensities than the non-erosive ones. The category with intensity >2.75 - ≤5 mm h^{-1} showed, as the non-erosive categories, a positive correlation between the rainfall amount and duration (Figure 3.6). In contrast, the rainfall amount of the category, which includes the strong rainfall events with intensities >5 mm h^{-1}, was in negative correlation with the rainfall duration: Higher precipitation was associated with shorter rainfall duration. The events of this category had in comparison to the rainfall events with intensity ≤5 mm h^{-1} shorter rainfall durations, which did not exceed two hours.

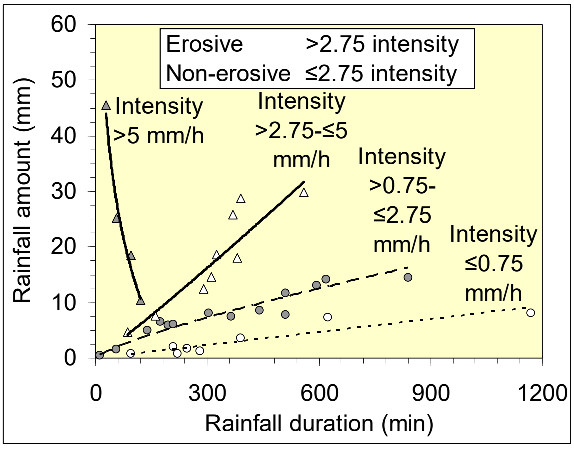


Figure 3.6: Relationship between the rainfall amount and duration under the categories with different rainfall intensities over the rainy season in 2008

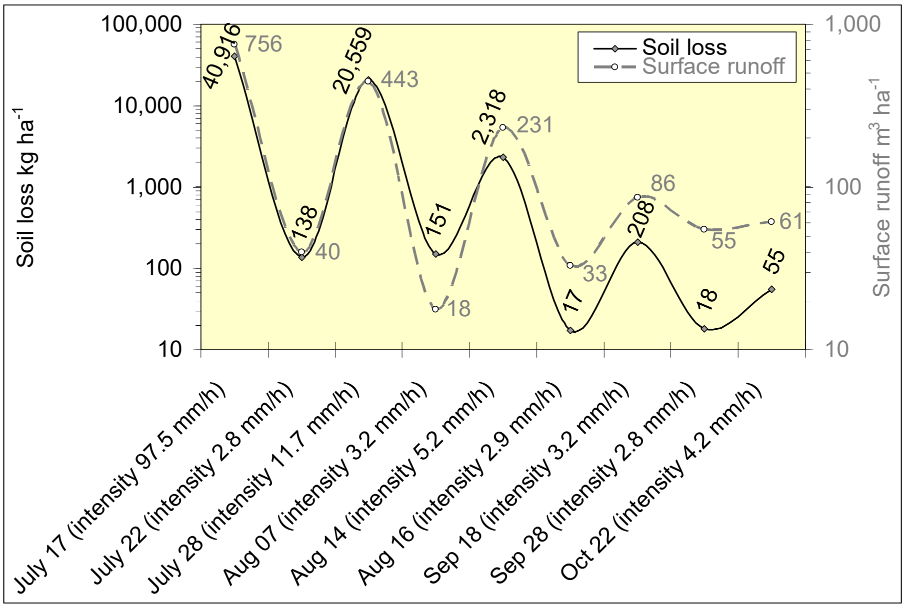


Figure 3.7: Runoff and soil loss over the observation period (July 15th - October 30th, 2008)

Over the observation period (July 15th – October 30th, 2008), nine erosive rainfall events were recoded. These generated on all investigated 33 plots a total runoff of 1,722 m^3 ha^{-1}

and a total soil loss of 64,380 kg ha^{-1} (Figure 3.7). Higher runoff and soil loss were associated with higher rainfall intensity.

Table 3.4: Summary of the results of the variance analyses for the relationship between the runoff/soil loss and the study factors (vegetation cover and slope gradient)

Contrast		Runoff m^3/ha Pr > F	Soil loss kg/ha Pr > F
1st analysis: steep slope category is excluded from the analysis			
V1:	Maize & tea versus grassland, low forest and high forest	0.0009***	<0.0001***
V2:	Maize versus tea	0.2550	0.4710
S1a:	Slight slope (>10°-≤20°) versus moderate slope (>20°-≤30°) for all the 5 levels of the vegetation cover	0.1936	0.3770
I11:	Interaction V1 x S1a	0.8279	0.7198
I21:	Interaction V2 X S1a	0.3047	0.3692
2nd analysis: maize is excluded from the analysis			
V3:	Tea versus grassland, low forest and high forest	0.0001***	<0.0001***
V4:	Grassland versus low forest and high forest	0.6424	0.0009***
V5:	Low forest versus high forest	0.6580	0.7257
S1b:	Slight slope (>10°-≤20°) versus moderate slope (>20°-≤30°) for 4 levels of the vegetation cover, excluding maize	0.4464	0.7324
S2:	Slight & moderate slopes (>10°-≤30°) versus steep slope (>30°-≤40°) for 4 levels of the vegetation cover, excluding maize	0.0844	0.0444*
I31:	Interaction V3 x S1b	0.6454	0.8064
I41:	Interaction V4 x S1b	0.4742	0.4481
I51:	Interaction V5 x S1b	0.1354	0.4683
I32:	Interaction V3 x S2	0.5879	0.7522
I42:	Interaction V4 x S2	0.1192	0.7150
I52:	Interaction V5 x S2	0.9523	0.8934

Analyses of variance were performed to compare the total runoff and soil loss of the different combinations of the vegetation cover and slope gradient. Results regarding the total runoff and soil loss for the period between July 15th and October 30th (Table 3.4), show that there is no significant difference between the low and high forest for both criteria the runoff and soil loss (contrast V5, I51, and I52 in Table 3.4). The same holds true for maize and tea cultivations at slopes ≤30° (contrast V2 and I21 in Table 3.4). However, maize and tea fields at slopes ≤30° had significantly higher runoff and soil loss than grassland and forestland (contrast V1 in Table 3.4). In addition, tea plantations generated significantly higher runoff and soil loss than grasslands and forestlands at all the three slope gradients (contrast V3 in Table 3.4). Significantly greater values on grassland than forestland were only associated with the soil loss but not with the surface runoff (contrast V4 in Table 3.4). Furthermore, the slope gradient had a distinguished impact on the runoff and soil loss. On the one hand, higher runoff and soil loss were recorded at steep slopes than at the slight and moderate slope gradients (contrast S2 in Table 3.4 and Figure 3.8), with the exception of the forestland's runoff, where no significant difference was discerned among the different slope gradients (Figure 3.8). On the other hand, there was an indication that tea plantation, maize cultivation, and grassland at moderate slopes produced higher runoff and soil loss than slight slopes did (Figure 3.8). However, hypotheses related to the equality of the slight and moderate slope were not rejected (contrast S1a and S1b in Table 3.4).

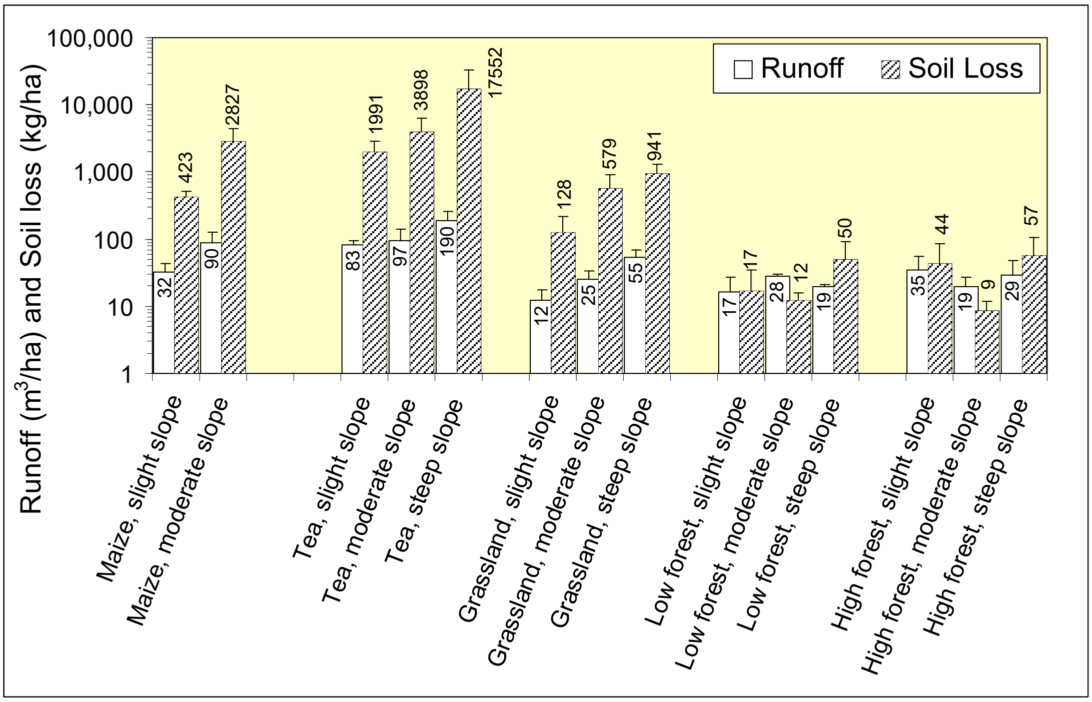


Figure 3.8: Arithmetic means of the total runoff (m^3 ha^{-1}) and soil loss (kg ha^{-1}) of each combination of the vegetation cover and slope gradient over the period July 15th - October 30th, 2008 (figures indicated in the diagram are extrapolated values of the plots of 7 m^2 in size to the hectare scale)

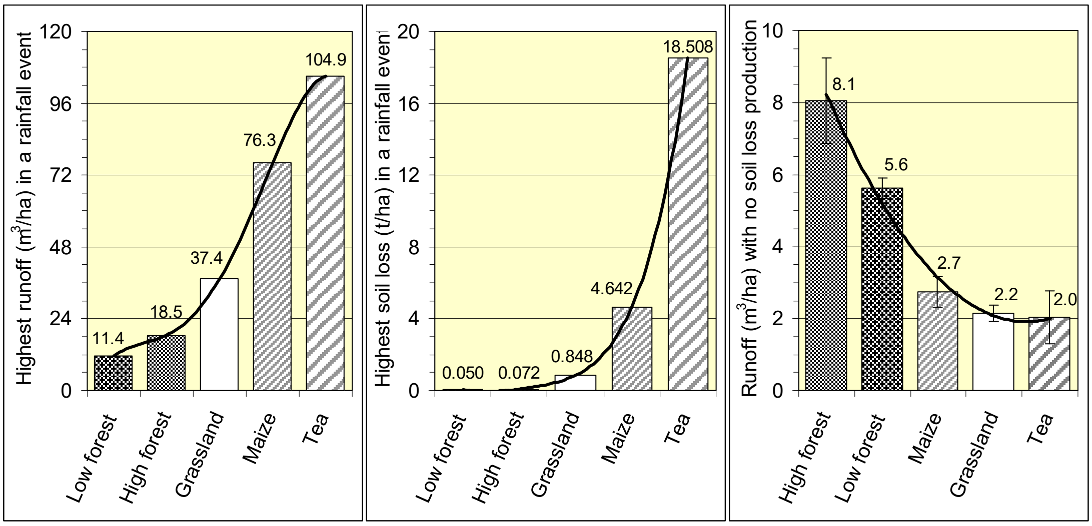


Figure 3.9: The highest runoff (left) and highest soil loss (middle) generated in a plot of the different vegetation covers over the observation period July 15th - October 30th, 2008 as well as the average of the five highest runoff values at which no soil loss was generated (right) on the different vegetation covers over the same observation period.

The highest recorded values of runoff and soil loss in a vegetation cover over the observation period are shown in Figure 3.9. Without any exception, all of these highest values originated from the rainfall event of July 17th, which had the highest intensity of 97.5 mm h^{-1} among all erosive rainfall events. A close relationship between the vegetation cover and discharge as well as between the vegetation cover and soil loss is distinctly obvious. Tea plantation attained the highest runoff and soil loss, followed by agriculture (maize cultivation) that does not include slopes >30°, then grassland, and lastly forestland. Tea plantation produced 23 times and 302 times more soil loss than grassland and forestland, respectively (Figure 3.9). The differences in the runoff values between the various vegetation covers were clearly high, but not as dramatically pronounced as in the case of the soil loss values (Figure 3.9). Of high significance is that soil losses at forestlands begin at considerably higher runoff values than the other investigated land use forms do. High forest did not produce any soil loss until, in comparison to tea cultivation and grassland, in average, around four times higher runoff was generated (Figure 3.9).

3.24. Discussion

Reliable research-based-information on the degree of erosion on different land use forms and slope gradients is lacking in the study area. The present study aims at comparing soil loss and surface runoff on the most frequent vegetation covers at different slope steepness. The landscape in the study area is a mosaic of agriculture, horticulture, grass, and forest, which all, except the forestlands, appear in small to very small patches that do not exceed a quarter hectare. Small-sized erosion plots of 7 m^2 in size were used to compare the runoff and soil loss on uniform slopes of the different combinations of the vegetation cover and slope gradient on the dominating soil (yellow-brown soil). Various studies (e.g., Braud et al. 2001, Descheemaeker et al. 2006, Mathys et al. 2005, Mohammad and Adam 2010, Ngatunga et al. 1984, Vacca et al. 2000) employed in fields small plots of a size ranging between 1 and 50 m^2 to compare erosion on different soil types, vegetation covers or land use forms. The used small plots of 7 m^2 in size proved to be appropriate for comparing soil erosion in different vegetation covers and slope gradients, as there was no indication that the gained results are not in agreement with similar studies dealing with soil erosion. Taking forestlands as an example, Hill and Peart (1998) determined for forestlands in southern China, based on extensive literature review, an average erosion rate of 50 kg ha^{-1} a^{-1}. Zhang et al. (2011) estimated an erosion rate of 38 kg ha^{-1} a^{-1} in average for China’s forestlands using USLE (Universal Soil Loss Equation) model. In the present study, an average soil loss of 28.5±9.7 kg ha^{-1} was recorded at the low and high forests over the observation period. The estimated higher values by the above-mentioned studies could be attributed to the use of erosion models. However, the soil erosion values determined in the various studies are not far apart from each other.

The study involved a sample size of 33 erosion plots. The variability was largely depending on the level of the study factors with higher variation on farmlands and steep slopes. Moreover, the soil loss had higher variability than runoff. There was no any evidence that the assumptions of the ANOVA were violated for any of the analyses conducted. The difference between the means of the levels of the vegetation cover was too large, so that the probability of failing to reject a false null hypothesis was too small. This was more pronounced for the soil loss than for the runoff. The power (the probability of rejecting a falls null hypothesis, cf. Kirk 1995) of the test for the vegetation cover at a significance level of 0.05 was >0.99 and 0.85, when analysing the soil loss and runoff, respectively. However, the power of the test for the slope gradient was lower having values of 0.78 and 0.35 for the soil loss and runoff, respectively. It can be concluded that the sample size was sufficient to detect the differences between the means of the different levels of the vegetation cover. However, this was not always the case for the slope-gradient factor, particularly when considering the runoff. According to Kirk (1995) the estimated sample size for each of the combination of the vegetation cover and slope gradient in a completely randomised factorial design to achieve a power of 0.9 for detecting an effect of the slope gradient on the runoff, with magnitude in accord with Figure 3.7, is six. For further field studies with the interest of cost reduction, the sample size may best be weighted to include twice as many samples in farmlands (maize and tea) and at steep slopes, due to their higher variability than the other levels of the study factors.

Previous studies (Koulouri and Giourga 2007, Nearing 1997) found that slope has a considerable impact on erosion. This was confirmed by the results of the present study, as the impact of the slope on the surface runoff and soil loss was significant, particularly the steep slope gradient had greatly increased the runoff and soil loss. The response of the different vegetation covers was, however, distinct. While there were no differences or little differences between the different slope gradients in forestlands (differences between slopes ≤ 30° and slopes > 30° of approximately 0 m^3 ha^{-1} runoff and 35 kg ha^{-1} soil loss), grasslands showed higher differences (35 m^3 ha^{-1} runoff and nearly 542 kg ha^{-1} soil loss as differences between slopes ≤ 30° and slopes > 30°), and the greatest differences were observed on tea fields (99 m^3 ha^{-1} runoff and 14,417 kg ha^{-1} soil loss as differences between slopes ≤ 30° and slopes > 30°). This supports the argumentation that forestland is the most appropriate land-use form at steep slopes towards substantial reduction of soil erosion.

According to Jia et al. (2002), Zhang et al. (2004), and Wei et al. (2007), vegetation cover is the key factor affecting soil erosion and surface runoff in the mountainous region. The presence of vegetation intercepts rainfall drops, increases infiltration, reduces surface runoff and, thus, significantly prevents sheet erosion (Woo and Luk, 1990, Woo et al. 1997).

Results of the present study clearly indicate that soil loss is more sensitive than runoff to changes in vegetation cover. Nearing et al. (2005), investigated the response of seven soil erosion models to precipitation and vegetation related parameters and found that the soil loss is more affected by changes in ground surface cover than the runoff. Among the factors affecting surface runoff and soil erosion, vegetation cover is the one that can be manipulated via land use policies (Chen et al. 2003).

Tea plantations at slopes >30° proved to be the most susceptible vegetation cover to erosion. Tea plantations in the study area are cultivated in rows. The space between each two rows in the tea plantations is as the same as the average height of the tea plants equalling around 40 cm. Under the tea, peanut was cultivated: Seeding took place over the last two weeks of April, while harvesting over the last two weeks of September by removal the entire plants by hand. There was no evidence that harvesting the intercrop affected erosion, as during and after the harvesting time only little rainfalls with low intensity <5mm h^{-1} had been recorded. However, the intercrop cultivation was not dense and in average 65% of the surface soil remained bare between two rows of tea. Bare soil surface is exposed to rainfall drops that cause greater discharge and soil loss than soils covered with vegetation. A general conclusion that tea plantations induce the highest soil loss may be false, if the cultivation technique is not considered. The conclusion, on the other hand, is valid for the cultivation technique used in the study area, as large proportion of the surface remained bare soil. However, tea generates a significant income for the local community, although it is a relatively new cash-crop in the study area. To maintain tea cultivation in the study area, technique used must be altered in order to improve production but, more significant, to reduce erosion. Zehetner et al. (2008) suggested using terracing technique in tea plantations in order to manage that eroded materials that can be trapped and downhill transportation can be reduced. Field (1970) and Stigter (1987) proved that organic mulch between rows in tea plantations prevents soil losses.

In agriculture activities, soil tillage generates high surface runoff and soil loss and causes high erodibility (Bakker et al. 2004, Uri and Lewis 1998). The present study dealt only with the main cultivated summer crop in the study area, which is maize in a winter-wheat-summer-maize rotation. The study did not consider other summer crops. It is, however, well recognized from Basic et al. (2004) and Putthacharoen et al. (1998) that the degree of erosion is depending on the cultivated crop. Results, therefore, are only valid for the studied maize crop. Nevertheless, introducing soil-friendly farming practices (Gaynor et al. 1995, Gould et al. 1989) that minimise tilling and thus reduce erodibility, may support achieving the objectives of soil and water conservation in the study area.

Grasslands, which were former abandoned farmlands that left to natural succession, developed in few years to lands covered by grasses and herbs. In comparison to cultivation of maize and tea, grassland had less runoff and soil loss. Fullen (1998) found that grass intercepts the force of rain drops and accelerates infiltration. Ban of tillage in slope lands can considerably reduce runoff and soil losses as found by Feng et al. (2010), López-Bermúdez et al. (1998) and Souchère et al. (2003). However, results showed that over the observation period soil loss on grasslands was 19 times higher than forestlands. This argues for continuing the afforestation activities of grasslands to substantially reduce soil erosion.

Forestlands, in comparison to the other investigated vegetation covers, generated the least total soil loss (28.5±9.7 kg ha^{-1} in comparison to 553.7±183.7 kg ha^{-1} on grasslands and 9,204.5±3,207.9 kg ha^{-1} on tea plantations) and runoff (24.6±3.8 m^3 ha^{-1} in comparison to 29.8±7.8 m^3 ha^{-1} on grasslands and 132.8±22.1 m^3 ha^{-1} on tea plantations) over the entire observation period.

Analyses showed that the runoff and soil loss produced on both forest types were statistically insignificant. The forestland's runoff was not affected by the slope degree. There was, however, an indication that soil losses on the steep slope gradient were higher than on slight and moderate slopes. Dissmeyer and Foster (1984) found that the slope degree has an effect on the forestland's erosion and that the soil loss is much more responsive to changes in slope degree than the runoff. However, in the Three-Gorges-Reservoir area, Dong et al. (2006) did not find a significant effect of the slope gradient on the forestland's soil loss using ^{137}Cs tracing method.

Nevertheless, forests with well developed canopy, litter-humus layer, and root system have substantial capacity to intercept rainfall and increase infiltration (Chang 2006, Neary et al. 2009). Taking into account the ecological and socio-economical benefits of forests, it becomes apparent that forestlands are the most effective rural land-use to reduce erosion and, thus, improve the surface water quality in the study area. Results of the present study argued that both low forest and high forest are the most suitable for soil and water conservation purposes as little runoff and negligible soil loss have been produced. However, erosion in forestlands depends on how forests are managed (Anderson et al. 1976, Hartanto et al. 2003, Sidle et al. 2006). Management systems, which focus on attaining high stand stability in terms of high resistance and high resilience to maintain the protective functions of forests, are appropriate for soil and water conservation purposes. Nevertheless, scientific investigations comparing different forest management practices to clarify to how much forest management affects soil erosion is still lacking in southern Shaanxi Province.

3.3. The afforestation Experiment (Publ. IIc)

The below information is based on the publication of Summa et al. (2010).

For over five decades the area of natural forests in the Qinling Mountain have been strongly decreased (He et al. 2008 and Leefers 2005), as large-scale deforestation took place to boost the agricultural and industrial modernization of the country. Forest lands were converted to agricultural lands and soils on steep slopes were prone to erosion and lost their fertility as a result. The inappropriate land use caused flooding along China's two main rivers, the Yellow River and the Yangtze, which are historically, culturally, and economically of critical importance to Southern and Northern China (Xu et al. 2011). Ding and El Kateb (2011) studied the annual runoff discharge and sediment load variation in the Jialing River over 50 years (1956-2006). The Jialing River, the second largest tributary of the Upper Yangtze River, originates at the southern foot of Qinling Mountain in the Shaanxi Province. Ding and El Kateb (2011) could recognise two phases (1956-1985 and 1986-2006) with distinctive sediment yields over the monitoring period. The shift after the year 1985 was attributed to the construction of dams in Jialing River basin that led to considerable reduction of the sediment transport. The sediment yield after the construction of the dams could be characterised by two phases, whereas a substantial decline of the sediment transport was recorded after the year 1991 having an average annual yield of 33.2±6.85 million tons, compared to more than five times higher sediment before 1985. This drastically reduced sediment was a result of the large-scale soil and water conservation measures and increased afforestation activities. According to Zhang et al. (2000), most of the afforestation was monoculture of fast growing species. This bears a high risk for biotic and abiotic damages (Mosandl 1998, Gadgil and Bain 1999). Thomasius (1992) recommends adapted tree species while Forrester et al. (2006), Kelty (2006), and Wood and Vanclay (1995) propose a mix with native species to reduce the risk of damage.

An afforestation experiment was established as part of the Sino-German project "Rehabilitation degraded land ecosystem in the mountainous area of the Southern Shaanxi Province, China" (El Kateb et al. 2009). The objectives of this study are (1) to assess whether native tree species can be used to afforest abandoned farmlands, (2) to determine whether site preparation techniques such as clearance of competing ground vegetation have an impact on the survival and growth of the species under study.

The study site is located near the city of Shangnan in south-east of the Shaanxi Province. It lies 600 m above sea level. The precipitation averages between 710 mm a^{-1} and 930 mm a^{-1} and the mean annual temperature varies between 7.8 °C and 13.9°C. The experiment is established on three blocks or sites (site 1: Gua Jia Cun, site 2: Suo Yu He and site 3: Shi Li

Pu), all of poor site conditions with thin soil layer on former agricultural lands covered by grass. All blocks have a slop steepness of over 31°.

Four native tree species of economical and ecological importance were planted in October 2008. These are Chinese Red Pine (Pinus tabuliformis), Chinese Cork Oak (Quercus variabilis), Shantung Maple (Acer truncatum) and Chinese Pistache (Pistacia chinensis). Chinese Red Pine and Chinese Cork Oak were container saplings. Shantung Maple and Chinese Pistache were bare root saplings and the roots were strongly cut. The age of the seedlings was one year old for Chinese Red Pine and Chinese Pistache, and 2 years old for Chinese Cork Oak and Shantung Maple.

The underlying statistical design of each of the three afforestation blocks is a 4 x 4 Latin Square (16 units or cells per block) with the subunit levels of treatment arranged in a split-plot design (Figure 3.3.1). Each unit was subdivided into two subunits. Each subunit randomly received one of two levels of a site preparation technique related to reduction of the competitive impact of the ground vegetation: (1) no clearance of ground vegetation or (2) annual clearance of ground vegetation over a period of 3-5 years. The hypotheses testing and statistical analyses associated with the experimental design is shown in Table 3.3.1.

The number of plants in each cell is 90 (corresponding to 6,250 individuals ha^{-1}). The reason for this high initial density is that a part of the saplings is foreseen to be collected for biomass and root investigations. Planting was arranged in rows and columns, so in one subunit there were five rows and nine columns. The size of one cell is 12 m x 12 m, resulting in a total planted area of 6,912 m^2 (3 blocks x 16 cells x 144 m^2).

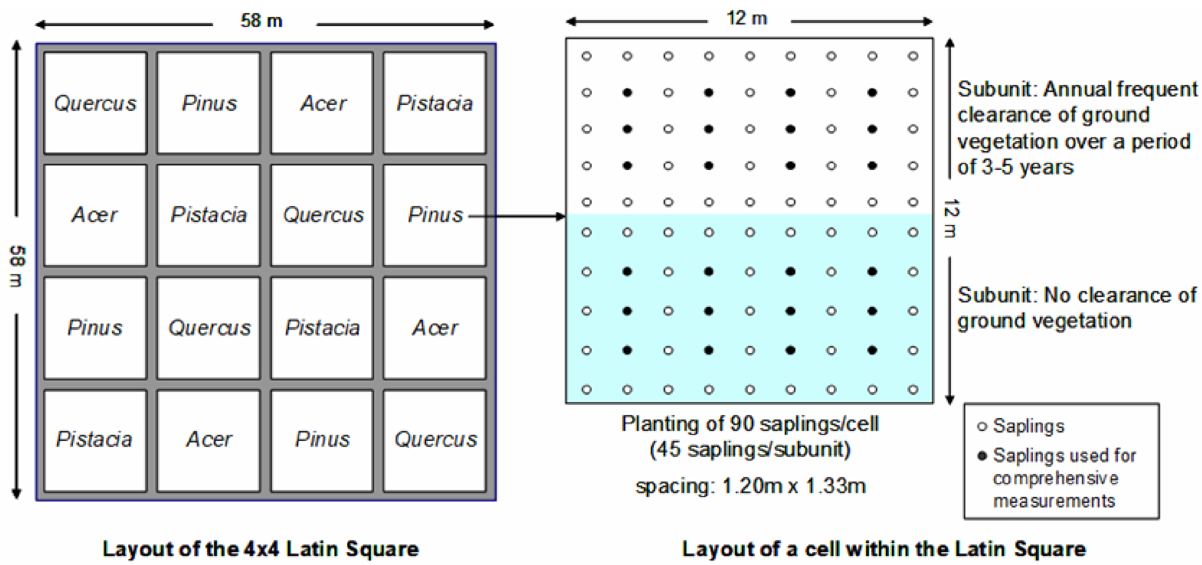


Figure 3.3.1: Layout of a block (4x4 Latin Square Design)

Table 3.3.1: Hypotheses and ANOVA table for the analysis of the studied sites (each includes a plot of 4 species) in (3) 4x4 Latin Squares with 2 subunit treatments arranged in a split-plot across cells (MS = Mean Square).

Source of variation	Degrees of freedom		F Statistics	Null hypothesis
Total	$ab^2c - 1$ =	95		
Between cells	ab^2-1 =	47		
1. A (sites)	a-1 =	2	MS 1/MS 6	H_0: $\mu_{\text{site 1}} = \ldots = \mu_{\text{site a}}$
Site 1 vs. 0.5 (site 2 + site 3)		1	MS 1a /MS 6	H_0: $\mu_{\text{site 1}} = (\mu_{\text{site 2}} + \mu_{\text{site 3}})/2$
Site 2 vs. site 3		1	MS 1b /MS 6	H_0: $\mu_{\text{site 2}} = \ldots = \mu_{\text{site 3}}$
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: $\mu_{\text{species 1}} = \ldots = \mu_{\text{species b}}$
Container vs. bare root		1	MS 4a /MS 6	H_0: $\mu_{\text{Pinus}} + \mu_{\text{Quercus}} = \mu_{\text{Acer}} + \mu_{\text{Pistacia}}$
Pinus vs. Quercus		1	MS 4b /MS 6	H_0: $\mu_{\text{Pinus}} = \mu_{\text{Quercus}}$
Acer vs. Pistacia		1	MS 4c /MS 6	H_0: $\mu_{\text{Acer}} = \mu_{\text{Pistacia}}$
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	$ab^2(c-1)$ =	48		
7. C (treatment)	d-1 =	1	MS 7/MS 11	H_0: $\mu_{\text{traatment 1}} = \ldots = \mu_{\text{traatment d}}$
8. AC	(a-1)(c-1) =	2	MS 8 /MS 11	H_0: Interaction effect = 0
9. BC	(b-1)(c-1) =	3	MS 9 /MS 11	H_0: Interaction effect = 0
10 ABC	(a-1)(b-1)(c-1) =	6	MS 10 /MS 11	H_0: Interaction effect = 0
11. Error b	***ab(l-1)(c-1) =***	**36**		

Data is collected at the end of each growing season to gain information about the development of the afforestation including vitality, quality, damage, total height, annual height increment, root collar diameter and crown development of the plants,

Information about the planting materials at the initial phase, which was based on 60 randomly selected saplings per species from the initial planting-materials, is indicted in Figure 3.3.2. It can be said, that the planting materials were relatively homogenous, as the coefficients of variation were relatively low. Pinus had the best initial quality among the species, as it has the highest root length-total height ratio (Figure 3.3.2).

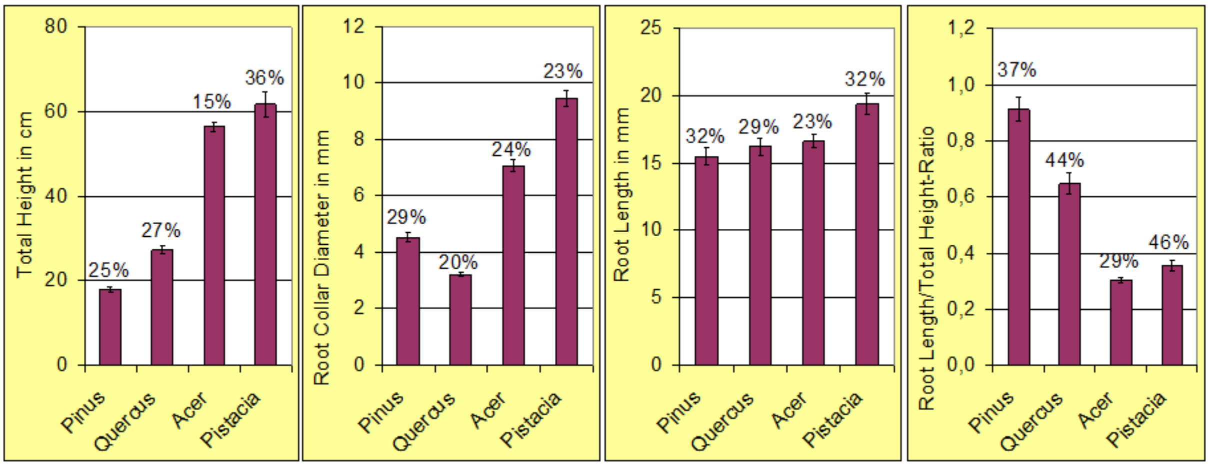


Figure 3.3.2: Arithmetic mean of the total height, root collar diameter, root length, and root-length total-height ratio of the initial planting material (figures above bars indicate the coefficient of variation)

Results after the first observation year, revealed that in accordance with the quality of the initial planting materials the survival rate is satisfying (Figure 3.3.3). Pinus showed the highest survival rate, followed by Acer, Quercus and Pistacia. Pinus increased in height by 80% of the initial height. Quercus and Acer, more or less, remained at their initial height, while the Pistacia saplings decreased in height due to dieback of their shoots. These outcomes after a short observation period could be attributed to the transplant shock or the poor site quality. Summa (2013) conducted further investigations at the second year after planting. He revealed that survival and growth of all four studied tree species were satisfying after the second year of the observation period. However, the container plantings (Pinus and Quercus) showed higher survival rate and height increment than the bare root seedlings (Acer and Pistacia).

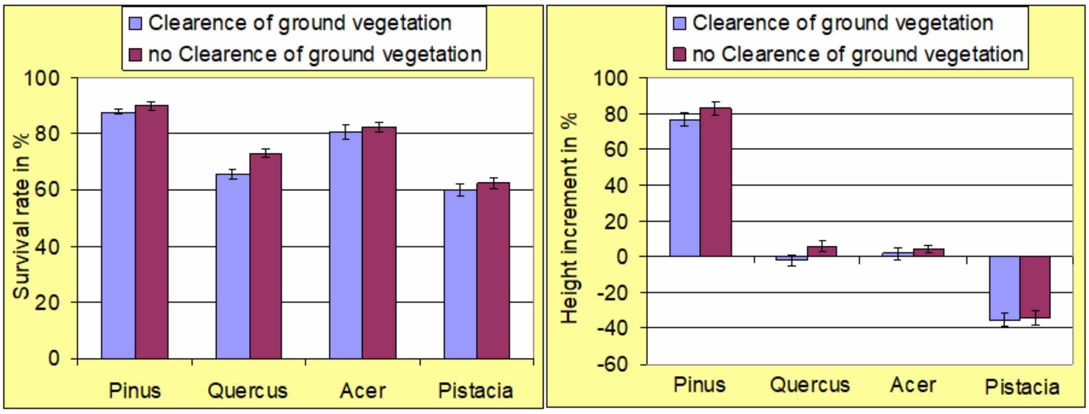


Figure 3.3.3: Survival rate (left) and height increment in % (right) one year after planting

The frequent clearance of ground vegetation had no significant effect on survival and growth. However, there was an indication that the clearness operation leads to damaging or cutting the small plants. Summa (2013) found that the effect of the frequent clearance of ground vegetation is negligible.

Results of the short-term observation of one year could imply that native tree species can be used to afforest abandoned arable lands. This was again confirmed by Summa (2013) after the second year of observation.

4. III. Examples from Desert Lands, Egypt

4.1. An overview of the Experiments (Publ. IIIa)

The below information is based on the publications of El Kateb et al. (2015).

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. The largest subtropical desert with arid climate is the Sahara (9.1 million km^2) in Northern Africa. Subtropical deserts offer plenty of unutilised lands. They are characterised by low annual precipitation, but they also receive sufficient sunlight and provide the opportunity for trees to grow year-round. These can lead to high photosynthetic ability and advanced tree growth and carbon stock allocation, if water is available.

In the mid 1990s, Egypt launched the “National Programme for the Safe Use of Treated Sewage Water for Afforestation”. The main objectives of this programme are to make use of unutilised sewage water for the establishment of forest plantations in desert lands and to support the efforts exerted to stabilise greenhouse gas concentrations in the atmosphere. As a pilot, four thousand hectares were afforested around the country.

Although the management of the plantation forests conducted within the pilot project was very poor, the outcomes of the pilot project were very promising, confirming that sewage water can be used for the establishment of new forest plantations, and showing high potential for afforestation of multipurpose species of socio-economic importance in desert lands of the country (Khalifa et al. 2013). 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 (El Kateb and Mosandl 2012). However, Egypt lacks experience in the forest sector. In order to support the optimisation of the Egyptian National Programme, the Institute of Silviculture at the TUM established in collaboration with Egyptian scientists at different research institutions a large-scaled project to afforestation in arid regions using treated sewage water for irrigating the plantation forests. The approach is the development of a scientifically based decision-support system for the sustainable management of plantation forests in arid regions (Figure 4.1). The publ. IIIa (El Kateb et al. 2015), introduces the entire project and describes in details seven experiments (cf.Table 4.1) including data collection, layout of the statistical designs and relevant statistical analyses. These experiments investigate the impact of various factors (tree species, irrigation water quantities, irrigation systems, soil improvement techniques and their combinations) on survival and growth of the new plantations. The objectives of these experiments are to identify the proper irrigation system, the most favourable level of water quantity for each species under different environmental conditions, the appropriate soil improvement techniques and the most effective silvicultural practice for each species depending on the desired goal of the afforestation.

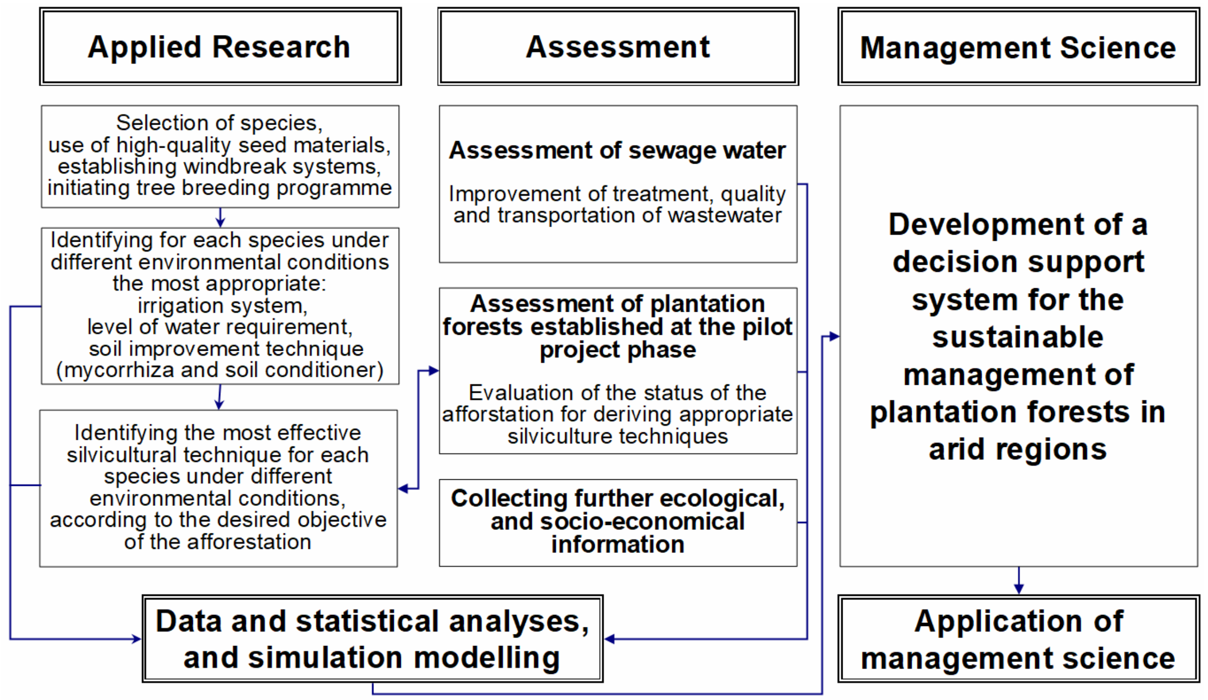


Figure 4.1: Scientific approach towards management of plantation forests in arid regions.

Table 4.1: Experiments on the establishment, early development and assessment of afforestation in arid regions

Experiment	Study factors beside the species factor	Size (ha)
Experiment Ia	Water quantity (5 levels)	2.7
Experiment Ib	Irrigation systems (4 levels) and water quantity (3 levels)	1.6
Experiment II	Silvicultural techniques	31.4
.Experiment IIIa	Soil improvement techniques (4 levels)	2.9
Experiment IIIb	Soil improvement techniques (4 levels) and water quantity (3 levels)	3.3
Experiment IIIc	Mycorrhiza and soil conditioner in a nursery (4 levels)	0.04
Experiment IV	Growth potential of three plantations including different researches	

Within the experiments that investigate the growth potential of the plantations (Experiment IV in Table 4.1), a study that deals with the individual-tree biomass (Publ. IIIb.: El Kateb et al. 2022) is in details discussed below.

4.2. The individual-tree biomass-experiment (Publ. IIIb)

The below description is based on the publications of El Kateb et al. (2022).

4.21. Introduction

“Egypt, the country with 7,000-year-old record of civilization, has a unique situation 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 River”. The country has a yearly fixed water share of Nile water amounting 55.5 109 m^3. The population is increasing reaching currently over 100 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 valuable nutrients, water and energy sources" (El Kateb et al. 2015). Wastewater from municipal activities or sewage water has a sufficient content of the primary plant nutrients "nitrogen" and "phosphorus". Accordingly, sewage water can be partially treated and, as long as no heavy-metal pollutants exist, can be used to provide the required water to irrigate trees or other plants that are not intended for food or fodder production. Furthermore, sludge or solid waste that remains after the treatment of wastewater can be used for the production of renewable energy (e.g., biogas) and soil conditioner (El Kateb 2015).

In order to tackle challenges of increasing amount of sewage water with increasing population, in the mid 1990s, the Egyptian Government initiated a national programme for using primary-treated sewage water for afforestation of desert lands. Within the frame of this programme, a pilot project was conducted to determine the success/failure of afforestation using treated sewage water. Over 4,000 hectares of plantation forests spread over the desert lands of the county were established. First results of the Egyptian national programme showed great potential for afforestation in desert lands using primary treated sewage water. Although the overall management of the plantations was inadequate (poor quality of seeds and planting materials, frequent irrigation failures and inappropriate forest management), El Kateb and Mosandl (2012) determined high growth rates of the three dominant tree species among two plantation forests in Egypt.

Nonetheless, little information about the plantation forests in Egypt is available. Zalesny Jr. et al. (2011) described strategies to maximise the potential of afforestation in Egypt and the long-term impacts on the natural resource base from afforestation. Evett et al. (2011) evaluated the feasibility of the afforestation efforts in Egypt including recommendations for irrigation. Farahat et al. (2012) estimated the aboveground biomass in Sadat City, one of the forest plantations in Egypt. Farahat and Linderholm (2012 b) investigated the growth performance of four irrigated plantation forests in Egypt. Farahat and Linderholm (2012 a) studied the impacts of desert plantation forests on biodiversity. Baldasso and Kress (2013) established a management plan for the Serapium Forest, one of the plantation forests in desert lands of Egypt. However, none of these studies has dealt with the accurate estimation of volume, density and carbon accumulation of the individual trees.

In the largest plantation in Egypt, the Serapium Forest, the three dominant species were studied, namely: Khaya senegalensis (Desr.) A.Juss., Corymbia citriodora (Hook.) K.D. Hill & L.A.S. Johnson and Casuarina equisetifolia subsp. equisetifolia (Figure 4.2). Trees of different classes of the diameter at breast height (DBH) were felled and their roots excavated (destructive sampling). The objectives of this study is 1) to determine the form factor and stem volume as well as the biomass and carbon dioxide sequestration of the stem, crown and root of the individual trees of the three investigated species, 2) to identify "best" models describing the relationships between the size of individual trees and the different investigated criteria, and 3) to construct a scenario for the development of the investigated species, as there is almost no information available about the future development of the young plantation forests in desert lands of Egypt. The scenario will help in assessing the potential and developing management strategies for the afforestation of desert lands using sewage water for irrigation.

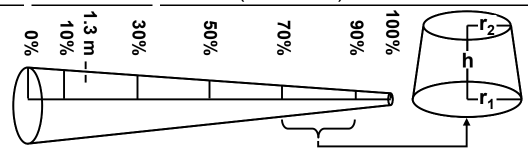
Figure 4.2: The investigated species: K. senegalensis, C. citriodora and C. equisetifolia (left to right).

4.22. Methodology

In the eastern Egyptian desert next to the municipal-wastewater treatment plants of the City of Ismailia, the study area is located in the Serapium Forest, which was established in 1998. The 210 ha plantation area of the Serapium Forest receives its primary treated wastewater with an average contents of ammoniacal-nitrogen (NH_4-N) of 25.0 mg l^{-1} and total phosphorous (TP) of 2.8 mg l^{-1}. Every single tree is irrigated and fertilised by the nutrients contained in the wastewater. The irrigation system is drip irrigation. According to Köppen-Geiger climate classification (cf. Kottek et al. 2006), the study area is characterised as BWh (main climate = arid (B), precipitation = desert (W) and temperature = hot arid (h)). In 2012, the study area received a total rainfall of 29 mm, had a total evapotranspiration of 1,817 mm, a mean annual temperatures of 21.6°C, a mean annual relative humidity of 53.9 %, and a mean annual wind speed of 2.5 m s^{-1} (FAO-Aquastat 2012). The soil belongs to the textural sand class with 92.5 % sand, 3.3 % silt and 4.2 % clay (UAE 2012).

The three dominating tree species in the Serapium Forest were studied. These are *Khaya senegalensis* (age = 128 months, stand density = 949 individual ha^{-1} and DBH classes are <15 cm, ≥15 cm - <20 cm, and ≥20 cm), *Corymbia citriodora* (age = 66 months, density = 1,095 individual ha^{-1} and DBH classes are <12 cm and ≥12 cm) and *Casuarina equisetifolia* (age = 82 months, density = 1,052 individual ha^{-1} and DBH classes are <12 cm, ≥12 cm - <18 cm, and ≥18 cm). Permission from the forest authorities was only given to only eight individuals per species to be felled. Samples were taken from a core area with 10 m distance to the edges. Selection of samples was restricted to those individuals not strongly forked or heavily damaged (there was no single *K. senegalens* available that did not show older browsing damage by camels). For the random selection of the sample trees, a starting point within the core area and the compass direction were randomly selected. Each 10m a tree was selected and marked till the selection of 24 samples was completed, from which each third tree (eight samples per species) was finally selected for felling and digging up of roots. Table 4.2 describes the data collection, while Figure 4.3 presents the diameters and heights collected on the sampled trees.

Table 4.2: Data collection

Variable	Abbre-viation	Unit	Description
Diameter at Breast Height	DBH	cm	Measurements were taken using diameter tapes at 1.3 m height (standing trees)
Total height of the standing trees	H	m	Recorded on the standing trees by the Vertex IV instrument (Haglöf Sweden AB 2007)
Crown length	L_c	m	= H - base of the first live branch excluding water shoots or epicormics (standing trees)
Eight crown radii		m	Determined at the 8 cardinal and sub-cardinal directions from the north to the northeast by projecting the edges of the crown to the ground (standing trees)
Crown radius	R_c	m	Arithmetic mean of the 8 crown radii
Crown volume	V_c	m^3	$= \frac{1}{3} \pi R_c^2 L_c$, assuming a cone shape
Crown surface area		m^2	$= \pi R_c (R_c^2 + L_c^2)^{0.5}$
Height (m) and diameters (cm) at different distances from the trunk base of the felled trees (cf. Figure 4.3)			
Stem volume	V_s	m^3	Summation of the volume $[\frac{1}{3} \pi h (r_1^2 + r_1 r_2 + r_2^2)]$ of six circular truncated cones, as indicated above
Root measurements			The roots of the investigated species are structurally different. For simplicity, the following uniform measurements for the three species were undertaken after exposure of soil. Lateral root spread: The width of the main lateral root/roots stemming from the root crown. The lateral root spread does not necessarily correspond to the root spread, which can be wider at greater depth from the soil surface. Maximum rooting depth (cf. Schenk and Jackson 2002): The largest depth from the crown root (primary root or other root with larger depth). Primary root and the three strongest coarse roots: Diameter at base, diameter at 30 cm from the base and length up to a diameter ≥ 2 mm.
Root volume	V_r	m^3	The root volume was roughly estimated, assuming a cone shape $[\frac{1}{3} \pi \times$ maximum rooting depth $\times$ (later root spread$/2)^2]$.
Fresh weight	Wf	kg	Determined for the entire stem, crown and root using weighing scale. In addition, samples were selected for

Variable	Abbre-viation	Unit	Description
			moisture estimation. Stem: Weight was recorded for each of the truncated cones/felled tree. A slice of 5 cm width of each of the six truncated cones in addition to a slice at the breast height per each felled tree were cut and weighed. Crown: The entire crown was separated in five components (foliages, dead branches, and live branches ≤ 1cm, > 1cm - ≤ 3cm, and > 3m). Branches were cut in small portions. Each component was well-mixed and weighed. For the determination of moisture, samples of approximately 5% of each component were randomly selected. Root: Weight of the entire excavated roots excluding the fine roots and coarse roots < 2 mm diameter. In addition, for the determination of moisture, 2 slices each, from the lateral root, primary root and the three strongest roots for each tree were weighed.
Dry weight	Wd	kg	All samples from stem, crown and root were first air dried (over four weeks) and then oven dried to constant weight at 65°C for 72 hours and weighed.
Ratio of dry weight to fresh weight	Rdf		= Wd ⁄ Wf
Dry weight	Wd	kg	= Wf Rdf
Volume Index	VI	m^3	= DBH^2 H ⁄ 10,000
Stem volume (cylinder)	V_z	m^3	= $\frac{\pi}{4}$ VI
Form factor	ff		Ratio of volume of the stem to the volume of the cylinder = V_s / V_z
Estimated stem volume	V_e	m^3	= V_z ff = $\frac{\pi}{4}$ VI ff
Stem density		kg m^{-3}	= Wd (stem) ⁄ V_s
CO_2 sequestration per tree		kg	= C content × ratio of CO_2 to C × dry weight = 50% × 3.666 × Wd
Annual CO_2 sequestration per tree		kg	= Co_2 sequestration ⁄ age in years

Exploratory data analyses were performed including scatter diagrams for a wider set of criteria and their relationships to understand what the data encompasses and to identify beforehand “unusual” observations (e.g., outliers, influential observations or suspected observations). Many authors (e.g., Box and Cox 1964, Tukey 1977, Belsley et al. 1980, Kleinbaum et al. 1988, Chatterjee and Yilmaz 1992, Barnett and Lewis 1994, Cook and Weisberg 1995) describe how to identify and treat such observations. As an example, diameters measured at different distances from the trunk base (Figure 4.3) showed around 4% “unusual” measurements. These had almost higher values than would be expected, because most probably measurements were conducted near a branch whorl. Best fitting polynomial model was identified followed by removing the unusual observation and re-identifying the best-fitting model. The obtained model parameters, i.e., regression coefficients, were used to determine the missing value, which was previously removed.

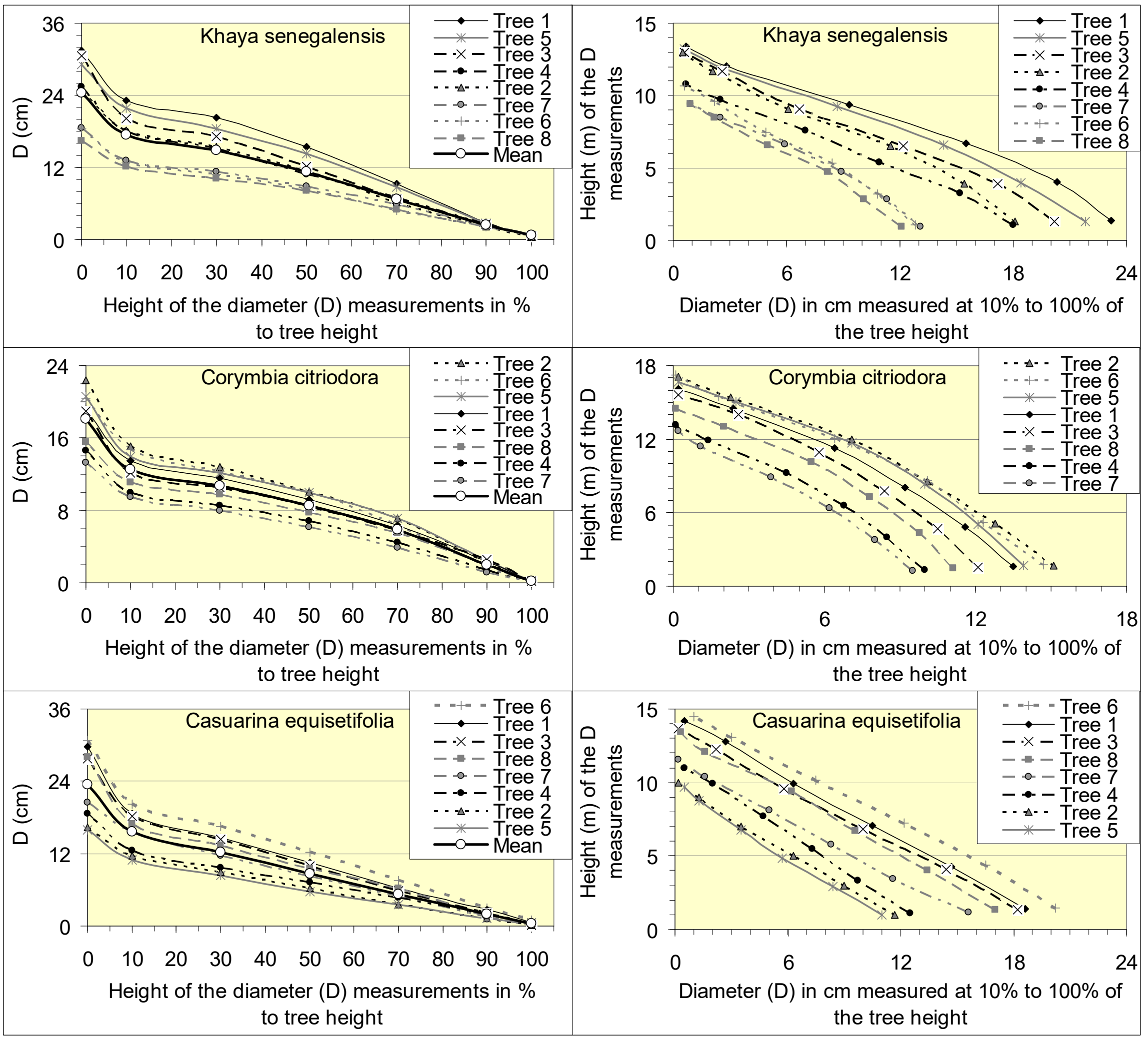


Figure 4.3: Diameters at different relative heights of each felled tree (left) and the relationship between the diameters at 10% to 100% of the tree height and their absolute distance (i.e., height) from the trunk base (right)

Most of the analyses used in the present study aims at identifying relationships between dependent and independent variables. For linear as well as 2nd and 3rd polynomial regression analyses, the programme of El Kateb (2014) was used. This includes a set of different transformations of scores (e.g., logarithmic, square root, reciprocal, arcsine square root or power transformations) for stabilising the variance (Kleinbaum et al. 1988, Kirk 1995). Analyses were simultaneously conducted for the different transformations (Figure 4.4 shows for simplicity examples of only those common transformations in Microsoft Excel). Before drawing inferences regarding the model estimates, residual analyses (Draper and Smith 1981, El Kateb 1991, Hartung 2009, Hartung and Elpelt 2011, Kleinbaum et al. 1988, Montgomery and Peck 1982, Schuchard-Ficher et al. 1982) were performed (Figure 4.4) to examine the assumptions associated with the regression model and to detect and treat outliers and influential observations. Models which do not violate the assumptions were first selected followed by deciding on the model with the highest “goodness of fit”. Furnival (1961) proposed a simple index to compare the fit of models using different transformations, with the lowest index value indicating the "best" fit. For the linear regression, the coefficients (slope (b_1) and intercept (b_0)) were tested: H_0: b_1 = 0 and H_0: b_0 =0. If the last hypothesis was not rejected and there was no serious change in the regression appearance, b_0 was removed from the regression equation. The same was undertaken for the polynomial regression.

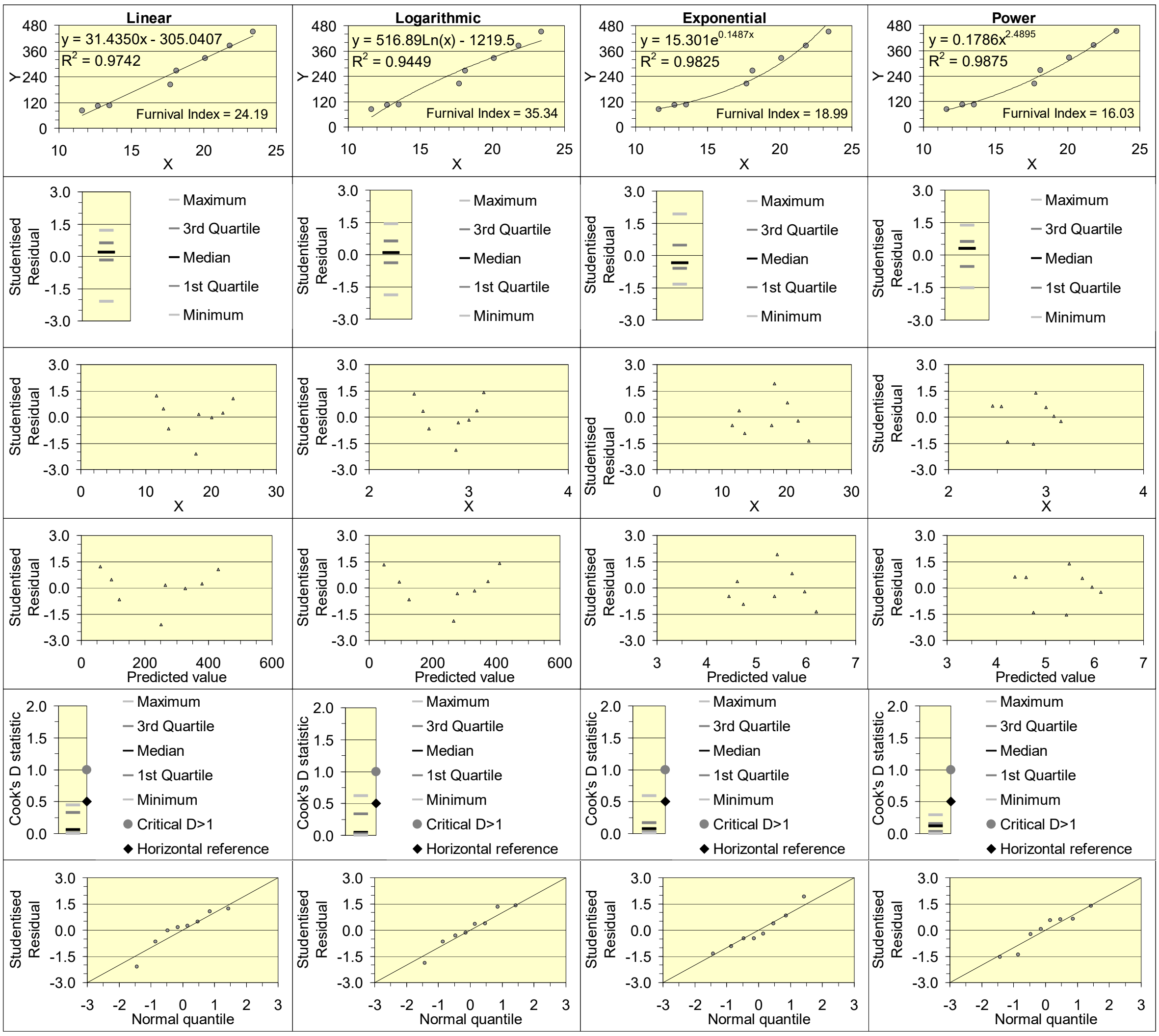


Figure 4.4: An example (relationship DBH (X) to total tree biomass (Y) of *K. senegalensis*) for the selection of the regression model that does not violate the assumptions according to El Kateb (2014). The Figure includes for the four presented transformations (left to right), scatter plot of Y vs. X, box-plot for the studentised residuals (a residual divided by an estimate of its standard deviation), residual plot of the studentised residual vs. X[1], residual plot of the studentised residual vs. the predicted value[1], box-plot for the Cook's D statistic[2] and quantile-quantile plot[3] of the studentised residuals from top to bottom, respectively. In this example, the model designated with “power” is selected.

[1]The homoscedasticity assumption is fulfilled, when the residuals represent a homogeneous and horizontal strip centred at zero with an almost constant width. The assumption is not met if a noticeable pattern is obvious.

[2]Observations whose Cook’s D statistic lies above the horizontal reference line at a value of 4 ⁄ number of observations are deemed to be influential (Rawlings et al. 1998). As a simple approximation, an observation whose Cook’s D statistic lies above 1 needs closer scrutiny (Cook and Weisberg 1995).

For the three investigated species, a scenario for the development of un-thinned stands from age 5 to 35 years was constructed In order to evaluate the potential of the afforestation in desert lands using nutrient-rich wastewater for irrigation. Based on the annual DBH increments (Di) and annual height increment (Hi) up to the age of felling the sample trees, relationships were constructed, assuming a decrease in the Di and Hi with increasing age. The annual increments were then used in calculating the arithmetic means of the relevant criteria (e.g., DBH, height, volume index and dry weight) for the various ages specified in the scenario.

The scenario is based on assumptions that nearly reflect the situation in the afforestation in desert lands. The stands are dense and thinning operations are not conducted. Every single tree is irrigated and fertilised by the nutrients contained in the wastewater. This slows down the self-thinning process and reduces the mortality rate due to less competition for resources between the individuals. We assumed that the density development is depending on the space of a theoretical crown expansion. Using the regression parameters in Figure 4.5 for the relationship volume index-crown radius after adjustment to the projected DBH and height values, a first prediction for the development of the number of individuals per hectare was made (10,000 m^2 ⁄ average crown projection area in m^2). We assumed a lessened mortality of 10% for all three species and an overlapping of the crowns of 25% for *K. senegalensis* and *C. citriodora*, due to their shade-tolerant ability (Glencross et al. (2016) reported that the characteristics of *C. citriodora* are consistent with a more shade tolerant species and França et al. (2015) classified *K. senegalensis* as moderately shade tolerant). Accordingly, a density-age relationship was constructed.

4.23. Results

Results of the estimation of the form factor (Table 4.3) showed that *C. citriodora* has the highest value, followed by *K. senegalensis* and *C. equisetifolia*.

K. senegalensis has the highest stem density (wood and bark) among the three species. *C. citriodora* and *C. equisetifolia* are similar in stem density (Table 4.4).

Table 4.3: The form factor based on an estimate of the volume of each felled tree

Species	Mean & Standard Error	Median	Minimum	Maximum
Khaya senegalensis	0.5056 ± 0.0072	0.5011	0.4842	0.5498
Corymbia citriodora	0.5160 ± 0.0048	0.5164	0.4975	0.5381
Casuarina equisetifolia	0.4733 ± 0.0071	0.4733	0.4490	0.5106

Table 4.4: *Stem density (kg m^{-3}) based on eight sample trees for each species.*

	Mean & Standard Error	Median	Minimum	Maximum
Khaya senegalensis	955.98 ± 12.72	966.30	876.73	992.96
Corymbia citriodora	633.47 ± 08.65	637. 05	586. 16	660.46
Casuarina equisetifolia	628.72 ± 11.72	634.24	565.65	666.40

The volume index and DBH were each used as a predictor in the estimation of the crown criteria as well as the volume, dry weight and carbon dioxide sequestration of the individual trees of the three species (Figure 4.5 to Figure 4.10). Both the DBH and volume index showed that they have high strength of relationship with the response variable (crown criteria, volume, dry weight or CO_2 sequestration). All relationships were always statistically significant, with p-values of $p<0.05$.

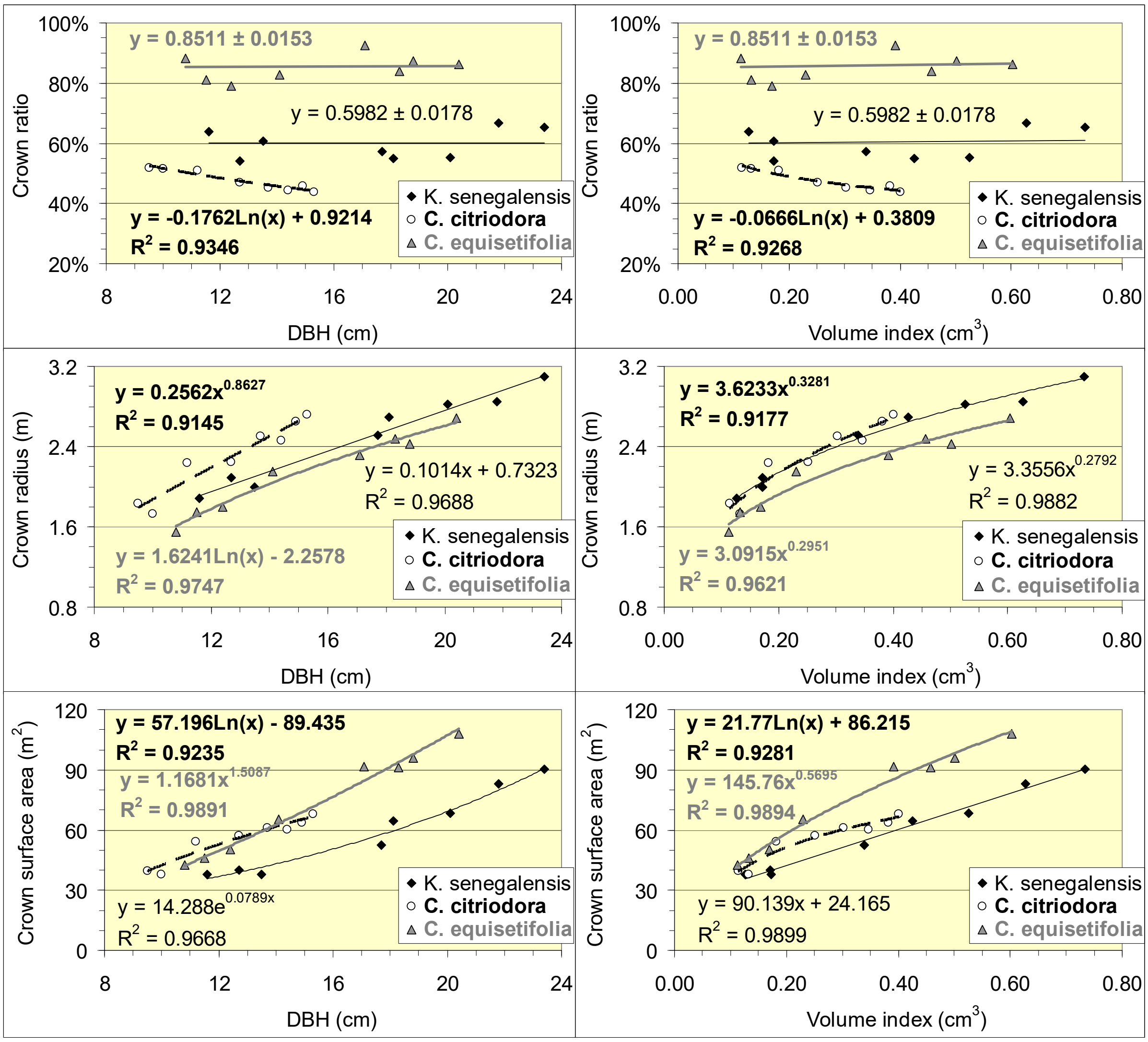


Figure 4.5: Different crown criteria in dependency of the DBH (left) and volume index (right).

The crown ratio (crown length to total tree height) of *C. equisetifolia* and *K. senegalensis* was independent from the stem size, while the crown length of *C. citriodora* decreased with increasing DBH and stem volume (Figure 4.5). At a same DBH value, the crown radius of *C. citriodora* was the largest among the investigated species, followed by *K. senegalensis* and *C. equisetifolia* (Figure 4.5). As the crown radius, the crown surface area was strongly dependent on the stem size and was largest for *C. equisetifolia*.

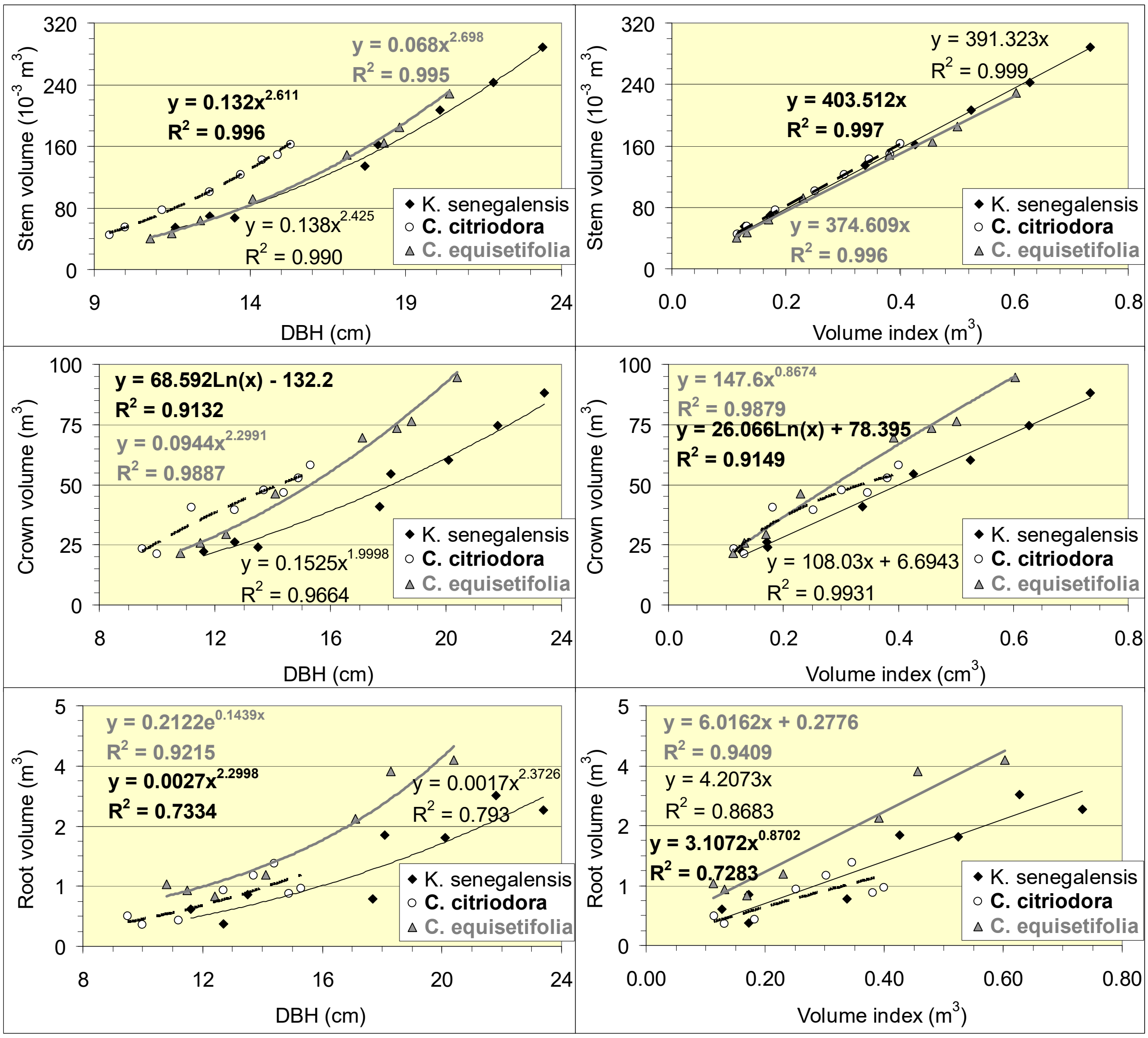


Figure 4.6: Relationship between the volume and DBH (left) or volume index (right).

Assuming a same DBH value for all three species, it can be concluded that the stem and crown volumes of *C. citriodora* are higher than those of *C. equisetifolia* and *K. senegalensis* and that the root volume of *C. equisetifolia* > *C. citriodora* > *K. senegalensis* (Figure 4.6). These outcomes are not necessarily identical, if a same tree volume-index is taken into account for all species. In this event, the stem volume of *C. citriodora* is > *K. senegalensis* > *C. equisetifolia*, the crown volume of *C. equisetifolia* > *C. citriodora* > *K. senegalensis* and the root volume of *C. equisetifolia* > *K. senegalensis* > *C. citriodora* (Figure 4.6).

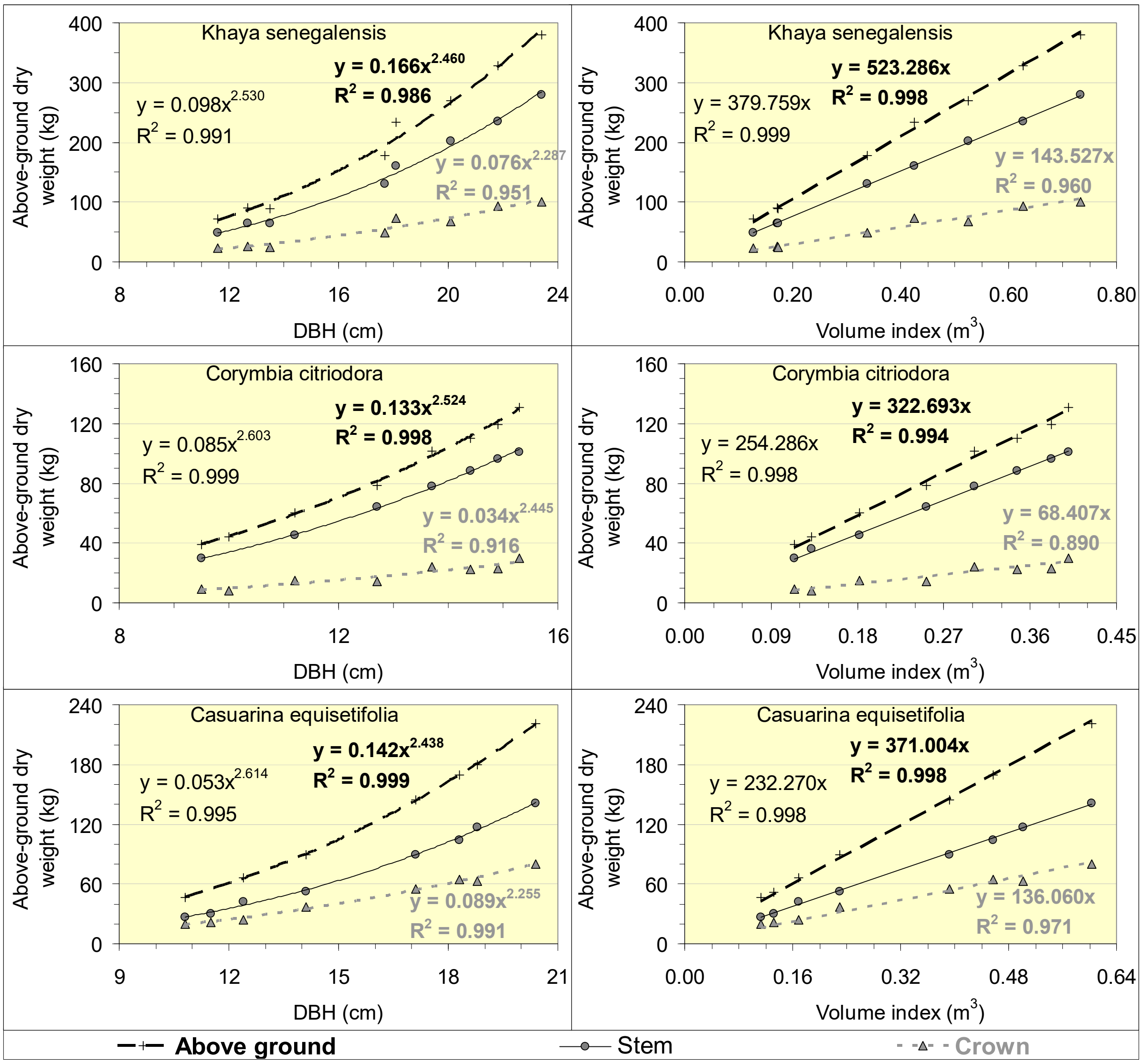


Figure 4.7: Aboveground biomass as a function of the DBH (left) and volume index (right).

According to the age of the investigated species, the highest aboveground biomass has *K. senegalensis*, followed by *C. equisetifolia* and *C. citriodora* (Figure 4.7). The ratio of the crown biomass to the aboveground biomass of *C. equisetifolia*, *K. senegalensis* and *C. citriodora* equals 136.1/371.0 = 36.7%, 143.5/523.3 = 27.4% and 68.4/322.7 = 21.2%, respectively (Figure 4.7, right). The ratio of the root biomass to the total tree biomass equals 79.0/401.7 = 19.7%, 71.4/439.8 = 16.2% and 93.0/616.3 = 15.1% for *C. citriodora*, *C. equisetifolia* and *K. senegalensis*, respectively (Figure 4.8, right). The highest total accumulated tree biomass has *K. senegalensis*, followed by *C. equisetifolia* and *C. citriodora*, which is attributed to the age of the investigated stands. The same outcomes are to be expected for the carbon accumulation (Figure 4.10). Nevertheless, the annual CO_2 sequestration of an individual tree is highest for *C. citriodora*, followed by *C. equisetifolia* and *K. senegalensis* (Figure 4.9).

For all the three species, the stem has the highest portion of the total carbon stored in a tree with 61.6%, 63.3% and 52.8% for *K. senegalensis*, *C. citriodora* and *C. equisetifolia*, respectively (Figure 4.10, right). The crown has a share in the tree carbon storage of 23.3%, 17.0% and 30.9% for *K. senegalensis*, *C. citriodora* and *C. equisetifolia*, respectively.

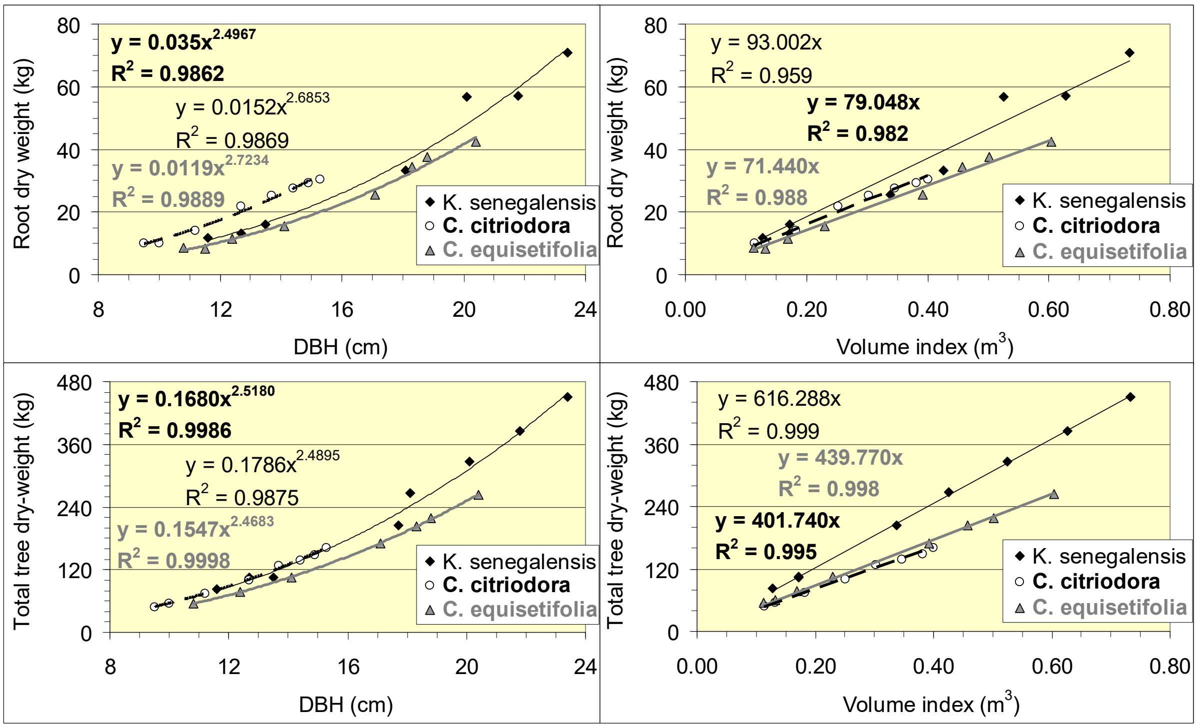


Figure 4.8: Belowground biomass as a function of the DBH or volume index (top), and total tree-biomass as a function of the DBH or volume index (bottom).

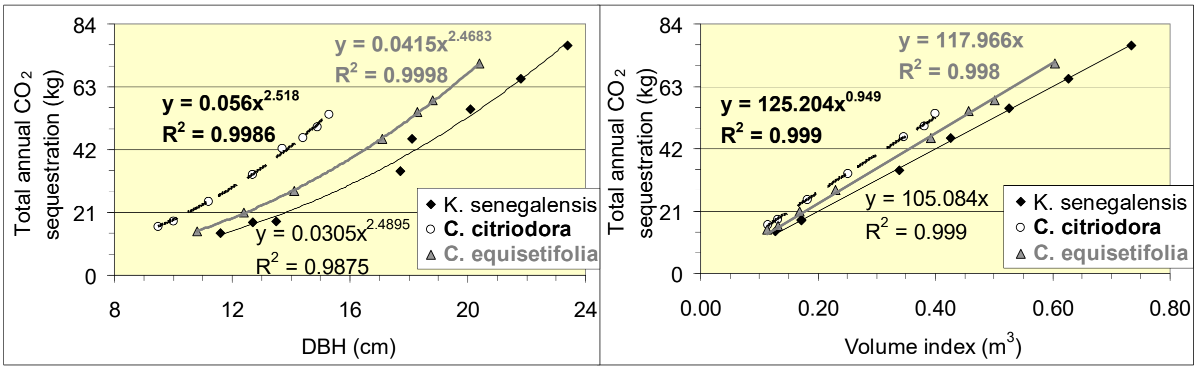


Figure 4.9: Annual CO_2 sequestration per tree as a function of the DBH (left) and volume index (right).

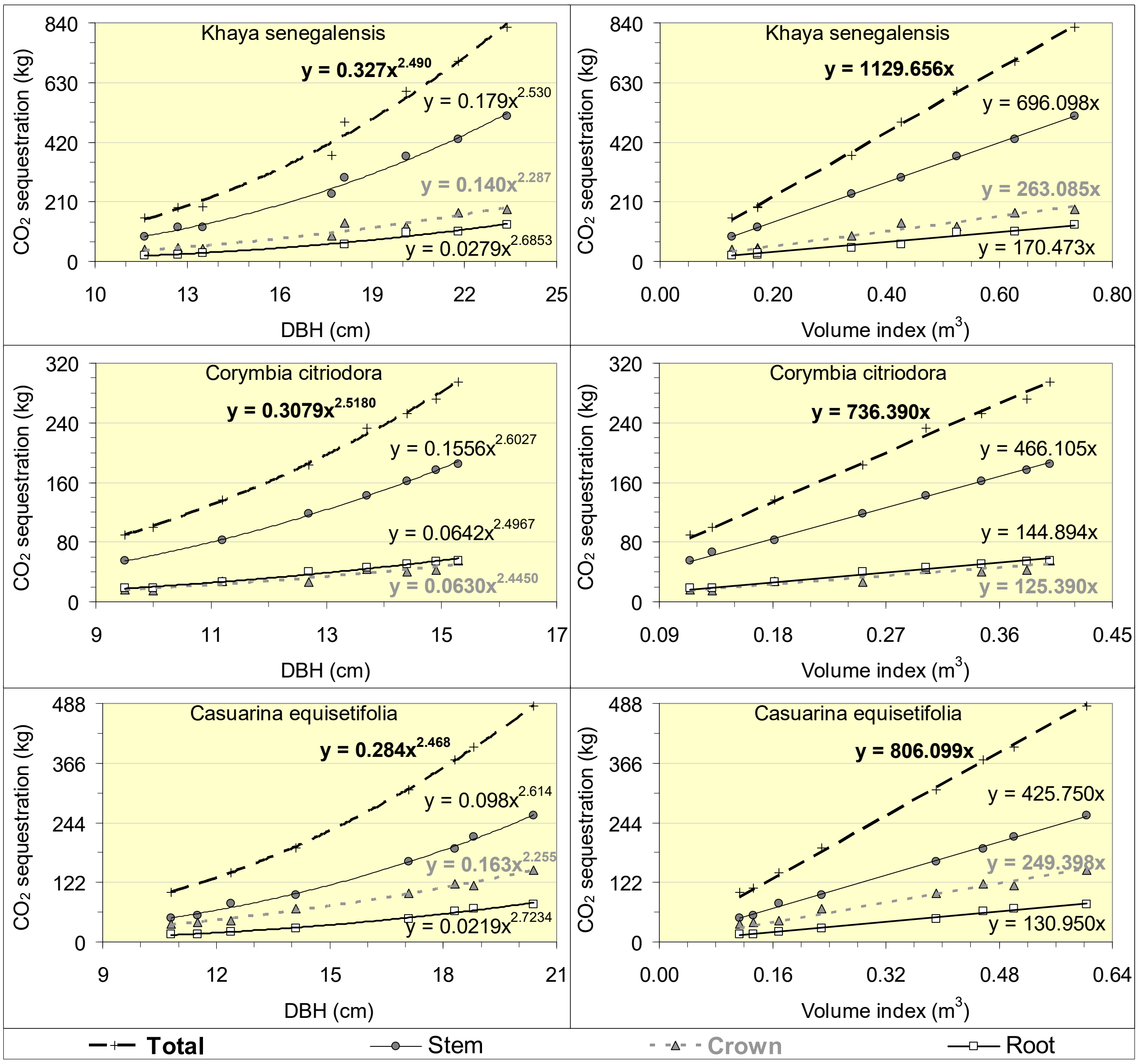


Figure 4.10: CO_2 sequestration per tree at the age of felling as a function of the DBH (left) and volume index (right). R^2 for the presented regression equations are the same as those for the dry weight, since the CO_2 sequestration is a result of multiplying the dry weight by a constant (C content × ratio of CO_2 to C).

The results of the scenario for the development of un-thinned stands are illustrated in Figure 4.11 and Figure 4.12, where the assumptions of the scenario regarding density, mean DBH and mean height are presented at the top of Figure 4.11. Despite the constructive assumptions, results clearly reveal the high potential for afforestation irrigated by nutrient-rich wastewater in desert lands. At the age of 25 years, the basal area for all three species exceeds 31 m^2/ha. All three species at this age attain stem volumes of over 398 m^3/ha and both in aboveground and belowground biomass over 860 t/ha carbon dioxide is sequestered. The highest annual CO_2 sequestration of 53 and 43 t/ha is achieved at the age of 15 years by *C. citriodora* and *C. equisetifolia*, respectively, while *K. senegalensis* reaches ten years later an annual amount of 45 t/ha (Figure 4.11).

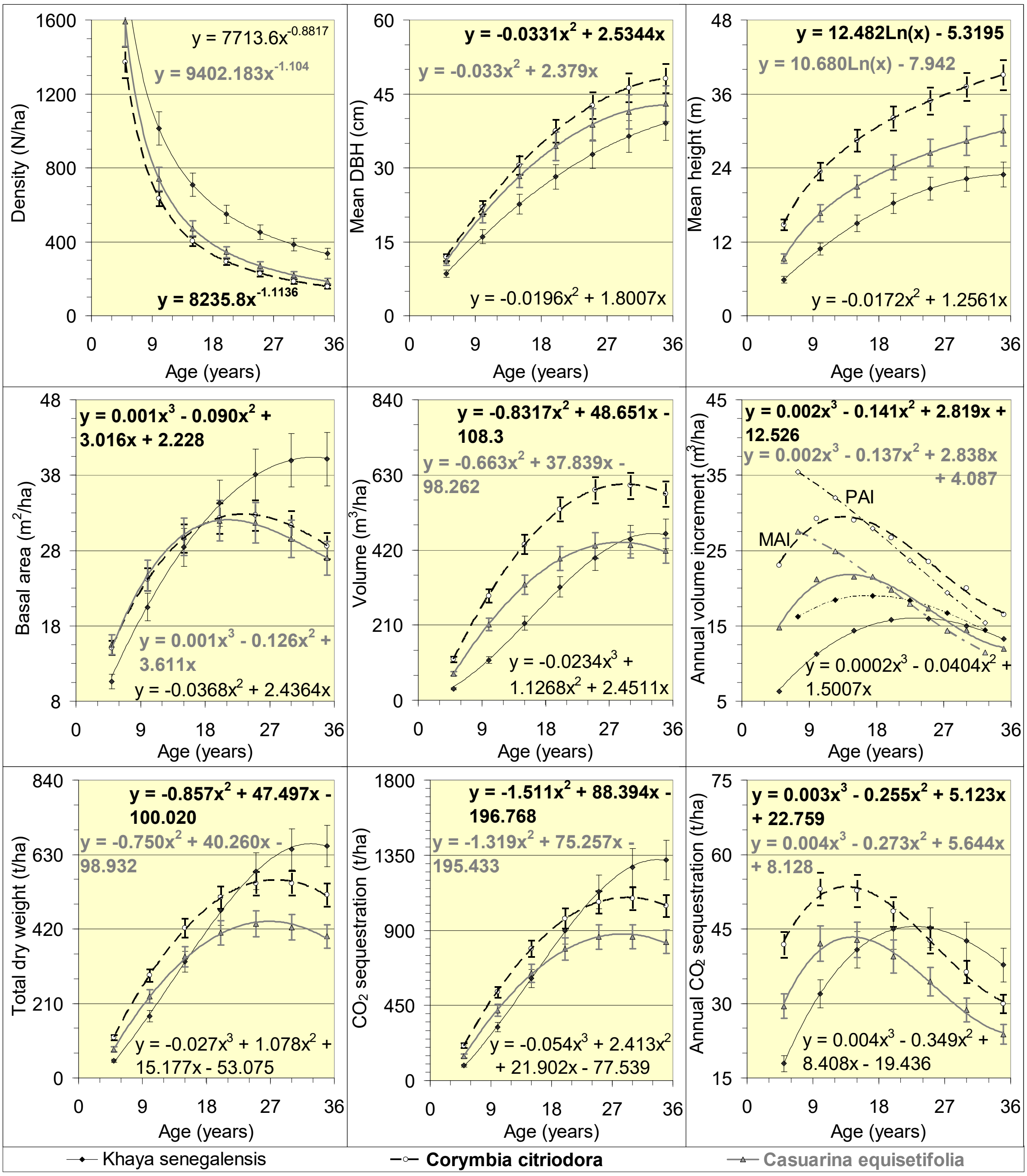


Figure 4.11: Projected development of un-thinned stands of the investigated species.

The outcomes suggest a harvesting time for *C. citriodora*, *C. equisetifolia* and *K. senegalensis* at 15-20, 15-20 and 30-35 years, respectively (Figure 4.11, middle right). The crossing point of the periodic annual increment (PAI, i.e., difference in volume between two periods divided by the number of years between those two periods) and mean annual increment (MAI) is an indication for attaining the culmination of the MAI, which will further be descended.

In Figure 4.12 some outcomes of the scenario related to the mean of the individual trees are presented. The highest mean annual volume increment and the highest carbon dioxide sequestration are projected for *C. citriodora*, followed by *C. equisetifolia* and *K. senegalensis*. At the age of 25, the means of the individual trees achieve 103, 64 and 35 10^{-3} m^3 (annual volume-increment) and 188, 128 and 100 kg (total annual CO_2 sequestration of the aboveground and belowground biomass) for *C. citriodora*, *C. equisetifolia* and *K. senegalensis*, respectively.

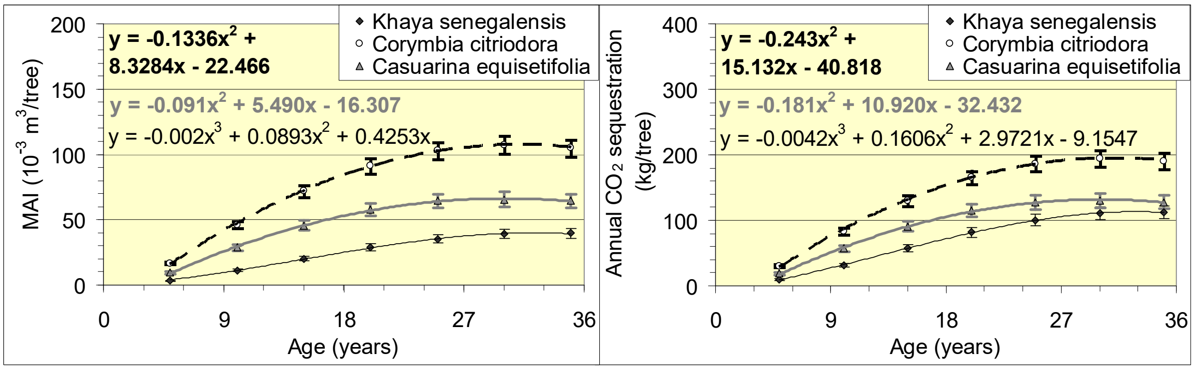


Figure 4.12: Projected means of the individual trees: Mean annual volume increment (MAI) and mean annual CO_2 sequestration of the aboveground and underground biomass.

4.24. Discussion

The study did not have the objective of statistically comparing the three investigated species. The Intensive data and statistical analyses were directed to reliable estimations of the regression coefficients for the individual trees. Both, the DBH and volume index proved to be appropriate predictors for the response variables. The coefficient of determination (R^2) was always high. This, however, was not a rationale for selecting the model, as a wider range of a predictor value usually leads to a higher R^2. Selection of models was based on careful examination of the assumptions associated with the regression models. Nevertheless, making inference, however, is only limited to the range of the exploratory criteria used in this study.

It should be noted that all root criteria are underestimated, since fine roots and parts of coarse roots with a diameter less than 2 mm could not be excavated. It should also be emphasised that the results of *K. senegalensis* are based on trees that suffered from camel browsing at an early age.

The determined form factor should be accurate, since it was based on the summation of the volume of six circular truncated cones for each sample tree. The values estimated for the form factor are, more or less, comparable to the results of other studies (Clement 1982, FAO 1981). The stem densities reported by other authors for the studied species (Brown 1997, Kindo et al. 2014, Okoye et al. 2014, Sotannde et al. 2015) correspond to the density values determined in the present study.

Only a few studies could be found that dealt with individual trees of a comparable age to the species investigated in the Serapium Forest. For *K. senegalensis* at an age class of 11-12 years in Sri Lanka, Warnasooriya and Sivananthawerl (2016) estimated, based on allometric relationships, a lower average of the total tree biomass than the values found in the Serapium Forest. For *C. citriodora* at the ages of 5 and 7 years in the Serapium Forest, Ismail et al. (2018) studied the wood mechanical properties and estimated the volume and aboveground biomass per individual tree. Their estimates were very close to the results of the 5.5 years old *C. citriodora* investigated in the present study. Xue et al. (2016) estimated the total biomass of individual trees of *C. equisetifolia* stands at age classes ≤5 and >6 - ≤15 in a tropical forest in Hainan Island in China. The results of their study regarding the average total biomass of the individual trees were considerably lower than the biomass of the *C. equisetifolia* irrigated by sewage water in the Serapium Forest. However, their estimates of the maximum total biomass of the individual trees were close to our results.

Table 4.5: Number of trees per ha estimated in the scenario (N ha^{-1}) compared to the existing density in plantation forests in Egypt (stem ha^{-1}). "Existing" data are obtained from Farahat and Linderholm (2012 b).

Species	Location	Age	N ha^{-1}	N ha^{-1} to stem ha^{-1}
Eucalyptus camaldulensis (performance of this species is assumed to be similar to *C. citriodora*)	Sadat City	9 years	713	64%
	Serapium	8 years	813	81%
	El Tur	13 years	473	63%
Casuarina spp.	Sadat City	10 years	740	61%
	El Tur	13 years	554	65%

The results of the scenario may seem astonishing, but it should be emphasised that in desert lands, where there is sufficient sunlight and trees are irrigated with nutrient-rich sewage water, competition, mainly for light, is to be expected when the canopy closes. Under such conditions, it must be assumed that the suppressed individuals survive longer, since competition occurs when individuals have limited resources. This explains the high densities of the investigated stands and other older stands irrigated by sewage water in Egypt (cf. Farahat and Linderholm 2012 b). Table 4.5 clearly indicates that the scenario is based on conservative assumptions: The projected number of trees ha^{-1} for the age ≥ 9 years in the scenario is at least 35% lower than the existing densities in Egypt. Furthermore, Wang et al. (2013) studied coastal shelterbelt-plantations of *C. equisetifolia* of four different ages in South China. They reported that 3, 6, 13 and 18 years old plantations have densities of 2,350 ± 87, 2,200 ± 82, 1,250 ± 144 and 975 ± 63 individual ha^{-1}, respectively. These represent much higher densities (60% more at an age ≥ 13 years) than considered in the scenario (Figure 4.11).

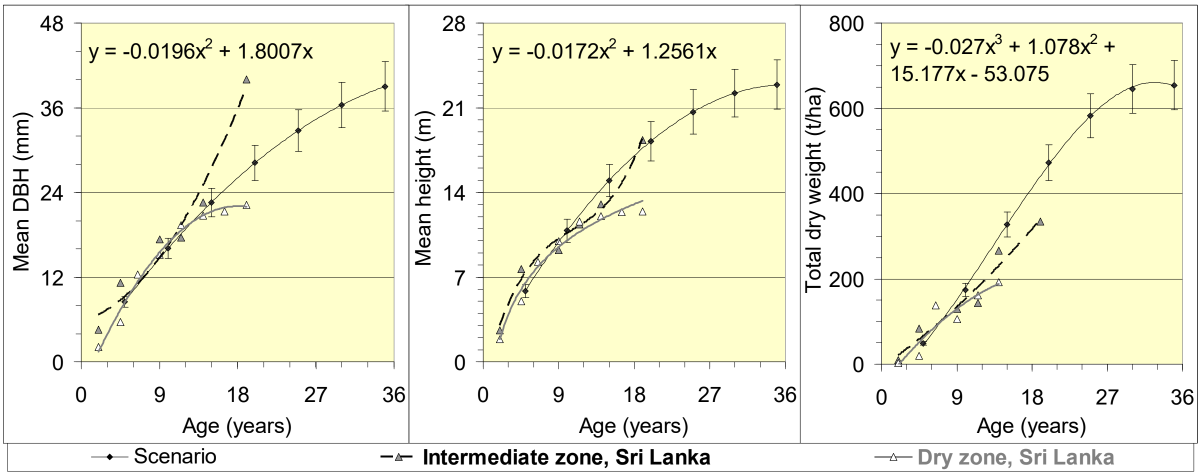


Figure 4.13: Comparison of the results of the K. senegalensis study conducted by Warnasooriya and Sivananthawerl (2016) in Sri Lanka and the scenario.

Fortunately, Warnasooriya and Sivananthawerl (2016) present sufficient data related to DBH and height measurements as well as estimates of the biomass using allometric relationship for *K. senegalensis*. The study was carried out in Sri Lanka on eight age classes (from 1 to 20 years) in two different zones: intermediate and dry. Thinning took place at the ages of 7, 15 and 20 years with stand densities prior to thinning of 1600, 800 and 400 stem ha^{-1}, respectively. Figure 4.13 compares these figures with the scenario. At the age of 19, the means of the DBH and height of the intermediate stands in Sri Lanka are higher than those values for the scenario. The difference in the biomass is due to two reasons. Thinning operations have been carried out in the Sri Lankan stands and the allometric equation used in the study of Warnasooriya and Sivananthawerl (2016) underestimates the aboveground biomass by 25%, on average. This is a result of applying the allometric equation to our data and comparing its estimates with the aboveground biomass weighed in the present study. Furthermore, Figure 4.13 shows that the assumptions underlying the scenario are moderate, as these stands in Sri Lanka are neither irrigated nor fertilised.

According to Snowdon and Benson (1992), Albaugh et al. (2006) and Campoe et al. (2013), irrigation and fertilisation have significant positive effects on growth and production. In brief: Snowdon and Benson (1992) reported 2.1 and 2.5 folds more annual volume-increment due to irrigation in combination with solid and liquid fertilisation, respectively; Albaugh et al. (2006) found that after seven years, the stand basal area of fertilised plots had a statistically significant increase of 62% over non-fertilised plots; Campoe et al. (2013) revealed that irrigation in combination with fertilization tripled production of the largest 20% trees compared to those non-treated.

It can be concluded that irrigation and fertilisation have a substantial effect on production, much more than was considered in the cautiously and conservatively constructed scenario. It should be mentioned that data were collected from inadequately-managed plantations, in which trees originated from very poor seeds and planting materials and plants were often not irrigated for long periods of time. Plantations were also not protected against browsing: *K. senegalensis*, in particular, suffered from intensive camel browsing.

Winjum et al. (1992) conducted a study that includes 94 forested nations and found that the median of the mean carbon (C) storage values for the boreal latitudes is 16 t C ha^{-1}, while in the temperate and tropical latitudes the median values are 71 t C ha^{-1} and 66 t C ha^{-1}, respectively. They projected that if the forest practices described in their study were "implemented on 0.6 to 1.2 10^9 ha of available land over a 50-yr period, approximately 50 to 100 GtC could be sequestered". We projected at the age of 25 for *K. senegalensis*, *C. citriodora* and *C. equisetifolia* 308, 291 and 234 t C ha^{-1} in desert lands in Egypt. This theoretically means that an area of desert lands irrigated by sewage water, which equals 30% of the 0.6 to 1.2 10^9 ha, is sufficient to sequester 50 to 100 Gt C in 25 years or half the 50-years period.

Without a doubt, results showed the high potential for afforestation in the desert lands of Egypt, despite the mismanagement of the plantation forests. Irrespective of the management quality, afforestation in arid regions, or desert afforestation using nutrient-rich wastewater, represents a unique situation in forestry. This may require further longer observations and new strategies as well as adapted management plans and practices for the different objectives of afforestation, whether for carbon sequestration, production of timber, biomass or biofuel crops, environmental motivations or recreation. However, it is becoming clear that plantation forests in desert lands can play an important role in reducing the greenhouse gas emissions in the atmosphere and stabilising the climate: High carbon storage in a short time period on sufficiently available and unused desert lands. Such afforestation may best be managed towards, firstly, carbon sequestration and, secondly, timber production. Some moderate thinning operations may have to be carried out at an early age (El Kateb et al. (2006) stated that the earlier a thinning operation is imposed, the sooner the target DBH is achieved). At maturity, at least 10% of the vigorous old trees should remain for further carbon storage. According to Stephenson et al. (2014) large, old trees actively fix large amounts of carbon compared to smaller trees.

Another indication for the success of afforestation in desert lands is illustrated in Figure 4.14 for some species that were planted within the frame of the project conducted by the Institute of Silviculture at the TUM and described in El Kateb et al. (2015). A short time after planting, the growth potential of diverse species is recognised (Figure 4.14).

Figure 4.14: Some examples of new planted species in desert lands of Egypt. From top left to bottom right: Acacia mangium 34 months, Azadirachta indica 42 months, Corymbia citriodora 6 months, Gmelina arborea 22 months, Jatropha curcas 22 months, Khaya senegalensis 42 months, Pinus canariensis 38 months, Swietenia mahagoni 13 months and Tectona grandis 6 months.

Finally, results of the conducted experiments clearly show the high potential of the afforestation in desert lands of Egypt, which can substantially support global efforts exerted to reduce greenhouse gas emissions in the atmosphere and to stabilize the climate. El Kateb et al (2022) summarise the Benefits of afforestation in arid regions as follows:

> “Climate change, desertification, water and food scarcity, drought, erosion and sea level rise are some of the threats facing many of the arid regions. Adaptation measures to climate change such as afforestation, agro-forestry, windbreaks, urban forestry and tree plantings along waterways and streets support global mitigation. All of these measures, particularly afforestation as an effective tool to carbon dioxide fixation, have the following multi-functional benefits:
>
> – Support adaptation to climate change.
> – Prevent environmental pollution.
> – Help maintain biological diversity and enhance wildlife habitats.
> – Support increasing infiltration rates and decreasing surface runoff.
> – Prevent desertification and erosion and protect coastal areas.
> – Lessen temperature fluctuation between day and night in desert climates.
> – Cooling and slight warming effects on summer days and winter nights, respectively, leading to reduced energy consumption.
> – Efficient use of scarce water resources.
> – Wood production and biofuel-crop production, as a renewable energy source.

- Protect human settlements from wind and sand.
- Improve air quality and reduce the impact of heat waves.
- Support food security for an increasing population through combating desertification and protection of agricultural lands from wind and sand damage. Afforestation for windbreaks in arid lands can be employed to protect cultivated areas (e.g., for food production). This leads to considerable reduction in environmental stresses (reducing plant damage by frost, sand deposits and insects, conserving moisture in plants and soil and creating favourable microclimates), improving habitats for decomposer organisms and enhancing the efficiency of irrigation and fertilisation, thus, achieving higher yields on the protected areas.
- Offering recreational opportunities and improving the aesthetic quality in arid regions.

In addition to these advantages, large-scale afforestation stimulates cloud formation and may also lead to rainfall (El Kateb and Mosandl 2012), which is urgently needed in arid regions".

5. Conclusions and recommendations

5.1. Recommendations for silvicultural experiments regarding experimental designs and statistical analyses

Forest is a complex ecosystem. Any intervention influences the different compartments of a forest. Forests are dynamic and a change in a compartment, or even in an individual of a compartment, leads to change in another compartment. Silvicultural measures usually modify or manage one or more compartments in a forest stand. This leads to modification of other compartments and raise the complexity. In silvicultural experiments strategy (Figure 5.1) must be set to gain reliable information. One of the objectives of silviculture is the assessment of a series of silvicultural techniques according to scientific, ecological, economic, social but also practical criteria, in order to support a decision-making about the desired silvicultural goal. The strategy for silvicultural experiments should be directed toward gaining as much meaningful information as possible in order to draw inductive conclusions (Figure 5.1) about the silvicultural measures.

Research strategy

- Precise formulating of objectives, hypotheses, and tasks toward solving a forestry problem.
- Selection of appropriate treatment options.
- Selection of an appropriate experimental design and related statistical analyses.
- Adequate sampling procedures
- Implementation of treatments and the entire research projects.

↓

Analysis strategy

- Analysis of initial status.
- Checking plausibility of collected data.
- Exploratory data analyses to analyse and understand complex relationships in data.
- Checking assumptions of the statistical analysis, model fitting and hypothesis testing.
- Fulfilment of the assumptions for model fitting and hypothesis testing.

↓

Validity

- Confirmatory approach (a priori hypotheses) towards the evaluation of evidence.
- Validity of the treatment effects.
- External validity to generalise experimental findings.

↓

Gaining meaningful information to inductive conclusions about the research questions.
Recommendation on appropriate silvicultural measures based on scientific knowledge.

Figure 5.1: Strategies to conducting silvicultural experiments and evaluating silvicultural techniques (cf. Hoaglin et al. 1991, Kimmelman et al. 2014, Kirk 1995, Tukey 1977).

The presented examples are based on the silviculture understanding of Mosandl et al. (2003) that laid emphases on gaining reliable information from silvicultural experiments. Such silvicultural experiments can provide recommendations based on scientific knowledge (e.g., species selection, quality of seeds and planting materials, necessity of protection, site preparation and silvicultural techniques to tending and thinning, etc) to minimise risks related to afforestation initiatives and thus lead to the success of the afforestation.

Some recommendations regarding the experimental designs and statistical analyses can be derived from the experiments introduced in this study. These are presented below.

- The first step in planning an experiment is the composition of a draft proposal that at least contains the objectives, description of the experiment (including the experimental treatments and materials and the size of the experimental units), an outline of the statistical techniques, and importantly inferences that can be made from the experiment. Last depends on the way in which the experiment should be carried out and the selected experimental design. Silvicultural experiments typically face challenges related to number of replicates, selection of the appropriate experimental design without sacrificing precision on the study factor of interest and finally the cost of the experiment. There are typical experimental designs available (Cochran and Cox 1992, Hartung 2009, Kirk 1995). Young researchers are often not aware that one design can be composed of one or more experimental designs. In El Kateb et al. (2015), some examples are given for combining more than one experimental design with the intention to reduce the cost and the area required for an experiment. For young researchers, it may be helpful to ask for advice from statisticians.
- The number of samples selected from an experimental unit is often a challenging factor in silvicultural experiments, particularly if observation is intended over a long period of time, when trees have become vigorous. Since trees can be affected by neighbourhood surroundings, it is common to install a core area surrounded by a buffer zone. Sample selection and data collection is only undertaken on the core area. Depending on the cost of the experiment, it is recommended to plan a large size of the core area to allow data collection over a sufficient number of samples that help reliable estimates of the population parameters at the end of the observation period. Sufficient numbers depend on the variation within the samples of trees, which is unknown at the planning phase. This makes a comparison between population means of different treatments (e.g., silvicultural techniques) difficult, particularly if the variability is high. However, comparing regression equations using dummy variable coding scheme or other coding (Kleinbaum et al. 1988) can help determine differences between treatments, when, roughly said, five to seven individuals for a treatment level are available. This small number of individuals will help quantifying associations between a dependent variable and one or more independent variables.
- In silvicultural experiments usually data is collected in fields with uncertainty that all measurements are correct. Suspected data recording, outliers or influential observations affect the estimation of the true parameters of a population leading to bias and unreliable results. In the study of El Kateb et al. (2022), a comprehensive description of how to identify, deal with such records is presented. The importance of the exploratory data

analysis and visualisation of data are emphasised to understand the complex mechanisms of a forest and detect meaningful relationships but also suspect records. In addition, residual analyses, transformation of data to stabilise the variance and examination of the assumptions associated with statistical models are exemplified. All of these analyses are of important consideration towards gaining reliable information and ultimately help drawing inductive inference from the results of an experiment.

- Analysis of variance (ANOVA) is a frequently used statistical method (examples are given in the experiments in the Ore Mountains (El Kateb et al. 2004) and Southern Shaanxi Province (El Kateb 2013)). A common use of the ANOVA is in performing multiple hypotheses tests (Kirk 1995, Kleinbaum et al. 1988, Toothaker 1991). The probability of making a Type I error (falsely rejecting a null hypothesis) increases with increasing number of tests (probability of type I error = $1-(1-\alpha)^C$, where α = significance level of e.g., 0.001, 0.01 or 0.05 and C = number of independent hypotheses to be tested). Orthogonal contrasts (Bortz 1985, Kirk 1995, Kleinbaum et al. 1988) can be used for testing a hypothesis about the equality of population means, when the p levels of a factor of fixed-effects are greater two. Orthogonal contrasts are independent linear comparisons between p-1 levels of the factor. The sum of squares for the p-level factor can be partitioned into p-1 orthogonal contrasts or according to Kleinbaum et al. (1988) into meaningful components associated with certain specific comparisons of particular interest (cf. examples indicated in the above-mentioned experiments). In this case, the same error mean-squares for the factor can be used in the hypothesis testing (F-test denominator) of the p-1 contrasts. According to Nogueira (2004), the orthogonal contrast technique is an efficient method of analysing experimental data to obtain the main effects and interaction effects, for comparisons between groups of means.
- Long-term observation is advantageous for reliable assessment of the success/failure of a technique or a measure (cf. El Kateb et al. 2004). Repeated measure analysis is an appropriate tool to examine changes in the measurements taken over time. According to Stevens (2012), repeated measures designs use the same subjects throughout different treatments and thus, may require fewer subjects overall. Because the subjects are constant, the variance due to subjects can be partitioned out of the error variance term, thereby making any statistical tests more powerful.
- Univariate analyses in contrast to multivariate (several dependent variables are studied simultaneously) are commonly used in testing the effect of a factor on each of the dependent variables separately. This approach can be misleading particularly for inexperienced researchers. A significant effect may be detected when all dependent variables are studied simultaneously. Multivariate analyses (Backhaus et al. 20121, Johnson and Wichern 2007, Stevens 2012) do consider the correlation among the

simultaneously studied variables, while univariate analyses do not. When dealing with multivariate data (in afforestation experiments, for example, data can be collected on diameter, height, number of branches, and many other relevant variables), it is recommended to first perform a multivariate analysis. If significant results appear, then univariate analyses can be conducted for each dependent variable to identify those variables leading to these outcomes.

- Investigating and assessing techniques in an experiment are crucial, before transformation of such techniques to large scale. This is of great importance in order to save in resources and in financial means and ensure the success of applying a technique. Results of the experiment conducted in the Ore Mountains (El Kateb et al. 2004) suggest that none of seven amelioration techniques had a substantial effect on survival, growth, production, or vitality of the young plantations.
- The quality of the management responsible for establishing and maintaining of afforestation areas represents a major challenge. Therefore, care should be taken to ensure that qualified personnel are available, as this is not a matter of course in many countries around the world and much of the success of afforestation measures depends on this aspect.

5.2. Closing conclusions

Successful afforestation concepts are becoming of enormous relevance. This is particularly true in connection with the increasing demand for emission certificates and the increasing commitments of many governments to mitigate climate change as well as the increasing public awareness of the role of forests in climate protection.

There is no doubt about the important role of afforestation and reforestation in mitigating climate change. With raising interest in afforestation, the magnitude of silvicultural experiments is also increasing. Silvicultural experiments related to afforestation can maintain gaining scientific-based knowledge that supports the global efforts to mitigate climate change, pollution, erosion, desertification, and biodiversity decline.

It must be emphasised, that management practices should be directed towards enhancing efficiency and developing sustainable forests of diverse species to achieve stability in terms of high resistance and high resilience. Diversity must be encouraged and, on the other hand, large-scale monoculture plantations for industrial use should be avoided, as far as possible. In contrast, integrated agro-forestry and forest-garden systems should be promoted. The realisation of such activities that advances mitigation and adaptation measures urgently require support at the national and international levels.

6. Summary

There is no doubt about the important role of afforestation and reforestation in mitigating climate change. With raising interest in afforestation, the magnitude of silvicultural experiments is also increasing. Examples of experiments dealing with afforestation, reforestation and related subjects under specific environmental conditions and at different geographical locations (Ore Mountains, Germany, Southern Shaanxi Province, China, and desert lands, Egypt) are briefly discussed below.

Ore Mountains, Germany: Large-scale deforestation had been caused by severe air pollution in the Ore Mountains. A silvicultural experiment was conducted with the overall objective to assess the success of the reforestation with native tree species. In a split-plot factorial design, three tree species (Norway spruce, rowanberry, and birch) under two levels of protection against game browsing (fenced and unfenced) and eight levels of site preparation techniques including control and seven amelioration techniques (soil cultivation, weed control, liming, and their combinations) were studied. Repeated-measures analyses were performed to examine the development of the young plantations over an observation period of seven years, and to test whether this development was dependent on the experimental factors (fencing and amelioration techniques). Spruce showed high survival rate and reasonable growth and good individual vitality. With the exception of survival, birch responded similarly to spruce. The low survival rate of birch was a result of the poor quality of the initial seedlings. This reveals the prerequisite for the use of appropriate seedling materials. The development of rowanberry was disturbed due to severe mouse damage, confirming the necessity of rodent control when planting cleared areas with species susceptible to rodent damages. The fencing factor was statistically insignificant, since the density of game population was not high to hinder the regeneration development. None of the amelioration techniques had a major effect on survival and growth of the three tree species. This shows how necessary it is to study such expensive techniques scientifically before putting them into practice.

Southern Shaanxi Province, China: The southern Shaanxi province is of special interest due to its role in diverting water to Beijing within the frame of the South-to-North Water Diversion Project. However, soil loss in the south of the Shaanxi Province is high and the region suffered from raising natural disasters of landslides and floods with considerably shorter intervals. The main reasons for this deterioration are deforestation and inappropriate land use. A Sino-German project was initiated with the overall objective to develop and demonstrate a "land use planning system" for a sustained land use. Information to support the development of the planning system is largely gained from three field experiments on

erosion, afforestation, and assessment of forest resources in addition to a socioeconomic study. The land use planning system will provide a range of prospective possibilities to improve the soil and water conservation in the region. More information about the planning system can be found in El Kateb et al. (2009), while the field experiments on erosion and afforestation are summarised below.

The erosion experiment was carried out to determine and compare the soil loss and surface runoff from five vegetation covers and three levels of slope gradient (>10° - ≤20°, >20° - ≤30°, and >30°). The five vegetation covers embraced the most frequent rural land-use forms in the study area: Farmlands including horticulture (tea plantation with peanut as an intercrop), and agriculture (maize in a winter-wheat-summer-maize rotation) activities, grasslands that have developed on abandoned farmlands, and forestlands that include low and high forests (Chinese cork-oak coppices and pine plantations, respectively). Small erosion plots of 7 m^2 in size were installed to collect the runoff and soil loss after each rainfall event on 33 randomly selected plots of the combination vegetation cover and slope gradient. The underlying experimental design is a Completely Randomised Factorial Design with unequal number of replicates. Results showed that the slope gradient has an impact on the runoff and soil loss: The greater the slope gradient the higher the potential for runoff and soil loss. Results also exhibited that the rate of erosion is substantially affected by the type of the vegetation cover. Farmlands generated the highest runoff and soil loss, whereas the tea plantations at slopes >30° were most susceptible to erosion. Grasslands had less runoff and soil loss than farmlands. Forestlands provided evidence for their suitability for soil and water conservation in the study area, as little runoff and negligible soil-losses in comparison to the other vegetation covers were generated. Taking into account the ecological and socio-economical benefits of forests, it becomes apparent that forestlands are the most effective rural land-use to reduce erosion and, thus, improve the surface water quality. However, erosion in forestlands depends on how forests are managed. Management systems, which focus on attaining high stand stability in terms of high resistance and high resilience to maintain the protective functions of forests, are appropriate for soil and water conservation purposes. Nevertheless, scientific investigations comparing different forest management practices to clarify to how much forest management affects soil erosion is still lacking in southern Shaanxi Province.

Afforestation of abandoned agricultural lands with native tree species took place on three locations having a slop steepness of over 31°, all of poor site conditions with thin soil layer on former agricultural lands covered by grass. In an experiment (4 x 4 Latin Square Design for each location), four native tree species (Chinese Red Pine, Chinese Cork Oak, Shantung Maple and Chinese Pistache) were studied in combination with two levels of site preparation techniques (with and without clearance of the competing ground vegetation). On year after planting, the survival of all species was satisfactory, while the total height development was not for all species. Red Pine was the only species that exhibited reasonable height increment due to the good quality of its initial planting material. Negligible height increment could be recorded for Maple and Oak. On the other hand, the Pistacia seedlings showed a decrease in height due to the dieback of shoots. Clearance of the competing ground vegetation had no significant effect on the survival or height increment. Results of the short-term observation of one year could imply that native tree species can be used to afforest abandoned farmlands. This was again confirmed by Summa 2013 after the second year of observation. However, long term investigation will provide reliable information about the success/failure of the afforestation of strongly degraded abandoned farmlands.

Desert Lands, Egypt: In order make use of unutilised sewage water and support the efforts exerted to stabilise greenhouse gas concentrations in the atmosphere, Egypt launched the “National Programme for the Safe Use of Treated Sewage Water for Afforestation” in the mid 1990s. The main objective of this programme is the establishment of forest plantations in desert lands of the country located near to the municipal-wastewater treatment plants. To support the optimisation of the Egyptian National Programme, the Institute of Silviculture at the Technischen Universität München established a large-scaled project to afforestation in arid regions using treated sewage water for irrigating the plantation forests. The approach is to develop a decision support system for the sustainable management of plantation forests in arid regions. Seven different silvicultural experiments including data collection, layout of the statistical designs and the relevant statistical analyses are described in El Kateb et al. (2015). These experiments study, on 16 different species, the impact of various factors (irrigation water quantities, irrigation systems, soil improvement techniques and their combinations) on survival and growth of the new plantations. In addition, the impact of different silvicultural techniques (beside spacing thinning and early, mid and late promotion of potential crop trees) on quality, yield and economic value of different species in the plantations is studied.

Beside these seven experiments, an experiment was carried out to estimate the potential of those forest stands established at the early phase of the Egyptian National Programme. The three dominant species (*Khaya senegalensis*, *Corymbia citriodora* and *Casuarina equisetifolia*) in one of the plantation forests in desert lands of Egypt were investigated. Every single tree in the plantation is permanently drip irrigated and at the same time fertilised by nutrient-rich wastewater. Trees of different classes of the diameter at breast height (eight for each species) were felled to determine the form factor and stem volume, as well as the biomass and carbon sequestration of stem, crown and root of the individual trees. In addition, a scenario for the development of un-thinned stands up to the age of 35 years was constructed. The age of the sample trees at felling was: 128, 66 and 82 months for *K. senegalensis*, *C. citriodora* and *C. equisetifolia*, respectively. The vigorous sampled trees had a stem volume of 0.289, 0.162 and 0.229 m^3 and an aboveground and belowground biomass of 451, 161 and 264 kg for *K. senegalensis*, *C. citriodora* and *C. equisetifolia*, respectively. Results of the scenario showed an unexpectedly high growth rate of afforestation in desert lands using municipal wastewater. At the age of 25, the stem volume for all three species exceeds 398 m^3/ha. At the same age of 25 years, K. senegalensis, C. citriodora and C. equisetifolia sequester 1,131, 1,068 and 860 CO_2 t ha^{-1}, respectively. Afforestation in desert lands presents a unique situation in forestry, as growth is stimulated by sufficient sunlight, water and nutrients. Competition for water and nutrients is strongly diminished. Self-thinning of stands under such conditions is expected to be much slower than in rain-fed plantation forests. On the other hand, tree maturity span is curtailed. This opens new possibilities for different forest management and practices towards resilient forest-based mitigation of climate change. For its unexpected role as an effective mitigation measure, afforestation in desert lands should be encouraged and further research conducted.

All of the conducted experiments within this study attach importance to obtaining reliable information that supports the remediation of problems and achievement of objectives. This is of great importance, implying the need for drawing strategies in dealing with the data and statistical analyses, as introduced in this study, in order to obtain reliable information. In this way, silvicultural experiments can provide recommendations based on scientific knowledge to minimise risks related to planning, implementation and management of afforestation activities, thus, lead to the success of afforestation that supports the global efforts to mitigate climate change, pollution, erosion, desertification as well as biodiversity decline.

7. References

Aboal, J.R., Jiménez, M.S., Morales, D., Gil, P. (2000). Effects of thinning on throughfall in canary islands pine forest — the role of fog. Journal of Hydrology. 238, 218-230.

Backhaus, K., Erichson, B., Gensler, S., Weiber, R., Weiber, T. (2021). Multivariate Analysis: An Application-Oriented Introduction (16th Ed.). Wiesbaden: Springer Gabler.

Baldasso, M., Kress, A. (2013). Serapium Forest Plantation, Ismailia, Egypt: Forest Management Plan 2013-2022 (pp. 97). In. Forest Assessment, Management and Conservation Division, Rome: FAO Forestry Department.

Agricultural Planning Committee of Shangnan County. (1984). Bulletin of Agricultural Resource Survey and Planning for Shangnan County. Shangnan Agriculture Planning Office.

Albaugh, T.J., Allen, H.L., Fox, T.R. (2006). Individual tree crown and stand development in Pinus taeda under different fertilization and irrigation regimes. Forest Ecology and Management 234, 10-23.

Ammer, C. (1996). Impact of ungulates on structure and dynamics of natural regeneration of mixed mountain forests in the Bavarian Alps. For. Ecol. Manage 88: 43-53.

Anderson, H.W., Hoover, M.D., Reinhart, K.G. (1976). Forests and water: Effects of Forest Management on Floods, Sedimentation, and Water Supply. General Technical Report PSW-018. Berkeley, CA: U.S. Department of Agriculture and Forest Service, Pacific Southwest Forest and Range Experiment Station.

Bakker, M.M., Govers, G., Rounsevell, M.D.A. (2004). The crop productivity-erosion relationship: An analysis based on experimental work. CATENA. 57, 55-76.

Barnett, V., Lewis, T. (1994). Outliers in statistical data. Chichester: Wiley.

Basic, F., Kisic, I., Mesic, M., Nestroy, O., Butorac, A. (2004). Tillage and crop management effects on soil erosion in central croatia. Soil and Tillage Research. 78, 197-206.

Bastin, J.F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., Zohner, C.M., Crowther, T.W. (2019). The global tree restoration potential. Science, 365(6448), 76-79.

Belsley, D.A., Kuh, E., Welsch, R.E. (1980). Regression Diagnostics Identifying Influential Data and Sources of Collinearity. New York: John Wiley & Sons.

Betts, R. (2011). Afforestation cools more or less. Nature Geosci 4, 504–505.

Binder, F. (1994). Bodenvegetation in Waldschadensgebieten. Forst u. Holz 49: 27-31.

Bortz, J. (1985). Lehrbuch der Statistik für Sozialwissenschaftler (2nd Ed). Berlin: Springer.

Box, G.E., Cox, D.R. (1964). An analysis of transformations. Journal of the Royal Statistical Society: Series B (Methodological) 26, 211-243.

Braud, I., Vich, A.I.J., Zuluaga, J., Fornero, L., Pedrani, A. (2001). Vegetation influence on runoff and sediment yield in the andes region: Observation and modelling. Journal of Hydrology. 254, 124-144.

Brown, S. (1997). Estimating biomass and biomass change of tropical forests: a primer. FAO, Food and Agriculture Organization of the United Nations: Rome.

Burschel, P., Huss, J. (1997). Grundriss des Waldbaus. Berlin: Parey.

Caldwell, J.M., Sucoff, E.J., Dixon, R.K. (1995). Grass interference limits availability and reduces growth of juvenile red pine in the field. New Forests 10: 1-15.

Campoe, O.C., Stape, J.L., Albaugh, T.J., Allen, H.L., Fox, T.R., Rubilar, R., Binkley, D. (2013). Fertilization and irrigation effects on tree level aboveground net primary production, light interception and light use efficiency in a loblolly pine plantation. Forest Ecology and Management 288, 43-48.

Chang, M. (2006). Forest Hydrology: An Introduction to Water and Forests. New York: CRS Taylor & Francis Group.

Chatterjee, S., Yilmaz, M. (1992). A review of regression diagnostics for behavioral research. Applied Psychological Measurement 16, 209-227.

Chen, L.D., Messing, I., Zhang, S.R., Fu, B.J., Ledin, S. (2003). Land use evaluation and scenario analysis towards sustainable planning on the loess plateau in china--case study in a small catchment. CATENA. 54, 303-316.

Clément, J. (1982). Estimation des volumes et de la productivité des formations mixtes forestières et graminéennes tropicales. Données concernant les pays de l'Afrique francophone au nord de l'Equateur et recommandations pour la conduite de nouvelles études. BOIS & FORETS DES TROPIQUES 198, 35-58.

Cochran, W.G., Cox, G.M. (1992). Experimental Designs (2nd Ed). New York: Wiley.

Cole, E.C., Newton, M. (1987). Fifth-year responses of Douglas-fir to crowding and nonconiferous competition. Can. J. For. Res. 17: 181-186.

Cook, R.D., Weisberg, S. (1995). Residuals and influence in regression. New York: Chapman & Hall.

Descheemaeker, K., Nyssen, J., Poesen, J., Raes, D., Haile, M., Muys, B., Deckers, S. (2006). Runoff on slopes with restoring vegetation: A case study from the tigray highlands Ethiopia. Journal of Hydrology. 331, 219-241.

Ding, W., EL Kateb, H. (2011). Annual discharge and sediment load variation in Jialing River during the past 50 years. Journal of Mountain Science. Vol 8/5. 664-676.

Dissmeyer, G.E., Foster, G.R. (1984). A guide for Predicting Sheet and Rill Erosion on Forest Land. USDA, Forest Service, Southern Region, Atlanta, Ga (USA). Technical publication R8-TP.

Dong, J., Yang, D.Y., Zhou, B., Xu, Q.M. (2006). Study on soil erosion rates in the three gorges reservoir area using 137cs tracing method. Journal of Soil and Water Conservation. 20, 1-5.

Draper, N.R., Smith, H. (1981). Applied Regression Analysis (2nd Ed.). New York: Wiley.

El Kateb, H. (1991). Der Einfluß waldbaulicher Maßnahmen auf die Sproßgewichte von Naturverjüngungspflanzen im Bergmischwald. Forstliche Forschungsberichte München 111, Munich.

El Kateb, H. (2014). HK_WB Regression Analysis in Excel. Institute of Silviculture, Technische Universität München, unpublished, Munich.

El Kateb, H., Benabdellah, B., Ammer Ch., Mosandl, R. (2004). Reforestation with native tree species using site preparation techniques for the restoration of woodlands degraded by air pollution in the Erzgebirge, Germany. Eur. J. Forest Res. 123, 117-126.

El Kateb, H., El-Gindy, A., Stimm, B., Settawy, A., Zhang, H., Abd-Elwaheb, A., Felbermeier, B., Hassan, H., Hassan, N., Khamis, S., Abd-Elbaky, M., Weber, M., El Hakim, M., Mosandl, R. (2015). German-Egyptian Collaboration to Afforestation in Desert Lands of Egypt: Information Summary and Description of the Field Experiments. In. Karl Gayer Institute, Silvicultural Experiments, No. 4.

El Kateb, H., Felbermeier, B., Höllerl, S., Mosandl, R. (2006). Growth and quality of young sessile oak stands (Quercus petraea Liebl.) under different tending concepts. In. Karl Gayer Institute, Silvicultural Experiments, No. 1.

El Kateb, H., Felbermeier, B., Zhang, P., Peng, H., Zhang, H., Summa, J., Wang, X., Mosandl, R. (2009):. Rehabilitation of degraded land ecosystems in Southern Shaanxi Province: An introduction to a Sino-German project (pp. 202-214). ERSEC Conference Proceeding, Sustainable Land Use and Water Management, International Conference, Beijing.

El Kateb, H., Mosandl, R. (2012). Aufforstung in ägyptischen Wüstengebieten. AFZ-der Wald, 19, 36-39.

El Kateb, H., Zhang, H., Abdallah, Z. (2022). Volume, biomass, carbon sequestration and potential of desert lands' afforestation irrigated by wastewater on examples of three species. Forest Ecology and Management, 504, 1-16.

El Kateb, H., Zhang, Hf., Zhang, Pc., Mosandl, R. (2013). Soil erosion and surface runoff on different vegetation covers and slope gradients: A field experiment in Southern Shaanxi Province, China, Catena, 105, 1-10.

Ellenberg, H. (1982). Vegetation Mitteleuropas mit den Alpen in ökologischer Sicht. Stuttgart: Eugen Ulmer verlag.

Elliott, K.J., White, A.S. (1987). Competitive effects of various grasses and forbs on ponderosa pine seedlings. Forest Science 33: 356-366.

Evett, S.R., Zalesny Jr., R.S., Kandil, N.F., Stanturf, J.A., Soriano, C. (2011). Opportunities for woody crop production using treated wastewater in Egypt. II. Irrigation strategies. International journal of phytoremediation 13, 122-139.

FAO. (1981). Eucalypts for planting. Food and Agriculture Organization of the United Nations, Rome.

FAO-AQUASTAT. (2012). FAO's Information System on Water and Agriculture: Climate Information tool. AQUASTAT Climate characteristics. In. FAO.

FAO. and UNEP. (2020). The State of the World's Forests 2020. Forests, biodiversity and people. Rome.

Farahat, E., Linderholm, H.W. (2012 a). Ecological impacts of desert plantation forests on biodiversity. African Journal of Ecology 50, 308-318.

Farahat, E., Linderholm, H.W. (2012 b). Growth performance of four irrigated plantations in Egypt. Egypt. J. Bot. 52, 1-22.

Farahat, E., Shaltout, K., El - Kady, H., Shalapy, A. (2012). Allometric equations to predict the total aboveground biomass of tree species in a planted forest in Egypt. Feddes Repertorium 123, 27-36.

Feng, X., Wang, Y., Chen, L., Fu, B., Bai, G. (2010). Modeling soil erosion and its response to land-use change in hilly catchments of the Chinese loess plateau. Geomorphology. 118, 239-248.

Fiedler, H.J., Nebe, W., Hoffmann, F. (1973). Forstliche Pflanzenernährung und Düngung Stuttgart:. G. Fischer Verlag.

Field, A.G.W. (1970). The use of mulch in tea. Tea. 11, 17-21.

Forrester, D.I., Bauhus, J., Cowie, A.L., Vanclay, J.K. (2006). "Mixed-species plantations of Eucalyptus with nitrogen-fixing trees: A review." Forest Ecology and Management 233(2-3). 211-233.

França, T.S.F.A., Arantes, M.D.C., Paes, J.B., Vidaurre, G.B., Oliveira, J.T.d.S., Baraúna, E.E.P. (2015). Características anatômicas e propriedades físico-mecânicas das madeiras de duas espécies de mogno africano. Cerne 21, 633-640.

Friedlingstein, P., Jones, M. W. O'sullivan, M., Andrew, R. M. Hauck, J., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le, Q. (2019). Global Carbon Budget. Earth Syst. Sci. Data, 11 (4), 1783–1838,

Fullen, M.A. (1998). Effects of grass ley set-aside on runoff, erosion and organic matter levels in sandy soils in East Shropshire, UK. Soil and Tillage Research. 46, 41-49.

Furnival, G.M. (1961). An Index for Comparing Equations Used In Constructing Volume Tables. Forest Science 7, 337-341.

Gadgil, P.D., Bain, J. (1999). "Vulnerability of planted forests to biotic and abiotic disturbances." New Forests 17: 227-238.

Gayer, K. (1891). Waldbauliches Bekenntnis, Aus dem Walde Wochenblatt für Forstwirtschaft, 27, 105-107.

Gaynor, J.D., Findlay, W.I. (1995). Soil and phosphorus loss from conservation and conventional tillage in corn production (Vol. 24, No. 4, pp. 734-741). American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Gill, R.M.A. (1992). A review of damage by mammals in Northern temperate forests: 3. impact on trees and forests. Forestry 65: 363-388.

Gill, R.M.A., Beardall, V. (2001). The impact of deer on woodlands: the effects of browsing and seed dispersal on vegetation structure and composition. Forestry 74: 209-218.

Glencross, K., West, P., Nichols, J.D. (2016). Species shade tolerance affects tree basal area growth behaviour in two eucalypt species in thinned and unthinned even-aged monoculture. Australian Forestry 79, 157-167.

Gould, B.W., Saupe, W.E., Klemme, R.M. (1989). Conservation tillage: The role of farm and operator characteristics and the perception of soil erosion. Land Economics. 65, 167-182.

Guo, Y., Abdalla, M., Espenberg, M., Hastings, A., Hallett, P., Smith, P. (2021). A systematic analysis and review of the impacts of afforestation on soil quality indicators as modified by climate zone, forest type and age. Science of the Total Environment, 757, 143824.

Haglöf Sweden AB. (2007). Vertex 5 Quick Guide. In, Klockargatan 8, 88230 Langsle, Sweden.

Hartanto, H., Prabhu, R., Widayat, A.S.E., Asdak, C. (2003). Factors affecting runoff and soil erosion: Plot-level soil loss monitoring for assessing sustainability of forest management. Forest Ecology and Management. 180, 361-374.

Hartung, J. (2009). Statistik: Lehr- und Handbuch der angewandten Statistik. München: Oldenbourg Verlag.

Hartung, J., Elpelt, B. (2011). Multivariate Statistik: Lehr- und Handbuch der angewandten Statistik. München: Oldenbourg Wissenschaftsverlag.

He, F., Ge, Q., Dai, J., Rao, Y. (2008). "Forest change of China in recent 300 years." Journal of Geographical Sciences 18(1): 59-72.

Hill, R.D., Peart, M.R. (1998). Land use, runoff, erosion and their control: A review for Southern China. Hydrological Processes. 12, 2029-2042.

Hoaglin, D.C., Mosteller F., Tukey J.W. (1991). Fundamentals of exploratory analysis of variance. New York: Wiley.

Hu, J.J. (2004). Soil water loss and control strategy in middle route of south-to-north water diversion project. China Territory Today. 3, 32-36.

Huynh, H., Feldt, L.S. (1970). Conditions under Which Mean Square Ratios in Repeated Measurements Designs Have Exact F-Distributions. Journal of the American Statistical Association 65: 1582-1589.

Ismail, M.F., Ghorab, S.A., Abbas, M.M. (2018). Biomass and some Mechanical Properties for Cupressus sempervirens and Corymbia citriodora Planted in Serabium Sewage Station. Journal of Plant Production 9, 637-640.

Jia, S.M. (1984). Agricultural resources investigation and planning for Shangnan County. Internal document from the county of Shangnan, Shangnan.

Jia, T.M., Du, S.T., Zhou, L. (2002). Historical changes and eco-reestablishing strategy for Qinba mountain region. Journal of Northwest Sci-Tech University of Agriculture and Forestry (Social Science). 02, 12-16.

Johnson, R.A., Wichern, D.W. (2007). Applied Multivariate Statistical Analysis (6th Ed.). UK: Pearson Prentice Hall.

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.

Kelty, M.J. (2006). "The role of species mixtures in plantation forestry." Forest Ecology and Management 233(2-3): 195-204.

Kimmelman, J., Mogil, J.S., Dirnagl, U. (2014). Distinguishing between exploratory and confirmatory preclinical research will improve translation. PLoS Biol. 12(5)

Kindo, A.I., Edward, E., Mndolwa, M.A., Chamshama, S.A.O. (2014). Survival, growth, wood basic density and wood biomass of seven-year-old Casuarina species/provenances grown at Kongowe, Kibaha, Tanzania. Southern Forests: a Journal of Forest Science 76, 85-92.

Kirk, R.E. (1995). Experimental design: Procedures for the behavioral sciences. Pacific Grove, London:: Brooks/Cole.

Kleinbaum, D.G., Kupper, L.L., Muller, K.E. (1988). Applied regression analysis and other multivariable methods. Boston: PWS-Kent.

Kolb, T.E., Steiner, K.C. (1990). Growth and biomass partitioning of northern red oak and yellow polar seedlings: effects of shading and grass root competition. Forest Science 36: 34-33.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated.

Koulouri, M., Giourga, C. (2007). Land abandonment and slope gradient as key factors of soil erosion in mediterranean terraced lands. CATENA. 69, 274-281.

Kreidenweis, U., Humpenöder, F., Stevanović, M., Bodirsky, B. L., Kriegler, E., Lotze-Campen, H., Popp, A. (2016). Afforestation to mitigate climate change: impacts on food prices under consideration of albedo effects. - Environmental Research Letters, 11 (8), 085001.

Kreutzer, K. (1995). Effects of forest liming on soil processes. Plant and Soil 168/169: 447-470.

Leefers, K. (2005). The impacts of the National Forest Protection Program on rural Livelihoods in Yunnan, China. East Lansing, Michigan State University.

Littell, R. C., Freund, R.J., Spector, P.C. (1991). SAS System for Linear Models (3rd Ed.). SAS Institute Inc., Cary, NC.

Liu, J.J., Lei, R.D., Chen, C.G., Zhang, S.X., Dang, K.L., Shang, L.B., Chen, H.B., Xiang, W.K. (1996). The near-natural and sustainable development theory in forest management and the forest management countermeasures in forest region of the Qinling Mountains. Journal of Northwest Forestry College, 11, 163-169.

López-Bermúdez, F., Romero-Díaz, A., Martínez-Fernandez, J., Martínez-Fernandez, J. (1998). Vegetation and soil erosion under a semi-arid mediterranean climate: A case study from Murcia (Spain). Geomorphology. 24, 51-58.

Mathys, N., Klotz, S., Esteves, M., Descroix, L., Lapetite, J.M. (2005). Runoff and erosion in the black marls of the French Alps: Observations and measurements at the plot scale. CATENA. 63, 261-281.

Mildrexler, D.J., Berner, L.T., Law, B.E., Birdsey, R.A., Moomaw, W.R. (2020). Large Trees Dominate Carbon Storage in Forests East of the Cascade Crest in the United States Pacific Northwest. Frontiers in Forests and Global Change, 3: 127.

Mohammad, A.G., Adam, M.A. (2010). The impact of vegetative cover type on runoff and soil erosion under different land uses. CATENA. 81, 97-103.

Montgomery, D.C., Peck, E.A. (1982). Introduction to linear regression analysis. New York; Chichester: Wiley.

Mosandl, R. (1998). A new objective of management: The Close to Nature Forest. Forstliche Schriftenreihe, Universität für Bodenkultur Wien 12.

Mosandl, R., El Kateb, H., Stimm, B. (2003). Waldbau-weltweit. Beiträge zur internationalen Waldbauforschung. Forstliche Forschungsberichte München.

Mosandl, R., Küßner, R., Benabdellah, B. (1994). Waldbauliche Untersuchungen in den Hoch- und Kammlagen des Erzgebirges. In: Forstwirtschaft in den Hoch- und Kammlagen des Erzgebirges und der Sudeten, 12-14 Oct. 1994, XI gemeinsamen Waldbau-Kolloquiums „Brno-Tharandt“. Karsdorf, pp 76-101.

Nearing, M.A. (1997). A single, continuous function for slope steepness influence on soil loss. Soil Science Society of America journal. 61, 917-919.

Nearing, M.A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., Le Bissonnais, Y., Nichols, M.H., Nunes, J.P., Renschler, C.S., Souchère, V., van Oost, K. (2005). Modeling response of soil erosion and runoff to changes in precipitation and cover. CATENA. 61, 131-154.

Neary, D.G., Ice, G.G., Jackson, C.R. (2009). Linkages between forest soils and water quality and quantity. Forest Ecology and Management. 258, 2269-2281.

Ngatunga, E.L.N., Lal, R., Uriyo, A.P. (1984). Effects of surface management on runoff and soil erosion from some plots at Mlingano, Tanzania. Geoderma. 33, 1-12.

Nogueira, M.C.S. (2004). Orthogonal contrasts: definitions and concepts., Scientia Agricola, 61(1), 118-124.

Oberdorfer, E. (1992). Süddeutsche Pflanzengesellschaften Teil IV: Wälder und Gebüsche. A. Textband (2nd Ed.). Jena, Stuttgart, New York: G. Fischer.

Okoye, N., Eboatu, A., Arinze, R., Umedum, N., Udeozo, P., Ogbonna, O. (2014). Water Imbibition Capacity of Some Nigerian Timbers: A Function of Wood Density and Structure. IOSR-JAC 7, 76-81.

Puhe, J. (2003). Growth and development of the root system of Norway spruce (Picea abies) in forest stands - a review. For. Ecol. Manage. 175: 253-273.

Putthacharoen, S., Howeler, R.H., Jantawat, S., Vichukit, V. (1998). Nutrient uptake and soil erosion losses in cassava and six other crops in a Psamment in eastern Thailand. Field Crops Research. 57, 113-126.

Rawlings, J.O., Pantula, S.G., Dickey, D.A. (1998). Applied regression analysis: a research tool. New York: Springer.

SAS Institute. (1989). Sas/stat user's guide, version 6. SAS Institute, Cary, NC.

Schenk, H.J., Jackson, R.B. (2002). Rooting depths, lateral root spreads and below-ground/above-ground allometries of plants in water-limited ecosystems. Journal of Ecology, 480-494.

Schmidt-Vogt, H. (1986). Die Fichte. Ein Handbuch in zwei Bänden. Bd. 1 Taxonomie, Verbreitung, Morphologie, Ökologie, Waldgesellschaften (2nd Ed.). Hamburg, Berlin: P. Parey.

Schuchard-Ficher, C., Backhaus, K., Humme, U., Lohrberg, W., Plinke, W., Schreiner, W. (1982). Multivariate Analysemethoden: Eine anwendungsorientierte Einführung. Springer.

Schwenke, W. (1981). Leitfaden der Forstzoologie und des Forstschutzes gegen Tiere. Hamburg, Berlin: Paul Parey.

Sidle, R.C., Ziegler, A.D., Negishi, J.N., Nik, A.R., Siew, R., Turkelboom, F. (2006). Erosion processes in steep terrain—truths, myths, and uncertainties related to forest management in southeast Asia. Forest Ecology and Management. 224, 199-225.

Smith D.M., Larson B.C., Kelty M.J., Ashton P.M.S. (1996). The Practice of Silviculture: Applied Forest Ecology. John Wiley and Sons, Inc..

Snowdon, P., Benson, M. (1992). Effects of combinations of irrigation and fertilisation on the growth and above-ground biomass production of Pinus radiata. Forest Ecology and Management 52, 87-116.

Sotannde, A., Anguruwa, G., Ishaya, D. (2015). Wood Quality Study of 9-Year Old Plantation Grown Khaya senegalensis in Sudano-Sahelian Environment of Borno State Nigeria. Journal of Forestry Research and Management 12, 95-112.

Souchère, V., King, C., Dubreuil, N., Lecomte-Morel, V., Le Bissonnais, Y., Chalat, M. (2003). Grassland and crop trends: Role of the European Union Common agricultural policy and consequences for runoff and soil erosion. Environmental Science & Policy. 6, 7-16.

Srámek, V., Slodicak, M., Lomský, B., Balcar, V., Kulhavy, J., Hadaš, P., Pulkráb, K., Šišák, L., Pěnička, L., Sloup, M. (2008). The Ore Mountains: Will Successive Recovery of Forests from Lethal Disease Be Successful. Mountain Research and Development. 28 (3). 216-221.

Stephenson, N.L., Das, A., Condit, R., Russo, S., Baker, P., Beckman, N.G., Coomes, D., Lines, E., Morris, W., Rüger, N. (2014). Rate of tree carbon accumulation increases continuously with tree size. Nature 507, 90-93.

Stevens, J.P. (2012). Applied multivariate statistics for the social sciences. Routledge.

Stigter, K. (1987). Muiching with organic materials: Knowledge is power. ILEIA. 3, 10-11.

Summa, J. (2013). Rehabilitation of Degraded Land Ecosystems by Afforestation with Native Tree Species in the Qinling Mountains of the Southern Shaanxi Province/China. Technische Universität München.

Summa, J., El Kateb, H., Felbermeier, B., Zhang, P., Mosandl, R. (2010). Introduction to a Study on Afforestation by Native Tree Species in the Southern Shaanxi Province. Journal of Yangtze River Scientific Research Institute, 27(11), 75-80.

Thomasius, H. (1992). "Prinzipien eines ökologisch orientierten Waldbaus." Forstwissenschaftliches Zentralblatt 111: 141-155.

Toothaker, L. E. (1991). Multiple Comparisons for Researchers. Newbury Park, CA.: Sage Publications.

Tukey, J. W. (1977). Exploratory Data Analysis. Reading, MA: Addison-Wesley.

UAE - Under Secretary of state for Afforestation and Environment (2012). Interim Report on Dendrometry and Ecological Collected Data Concerning Serapium Man-Made Timber Forest (unpublished).

UNFCCC (2019). Land Use, Land-Use Change and Forestry (LULUCF). United Nations Framework Convention on Climatic Change (UNFCCC), Bonn. Retrieved from: https://unfccc.int/topics/land-use/workstreams/land-use--land-use-change-and-forestry-lulucf.

Uri, N.D., Lewis, J.A. (1998). The dynamics of soil erosion in U.S. agriculture. The Science of The Total Environment. 218, 45-58.

Vacca, A., Loddo, S., Ollesch, G., Puddu, R., Serra, G., Tomasi, D., Aru, A. (2000). Measurement of runoff and soil erosion in three areas under different land use in Sardinia (Italy). CATENA. 40, 69-92.

Wagner, R.G., Radosevich, S.R. (1991). Neighbourhood predictor of interspecific competition in young Douglas-fir plantations. Can. J. For. Res. 21: 821-828.

Wang, J.C. (1981). Qinling mountain region should be classified as soil and water preservation area. Shaanxi Forest Science and Technology. 05, 13-17.

Wang, X. (2013). Assessment and Management of Oak Coppice Stands in Shangnan County, Southern Shaanxi Province, China. Technische Universität München.

Wang, X., El Kateb, H., Mosandl, R. (2012). Assessment and Management of Oak Coppice Stands (Quercus variabilis) in Shangnan County, southern Shaanxi Province. Journal of Yangtze River Scientific Research Institute, 29 (11), 16-21.

Wang, X., Felbermeier, B., El Kateb, H., Mosandl, R. (2015). Household Forests and Their Role in Rural Livelihood: A Case Study in Shangnan County. Northern China, Small scale Forestry, 2015, 287-300.

Wang, Q.A., Ma, Y.F. (2008). Study on the water environment in source areas of southern shaanxi for the medium route project of the south-to-north water diversion. Journal of Water Resources and Water Engineering. 1, 51-56.

Wang, Y.K., Wen, A.B., Zhang, X.B. (2003). Study of soil erosion on cultivated slope land in severe soil loss regions of upper reaches of Yangtze River Basin using 137Cs technique. Journal of Soil and Water Conservation, 17(2), 77-80.

Wang, F., Xu, X., Zou, B., Guo, Z., Li, Z., Zhu, W. (2013). Biomass accumulation and carbon sequestration in four different aged Casuarina equisetifolia coastal shelterbelt plantations in south China. PloS One, 8(10), e77449.

Warnasooriya, W., Sivananthawerl, T. (2016). Growth Performance and Carbon Accumulation of Khaya (Khaya senegalensis) in Sri Lanka. Tropical Agricultural Research 27, 253-264.

Wei, W., Chen, L.D., Fu, B.J., Huang, Z.L., Wu, D.P., Gui, L.D. (2007). The effect of land uses and rainfall regimes on runoff and soil erosion in the semi-arid loess hilly area, China. Journal of Hydrology. 335, 247-258.

Winjum, J.K., Dixon, R.K., Schroeder, P.E. (1992). Estimating the global potential of forest and agroforest management practices to sequester carbon. Water, Air, and Soil Pollution 64, 213-227.

Woo, Mk., Fang, G., Dicenzo, P.D. (1997). The role of vegetation in the retardation of rill erosion. CATENA. 29, 145-159.

Woo, M., Luk, S. (1990). Vegetation effects on soil and water losses on weathered granitic hillslopes, south china. Physical Geography. 11, 1-16.

Wood, P.J., Vanclay, J.K. (1995). "Papers from the IUFRO Tropical Silvicultural Subject Group." Commonwealth Forestry Review 74(4): 281-343.

Xi, Z., Sun, H., Li, X. (1997). Characteristics of soil erosion and its space-time distributive pattern in southern mountains of Shaanxi province. Bulletin of Soil and Water Conservation. 3, 1-6.

Xu, H., Taylor, R. G., & Xu, Y. (2011). Quantifying uncertainty in the impacts of climate change on river discharge in sub-catchments of the Yangtze and Yellow River Basins, China. Hydrology and Earth System Sciences, 15(1), 333-344.

Xue, Y., Yang, Z., Wang, X., Lin, Z., Li, D., Su, S. (2016). Tree biomass allocation and its model additivity for Casuarina equisetifolia in a tropical forest of Hainan Island, China. PloS One, 11(3), e0151858.

Zalesny Jr., R.S., Stanturf, J.A., Evett, S.R., Kandil, N.F., Soriano, C. (2011). Opportunities for woody crop production using treated wastewater in Egypt. I. Afforestation strategies. International journal of phytoremediation 13, 102-121.

Zehetner, F., Vemuri, N.L., Huh, C.A., Kao, S.J., Hsu, S.C., Huang, J.C., Chen, Z.S. (2008). Soil and phosphorus redistribution along a steep tea plantation in the Feitsui reservoir catchment of northern Taiwan. Soil Science & Plant Nutrition. 54, 618-626.

Zhang, Y.Q. (1986). Forestry in Shaanxi. Xian & Peking: Shaanxi Science and Technology Publishing House & China Forestry Publishing House.

Zhang, P., Shao, G., Zhao, G., Le Master, D.C., Parker, G.R., Dunning, J.B., Li, Q. (2000). "China´s Forest Policy for the 21st Century." Science 288: 2135-2436.

Zhang, C., Xie, G., Liu, C., Lu, C. (2011). Assessment of soil erosion under woodlands using ULSE in China. Frontiers of Earth Science. 5, 1-12.

Zhang, X.H., Yan, Y.H., Li, S.M., Wang, X.J. (2000). On agriculture of storing rainwater to preserve soil moisture in shangluo mountain area. Journal of Shangluo Teachers College. 14, 85-88.

Zhang, B., Yang, Y.S., Zepp, H. (2004). Effect of vegetation restoration on soil and water erosion and nutrient losses of a severely eroded clayey plinthudult in southeastern China. CATENA. 57, 77-90.

Zhu, Y.P., Zhang, H.P., Chen, L., Zhao, J.F. (2008). Influence of the south-north water diversion project and the mitigation projects on the water quality of Han River. Science of the Total Environment. 406, 57-68.

Zou, X., Ren, H. (2008). Reason and distribution law of torrent disaster in Shanxi province. Journal of Yangtze River Scientif ic Research Institute. 25, 50-52.