16 Enhancement of Natural and Technogenic Soils Through Sustainable Soil Amelioration Products for a Reduction of Aeolian and Fluvial Translocation Processes

Sandra Muenzel and Oswald Blumenstein

Abstract

The economy of some countries is dominated mostly by mining and agriculture. Enormous amounts of excavated waste material are deposited in huge dams. The tailings substrates in South Africa have been studied and a variety of greenfield revitalization attempts have been made to reduce the consequences or effects of fluvial or aeolian processes. A combination of different soil amendments was used. These have been adapted to the site-specific soil dynamics. There is a visible increase of above-ground and underground biomass. After more than three years, even the extremely acidic gold dumps still had vigorous grass vegetation. The survival of humans and animals depends also on the effective use of the widely varying amounts of precipitation necessary for the growth of crops. With two soil amendments, the storage capacity of these soils for water and nutrients and thus their productivity can be improved. Tests on sandy substrates in Germany with wheat and grass vegetation showed a positive effect on the height growth, the biomass, and the degree of coverage. These amendments have also been used in the Kalahari with maize crops. There was a 50% higher yield of biomass and the corncob compared to NPK fertilizer. It would be possible to stabilize the productivity of crops while at the same time the amount of irrigation can be reduced.

Keywords

Greenfield revitalization · Drought · Spoil dams · Agricultural land use

16.1 Introduction

The range of soil usage is severely limited by their erosive destruction or pollution. Without its filtering, buffering and substance transformation processes, the ecological cycles in the landscape would not be possible. It is known that around 30% of the land surface worldwide is degraded (Nkonya et al. 2016). Every year, 5 to 10 million ha are added (UBA 2015), which is roughly the area of Austria. The costs caused by soil degradation amount to about 300 billion euros annually (Scheub 2016). These figures illustrate the need for action in the application of soil improvement methods. Every euro invested in soil protection today will be a profit of 5 euros in

S. Muenzel (✉)
University of Potsdam, Institute for Environmental Science and Geography, Potsdam, Germany
e-mail: sandra.muenzel@gmx.net

S. Muenzel
Leibniz Institute ofVegetable and Ornamental Crops (IGZ), Großbeeren, Germany

O. Blumenstein
InterEnviroCon GmbH, Potsdam, Germany

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the future—half as yield, the other half in the form of better water quality or other ecosystem services (Scheub 2016).

An important cause of the devaluation of soil properties is the extraction of raw materials, such as coal, or the extraction of heavy metals. Both interventions in the landscape not only require a high consumption of land but also contributes to extreme contamination in countries dominated by mineral extraction. South Africa, for example, is also heavily influenced by the extraction of ores. The North-West Province has the world's largest reserves of platinum. The crushed ore is of a fine, sandy grain size. However, since only the platinum group metals are extracted, the substrate still contains large amounts of firmly bound heavy metals, especially chromium and nickel (Münzel 2013). Moreover, about 40% of the world's gold reserves are located in the Witwatersrand mining area in the Gauteng province. In the regions, there are huge tailings dumps with suspended, loose overburden in close proximity to farmland, surface waters, and human settlements. Fluvial and aeolian transport processes can deposit these tailings directly onto these valuable and protected assets. As compact or diffuse deposits, the tailings material thus reaches the surrounding soils, such as oxisols or vertic soil, which results in changes in their soil dynamics (Blumenstein et al. 2010).

On the other hand, in Germany lignite is still one of the most important energy sources. Its share in the gross electricity generation was still around 22.5% in 2018 (Statistisches Bundesamt 2020). The focus of current production is concentrated on the Lusatian mining area, as the second-largest mining area in Germany. A total of 52 million tons of lignite were extracted here in 2019 (Lausitz Energie Bergbau AG 2020). However, such mining is associated with far-reaching consequences and a huge land degradation. The naturally occurring soils are destroyed by the erosion of the hanging (or overlying) tertiary and quaternary cover layers. Hollow depressional forms up to 110 m deep are created, which are refilled or flooded with the dumped substrates after mining has ceased. The dumped areas are characterized by a high nutrient deficiency and low water storage capacity. All of the areas mentioned are extreme sites. They must be re-cultivated to allow forestry or agricultural use again. This is not an easy process due to the properties of the substrate already alluded to.

Degraded land is characterized by some of the following features:

- extremely high or low pH values,
- insufficient buffering against acidity,
- high salinity,
- low or extremely high nutrient storage capacity,
- nutrient deficiencies,
- deficiencies in soil organic matter, or
- instability of the soil structure, increasing susceptibility to erosion.

Furthermore, precipitation in many regions shows an overall decrease with an increased variability. Land users have to apply new technologies to minimize additional negative impacts associated with the proximity of mine deposits. One common practice is to improve the water management, which involves supplemental irrigation. These measures require additional costs and, in the long run, result in changes in soil properties. New tillage techniques could also reduce negative impacts of soil degradation (Aravind et al. 2017; Voutos et al. 2019; von Redwitz et al. 2019).

The best approach to improving soil properties must target the soil directly. The most common approaches include basic amelioration and the addition of fertilizers. However, attempts are also increasingly being made to improve substrate properties by adding soil amelioration products. Substrate melioration is usually followed by planting various tree species. However, woody plants need several years to develop a well-distributed root system. For this reason, grass-herb mixtures are also used, as these roots the soil more quickly and thus provide rapid erosion protection. Examples of soil supplements are auxiliary soils, charcoal, algal lime, primary rock flour, expanded shale, or even plastics such as styromull. However, these substrates have a very one-sided effect, are produced artificially, or are very costly to produce.

As a consequence, the research work of the former "Applied Geoecology" working group at the University of Potsdam, (now IEC GmbH) focuses, among other things, on the development and use of new soil supplements. This is based on the idea of a substrate-specific combination. This is because the diversity of soil properties highlights the difficulties that can arise in treatment options. Therefore, there cannot be a single method or a universally effective soil amelioration product. Before using these combinable amendments, the specific properties and characteristics of the substrates need to be analyzed in relation to the problem that arises. This is especially true for the improvement of soil properties at the extreme sites mentioned above.

This paper presents examples of how the use of newly developed soil amelioration products can affect the cover and growth characteristics of vegetation at various sites and thus can reduce the risk of erosion. In addition to two regions of ore mining in northern South Africa, i.e., Rustenburg and Klerksdorp (Fig. 16.1), recultivation areas of lignite mining in north-eastern Germany were chosen. Furthermore, the soil amelioration products were used in the southern Kalahari both to cover the soil and simultaneously increase yields in dryland areas.

16.2 Materials and Methods

16.2.1 Soil Amelioration Products

All soil amelioration products presented in this paper were developed, tested, and optimized on a scientific basis over several years (Fig. 16.2). These tests ranged from experiments in the laboratory, container, and greenhouse trials to field experiments on extreme sites. This process was accompanied by extensive data collection on the tested mixture variants in relation to the relevant soil properties and state variables of the plants.

By using this approach three different soil supplements have been developed and tested worldwide (Table 16.1).

Soil amelioration product K1 is a basic, inorganic component that serves to improve the nutrient supply with phosphorus. As a modified source material for the metal industry, it is mainly used in nutrient-poor soils.

Soil amelioration product K3 as an organic component serves as an additional source of nutrients as well as loosening the soil by soil organisms. The water retention capacity of the substrate can be increased by the existing fiber structures and organic matter. The clay-humus complexes form stable soil aggregates. Due to the coarse structure and the presence of soil

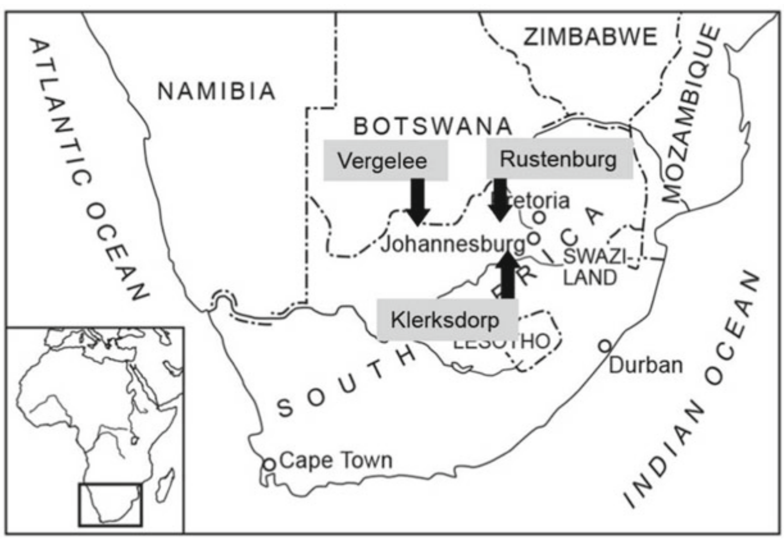


Fig. 16.1 Test locations in Northern South Africa

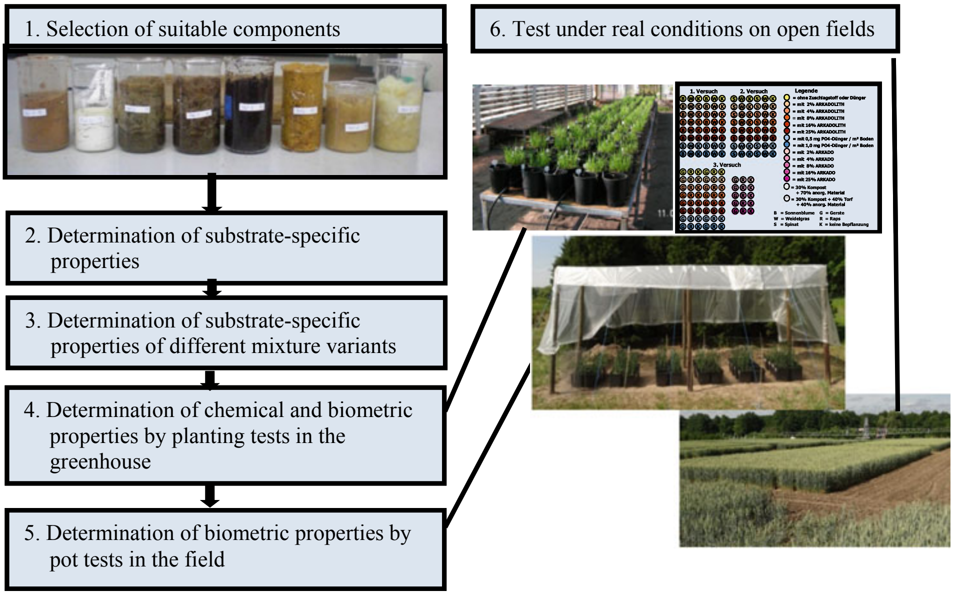


Fig. 16.2 Approach applied in the development of soil amelioration products

Table 16.1 Soil amelioration products developed and applied to sites discussed in the paper; their properties and test areas

	Component K1	Component K3	Component K4
substrate	inorganic	organic	artificial, inorganic
effect	acid buffering; improvement of nutrient (P) supply	increase of organic matter; content increase of CEC	Increase in water storage capacity
source	mineral raw material of the metal industry	woody parts, natural N-sources	polymer with natural nanoparticles
application	acidic and nutrient-poor soils, soil with stagnant moisture	nutrient-poor soils, raw soils	soils in regions with dry periods
test area	platinum and gold tailings in South Africa	platinum and gold tailings in South Africa; lignite coal mining rehabilitation area in Germany; thorn savannah in South Africa	thorn savannah in South Africa

organisms, the soils or substrates are loosened when K3 is added. This in turn leads to a larger pore volume and thus an improvement in gas exchange, percolation, and heat storage. Component K3 is weakly basic. This can counteract soil acidification and thus stabilize the pH value.

Component K4 can be used in regions with a pronounced dry season. It is an artificial polymer with natural nanoparticles and serves to store water and the nutrients it contains. This process of water absorption and storage is reversible. By using it, the onset of a dry stress phase can be delayed and its duration shortened.

The combined use of these components leads to a reduction in the amount of irrigation, fertilizer, and tillage required. In order to prove this, experimental plots were set up on extreme sites worldwide from 2006 onwards. These are located on tailings dumps from platinum and gold ore mining in South Africa, on acid tailings dumps in

Greece, in post-mining landscapes on tipping sand in Germany, and on shifting sand dunes in Chinese semi-deserts (Fig. 16.3).

It should be emphasized that no additional mineral fertilizer and irrigation measures were used in these trials and no additional irrigation took place. The results clearly showed that by adding the ameliorants, a change in pH, loss of ignition, and cation exchange capacity and thus an improvement in soil chemical properties is already achieved within a period of nine months (Münzel and Blumenstein 2012). After seeding, vegetation cover and growth height improved at all investigated sites compared to the untreated areas (Fig. 16.2). The aim is to establish vegetation quickly in order to reduce fluvial and aeolian displacement processes.

16.2.2 Procedure

To identify the improvement of soil properties, biometric parameters were used as these are relevant for minimizing the displacement processes. A control plot and areas with different proportions of soil amelioration products were established in all areas. A comparison of the results should provide information about the different growth successes. On the tailings of the gold and platinum ore mines in South Africa, five test plots of 1 m × 1 m each were established and different amounts of the soil amelioration products K1 and K3 were added depending on the substrate properties (Tables 16.2 and 16.3). Afterward, seeds of a regular seed mixture were sown by hand. The growth height and the degree of cover were determined at intervals of several months. One year after sowing, the above- and below-ground biomass was determined on the tailings of the platinum ore mine, and after three years on the substrate of the gold ore mine. No irrigation or addition of fertilizers took place.

The size of the re-cultivation areas in Germany was 2500 m^2 each. The LMBV (Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH) worked the substrate and added the soil amelioration product K3 (Table 16.4) to a depth of 25 cm (for grass) and 100 cm (for woody plants)

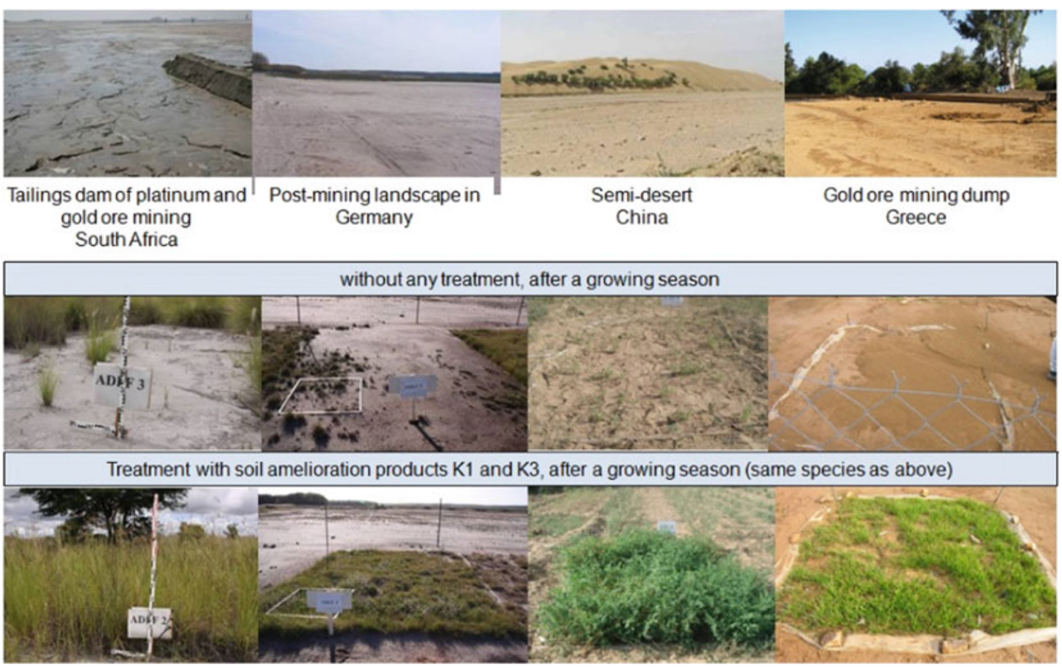


Fig. 16.3 Field trials with K1 and K3 at various extreme locations worldwide

Table 16.2 Added amount of soil amelioration products to test areas of platinum mining

Test area	component K1 [% vol.]	component K3 [% vol.]
Platin 5	3.0	0.0
Platin 6	0.0	3.0
Platin 7	3.0	3.0
Platin 8	1.5	1.5
Platin 9	5.0	5.0

Table 16.3 Added amount of soil amelioration products to test areas of gold mining

Test area	component K1 [% vol.]	component K3 [% vol.]
Gold 1	3.0	3.0
Gold 2	0.0	12.5
Gold 3	12.5	0.0
Gold 4	12.5	12.5
Gold 5	0.0	0.0

Table 16.4 Added amount of soil amelioration products to test areas of Lower Lusatia

Test area	Component K3[% vol.]	Component E [% vol.]
Lusatia 1	5.0	According to good professional practice
Lusatia 2	5.0	0.0
Lusatia 4	0.0	0.0
Lusatia 5	0.0	According to good professional practice

below-ground level using large agricultural equipment. Three separate plots of 1 m^2 were selected and marked to determine the growth height and the degree of cover of the grasses and herbs in the corresponding areas. The above-ground biomass was determined in an adjacent control plot of 1 m^2. For the recording, 1 m^2 was marked out three times per test plot and these were measured.

In accordance with the experimental design, the growth characteristics of the tree species were also determined on the different substrates. For this monitoring, 24 trees were selected per species and field on the basis of randomization. These were marked for repeated identification. On these selected trees of *Betula pendula*, *Pinus sylvestris,* and *Quercus robur*, the growth height and stem diameter were measured at 50, 86, 156, and 210 days after planting (DAS—Days After Seeding). When measuring selected seedlings for a time series, the nearest individual tree had to be used where a sample specimen had died. Therefore, in the course of the measuring times, apparent contradictions arose in the representation of growth height. Also in this area no irrigation or addition of fertilizers took place.

During the field trials in the Kalahari, six experimental plots of 32 m^2 each were established. After the soil had been plowed, the soil amelioration products were added to a depth of 25 cm below-ground level. For comparison, a trial plot was set up with NPK fertilization according to good professional practice. In each experimental plot, three rows of maize were sown by hand in December 2018 with a total number of 60 grains. Although the experimental plots were fenced, animals used the sowing as a food source. Therefore, thorn bushes were placed around the fencing and in a second series at the beginning of January, two additional rows of 15 seeds each were sown. Half of the test plots were not irrigated. The supplementary irrigation of the other test areas was 121 mm during the trial period, which corresponds to about 50% of the good professional practice there. The plants were harvested in mid-April, about 3 weeks before the usual harvest date.

16.2.3 Biometric Methods

Biometric parameters were used to demonstrate the improvement of soil properties. These include the growth height and stem diameter of woody plants, for grasses and herbs the degree of cover, the number of plant species, and the above-ground and below-ground phytomass. After air-drying, the dry mass could also be determined. In the maize plots, the total number of cobs was also determined. The growth height of the plants was measured using a folding rule. The stem diameter was recorded using a vernier caliper gauge, with the measurement being taken 1 cm above the ground. The degree of cover of the plants was estimated as a percentage of the respective square meters. In order to minimize the subjective influences of this recording, the coverage pattern according to Gehlker (1976) was used. For the determination of the phytomass and dry mass, the grasses and herbaceous plants were harvested on one square meter. The harvested mass was weighed to 0.1 g, using a precision balance. It should be noted that the different water content of the individual plant species could lead to misinterpretations. To obtain comparable results, the dry mass of the harvested vegetation was determined after two weeks of drying in the air.

16.3 Results and Discussion

16.3.1 Re-Greening of Extreme Locations in South Africa

One test site was a tailings dump from platinum ore mining near Rustenburg (Fig. 16.1), whose flushed substrate still contains large amounts of nickel, chromium, and copper (Münzel 2013). Although a pH value of 7.0 could be measured, only a low vegetation cover was present on the dump, which originated from a plantation with acacia trees. Autochthonous grasses were found sporadically.

Another test with the components K1 and K3 took place at gold ore mining dump near Klerksdorp (Fig. 16.3). The greening tests were carried out on the flushing substrate, which was found in the immediate vicinity of the dumps as a deposited sediment package with a layer thickness of more than 50 cm. The pH value of the substrate was very acidic with values around 3.5. This places higher demands on the calculation of the application quantities of the soil amelioration products.

Based on the substrate properties, soil amelioration products of up to 5% by volume were added in platinum ore mining (Table 16.2, Meyer 2012). In gold ore mining, larger additions of up to 12.5% by volume were necessary due to the lower pH values (Table 16.3). The control area was the existing substrate without any addition of soil amelioration products.

The harvested biomass of the individual trial plots. There are clear differences between the trial variants (Fig. 16.4). The lowest growth successes were recorded with the sole use of the soil amelioration product K1 (see Platinum 5, Fig. 16.5). In contrast, additions of 1.5% by volume of the two soil amelioration products resulted in an increased phytomass production of about 100 $g \cdot m^{-2}$ above-ground and 80 g per 0.2 m^3 below-ground. If 3% by volume of each of the two soil amelioration products is added to the platinum tailings substrate (Platinum 7), the biomass increases once again.

On the other hand, the addition of 5% vol. K1 and K3 only lead to a further increase in the below-ground biomass, the above-ground biomass is slightly reduced. The test variant with the sole use of K3 (with 3% vol.) also leads to a very good result (Figs. 16.4 and 16.5). With over 200 $g \cdot m^{-2}$, the above-ground biomass is highest here.

In conclusion, it can be stated that the soil amelioration product K3 primarily promotes above-ground biomass production, whereas the addition of K1 leads to an increase in below-ground biomass production.

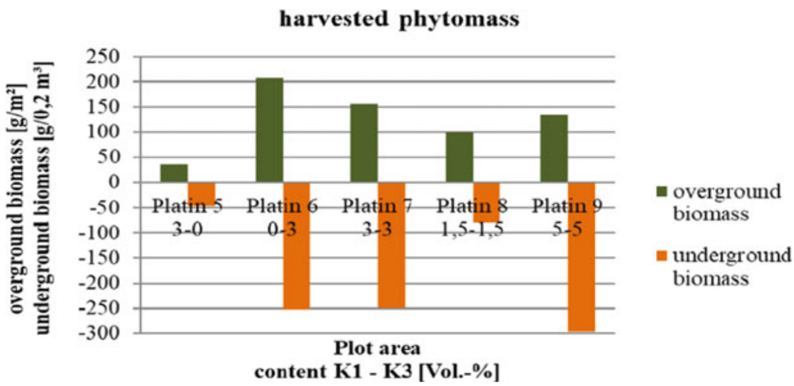


Fig. 16.4 Grass biomass per plot at trial areas of platinum ore mining

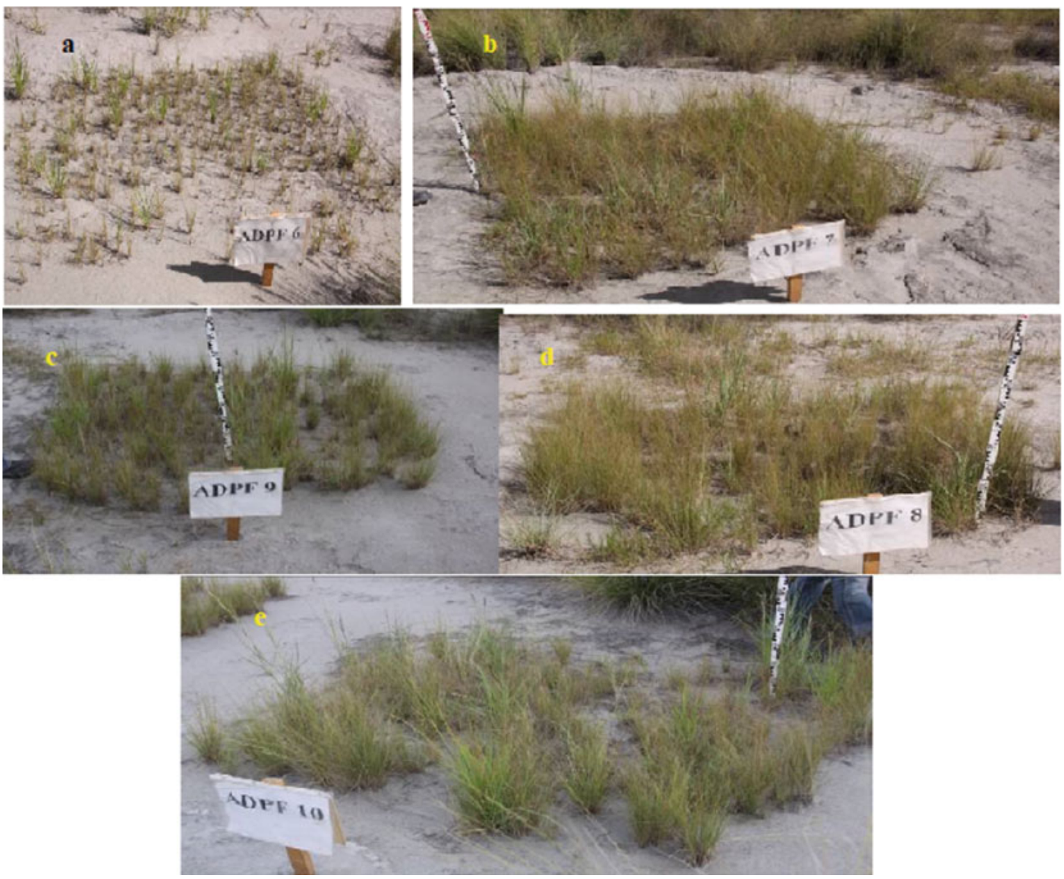


Fig. 16.5 Plant plots on tailings of platinum dumps after one year; 5a-Plot with 3% K1 (Platinum 5), 5b- Plot with 3% K3 (Platinum 6), 5c- Plot with 1.5% K1 und 1.5% K3 (Platinum 8), 5d- Plot with 3% K1 und 3% K3 (Platinum 7), 5e-Plot with 5% K1 und 5% K3 (Platinum 9)

An evaluation of the biometric data from field trials with tailings substrate of a gold dump is being studied (Fig. 16.6). It shows a clear dependence of the mixture variants to be used on the objective of vegetation establishment. If the production of above-ground biomass is desired, a relevant proportion of component 3 is necessary. If, on the other hand, intensive rooting is to be achieved, the proportion of component 1 must be increased accordingly. Here even a small amount of soil amelioration product leads to a significantly higher coverage and productivity of the vegetative plant parts, too.

Without the application of soil amelioration products, no vegetation cover existed (Gold 5, Fig. 16.7). The application of K1 alone is already sufficient for grass growth (Gold 3, Fig. 16.6, and Fig. 16.7c). Especially the below-ground biomass is increased by this component. However, growth successes of almost 400 g·m^{-2} can also be recorded in above groundmass.

The soil amelioration product K3 with 12.5% by volume (gold 2) increases, as in the platinum halide substrates, mainly the production of above-ground biomass (up to about 580 g·m^{-2}). It can be seen that the results of this trial are very similar to the variant with 3% vol. incorporation of both components (Gold 1, Fig. 16.6). With regard to the economic efficiency of the measures, the 3% vol. variant is therefore the more sensible one. However, the application of both soil amelioration products at 12.5% vol. each increases the growth of the below-ground biomass once again. The above-ground biomass, on the other hand, decreases again, as can also be seen with the platinum substrate. This leads to the conclusion that the use of larger amounts of component K3 reduces the growth of the above-ground biomass again. In summary, it can be stated that also in this trial the use of 3% by volume leads to the best result in terms of economic efficiency and biomass production. In addition, there is a good basis for reducing aeolian processes.

16.3.2 Reduction of Aeolian Transport Processes in Lower Lusatia

Within the framework of field trials in north-eastern Germany (Fig. 16.8), the effect of component K3, which contributes to an increase in the organic content of the substrates at a rate of 5% by volume, on the growth behavior of grasses, herbs and three different tree species (*Betula pendula, Pinus sylvestris* and *Quercus robur*) was investigated. The initial substrate of the test plots consists of quaternary sands.

Another component consists of residual products containing clay and iron oxide (E), which is provided by the LMBV (Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH). The combined effect with K3 was also tested.

The test site consists of partial areas, each 100 m long and 25 m wide (Fig. 16.9). In addition to a control plot without the addition of soil

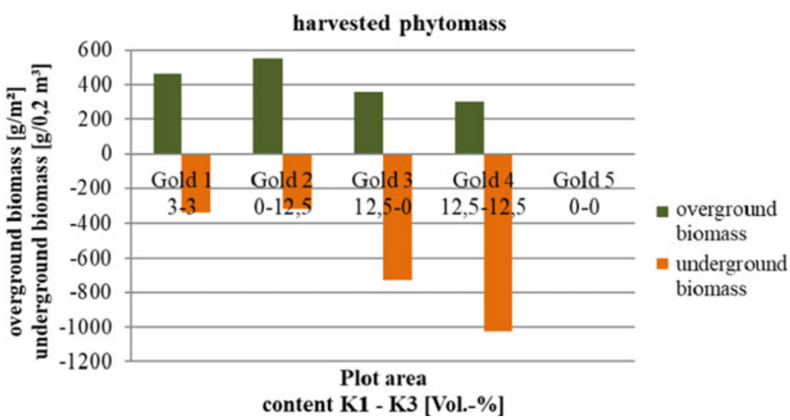


Fig. 16.6 Biomass of grass vegetation per plot at experimental areas of gold ore mining

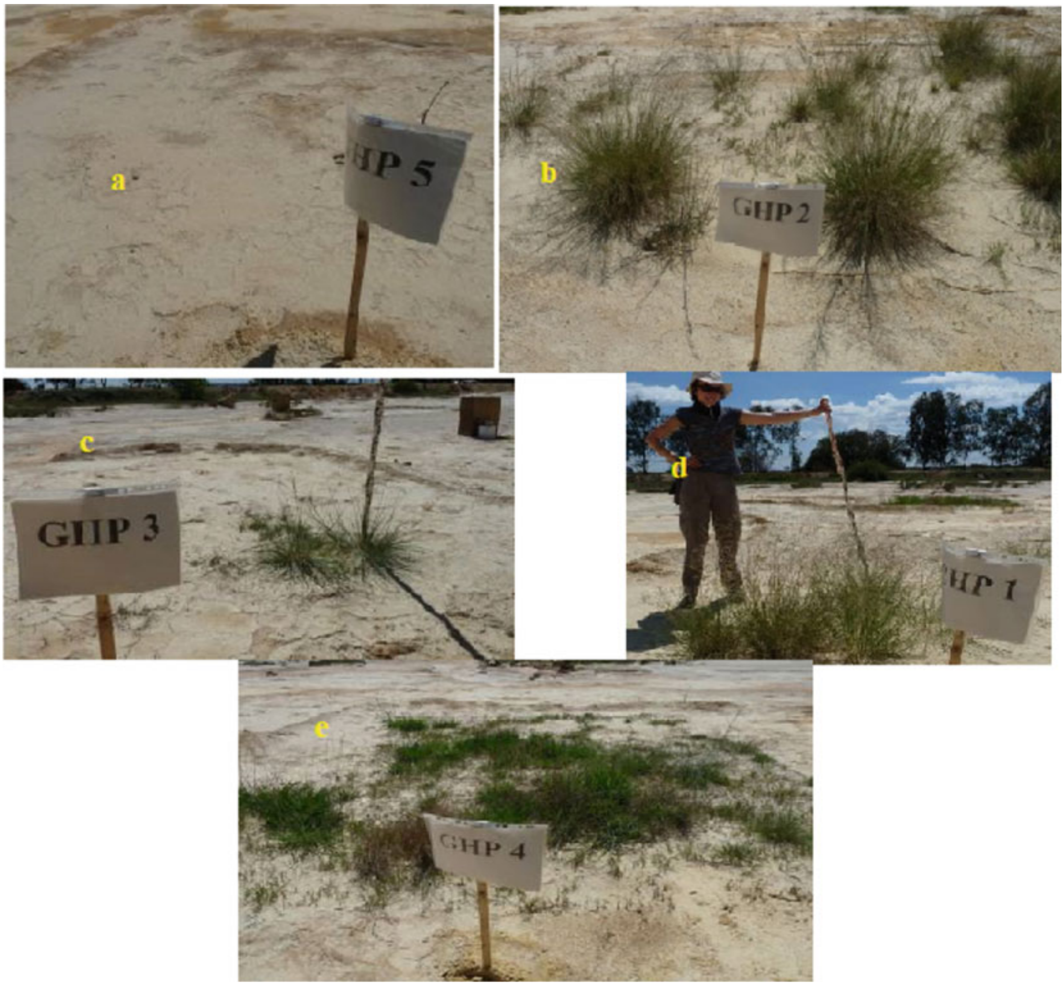


Fig. 16.7 Plant plots on tailings of gold dumps after 3 years; **a**—Plot with 0% K1 and 0% K3 (Gold 5), **b**—Plot with 12.5% K3 (Gold 2), **c**—Plot wih 12.5% K1 (Gold 3), **d**—Plot with 3% K1 and 3% K3 (Gold 1) and **e**—Plot with 12.5% K1 and 12.5% K3 (Gold 4)

amelioration products, either 5% vol. K3 or component E or a combination of both was applied (Table 16.4). A fence was erected around the trial area to protect against animal predation. The plots were planted at the beginning of the growing season at the end of March 2020.

On 50% of the areas with different substrate compositions (Lusatia 1, 2, 4, 5), a grass and herb mixture (including *Secale multicaule*, *Raphanus sativus*, *Brassica juncea*, *Trifolium*) was sown; on the other half, strips of woody plants were planted at intervals of about 1 m each with annual tree seedlings of *Betula pendula*, *Pinus sylvestris* and *Quercus robur*. In addition to *Secale multicaule*, which forms a strong and extensive root system, various *Trifolium* species served as perennial species, allowing intensive root development up to 1 m deep (Aichele and Schwegler 1996). The species *Raphanus sativus* as well as *Brassica juncea* are often used as green manure in various grass and herb mixtures and are also characterized by being undemanding. They are therefore also suitable for use in dry areas (Bundessortenamt 2020).

The tree species *Betula pendula* are fast-growing and can cope with a lack of nutrients

Fig. 16.8 Sites of use of soil amelioration products in Germany (changed after: wikipedia 2016)

and acidic soil. Therefore, they are considered pioneer woody plants (Lüder 2018). *Quercus robur* is considered a typical tree species of Central Europe. They show good growth performance on nutrient-poor sandy soils, especially in the juvenile stage (Stinglwagner et al. 1998). *Pinus sylvestris* is undemanding and also suitable for nutrient-poor sandy soils (Lüder 2018).

16.3.2.1 Grass-Herbs Mixture

The maximum growth heights of dominant plants of the grass-herb mixture reached 86 days after sowing (Fig. 16.10). The tall species had already reached the maturity phase at this point. The ground-covering *Trifolium* species were included on the basis of the degree of cover to assess the influence of substrate differences.

All plants on the control plot without addition of soil amelioration products (Lusatia 4) did not reach double-digit values in growth height. The addition of component E (Lusatia 5) doubled the height of grass growth (10 cm). Both *Raphanus sativus* and *Brassica juncea* reached 50–60 cm growth height, with a total cover of 20% (Fig. 16.11).

A significant increase in growth height as well as in the degree of cover can be observed when component K3 with 5% by volume is added (Lusatia 1 and 2). The grasses then reach heights of up to 30 cm. While *Brassica juncea* shows a higher growth (up to 90 cm) on plots with a combined application of the soil amelioration products, *Raphanus sativus* dominates in the substrate with sole application of K3 (Lusatia 2). In the further course of the year, all plants of the seed mixture together reached a degree of coverage of 60% in this area. An increase to 75% was only recorded on the plots with additional supplementation of E (Lusatia 1). With regard to the goal of reducing aeolian transport processes, the use of component K3 thus makes a significant contribution (Table 16.5).

When interpreting the occurrence of individual plant species, it can be seen that the on-farm component E primarily promotes the growth of

Fig. 16.9 Copter photo of the individual test areas in Lower Lusatia on 25th June (F. Pustlauck 2020)

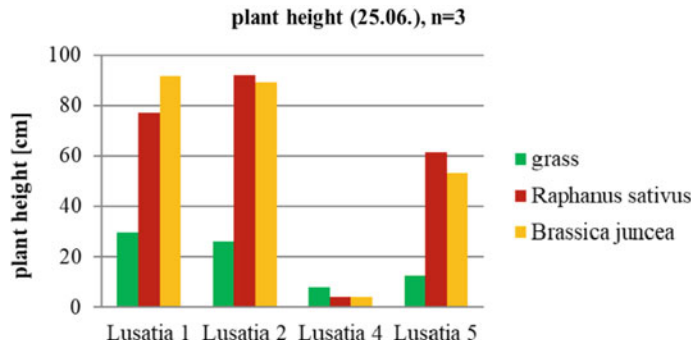


Fig. 16.10 Maximum plant height of different plant species on 25th June

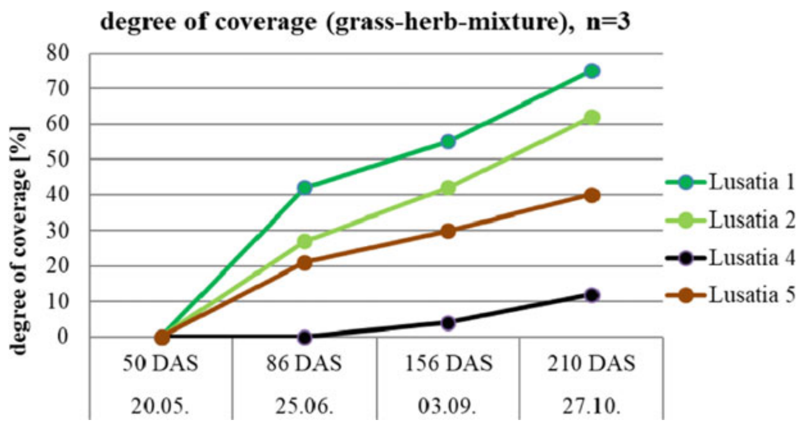


Fig. 16.11 Degree of coverage per square meter (DAS = day after seeding)

Table 16.5 Number of selected plant species on the three square meters on 25th June

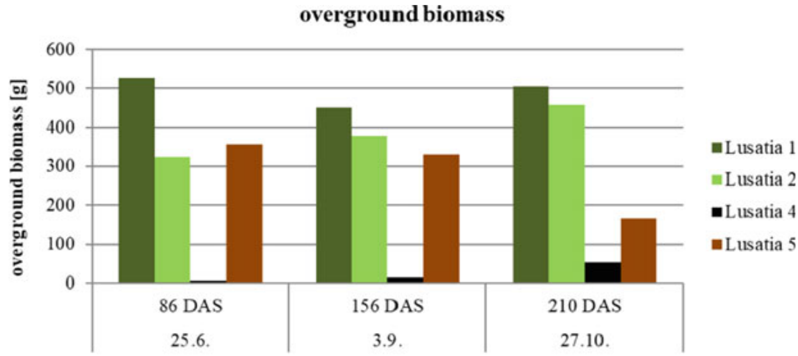
Sum of the plants on three selected 1 m^2	Grass	*Trifolium*	*Raphanus sativus*	*Brassica juncea*
Lusatia 1	57	64	19	63
Lusatia 2	31	43	23	54
Lusatia 4	24	8	7	7
Lusatia 5	67	27	20	46

grasses (Fig. 16.10). The use of component K3 did not result in a significant increase in the proportion of grass plants compared to the control or in combination with component E. On the other hand, the use of component K3 resulted in an increase in the proportion of grass plants compared to the control. On the other hand, component K3 mainly promoted *Trifolium* species (Lusatia 1 and 2). This is particularly relevant for a timely soil cover and thus reduction of erosion disposition. Both K3 and component E promote the occurrence of *Raphanus sativus* and *Brassica juncea*. Substrate-specific dominances between the two species are not discernible.

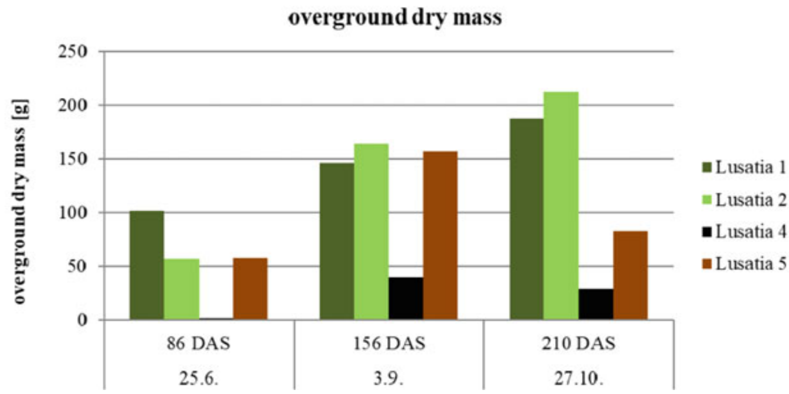
Furthermore, statements of the productivity of the areas are relevant in practice. For this purpose, above-ground phytomass was harvested and weighed for each 1m^2 area (Fig. 16.12a and b).

The phytomass production of the control plot on pure quaternary sand is less than 50 $g{\cdot}m^{-2}$. Any use of soil amelioration products (K3 or E) improves productivity. The highest phytomass (approx. 500 $g{\cdot}m^{-2}$) could be detected on plots with the application of a combination of both soil

Fig. 16.12 **a** Above-ground phytomass of one plot (DAS-days after seeding). **b** Dry matter of one plot (DAS-days after seeding)



(a) Above-ground phytomass of one plot (DAS-days after seeding)



(b) Dry matter of one plot (DAS-days after seeding)

amelioration products. When assessing the productivity of the dry matter, the area with the sole application of K3 was found to be the most productive. The sole application of the on-farm component E is associated with a low increase in productivity, which is only improved when K3 is added.

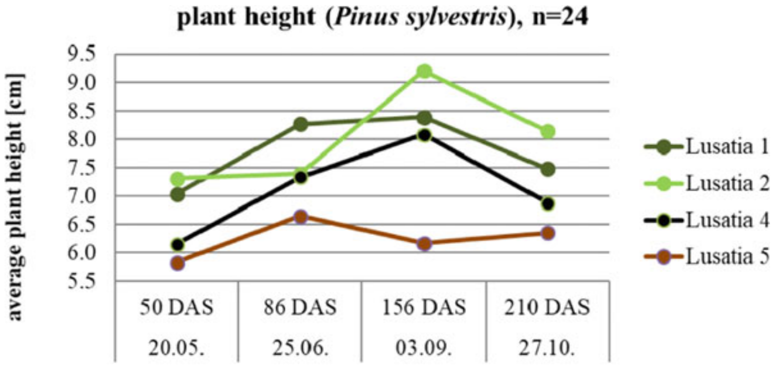
16.3.2.2 Woody Plants

The results of the height measurements of the planted *Pinus sylvestris* show that only an average growth of maximum 2 cm (Fig. 16.13a) was achieved in the whole year. *Pinus sylvestris*, which is well adapted to sandy sites, showed good development even on the control plots (Lusatia 4). Plants on plots with the addition of component E show the lowest growth height and the smallest stem diameter. It can be assumed that this has an inhibiting effect on growth. In contrast, *Pinus sylvestris* grows well with the addition of organic matter (K3, Lusatia 1 and 2), which can be seen above all in the increase in stem diameter (Fig. 16.13). The statements give a first trend, but cannot be generalized nor extrapolated.

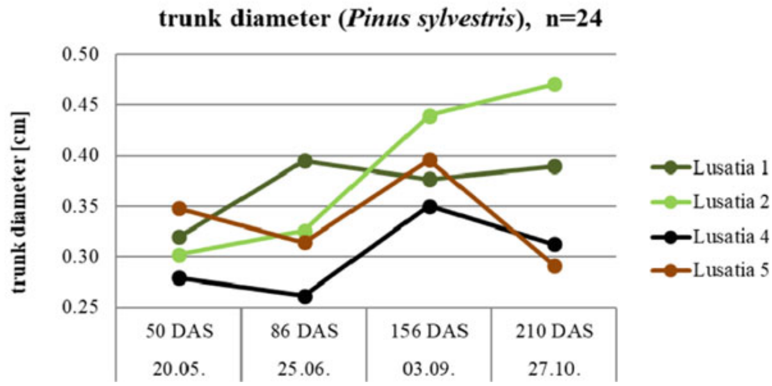
The planted *Quercus robur* hardly shows any changes in growth height and stem diameter over the course of the year (Fig. 16.14a and b). Only the increase in stem diameter due to component K3 can be considered a reliable statement. *Quercus robur* is subject to slow growth under these site conditions. This is not significantly accelerated by the soil amelioration products, which were used.

As a pioneer plant, *Betula pendula* shows rapid growth during its first vegetation period. A clear correlation is evident between applied soil amelioration products, growth height, and stem diameter. The approximately 20 cm tall annual *Betula pendula* trees grew about 10 cm on the pure quaternary sands of the mining areas (Lusatia 4, Fig. 16.15a). The application of

Fig. 16.13 **a** Plant height of *Pinus sylvestris* during one vegetation period (n = 24). **b** Trunk diameter (below) of *Pinus sylvestris* during one vegetation period (n = 24)



(a) Plant height of *Pinus sylvestris* during one vegetation period (n=24)



(b) Trunk diameter (below) of *Pinus sylvestris* during one vegetation period (n=24)

component E increases the growth process; the *Betula pendula* reach a growth height of 40 to 48 cm. In the combined application with K3, an inhibitory effect on growth becomes apparent (Lusatia 1). The sole soil improvement by the component K3 leads to the best growth characteristics. Growth heights of 65 cm on average and stem diameters of >1 cm are already achieved after 210 days (Fig. 16.15b). This corresponds to more than a doubling of the measured plant parameters compared to the control plot.

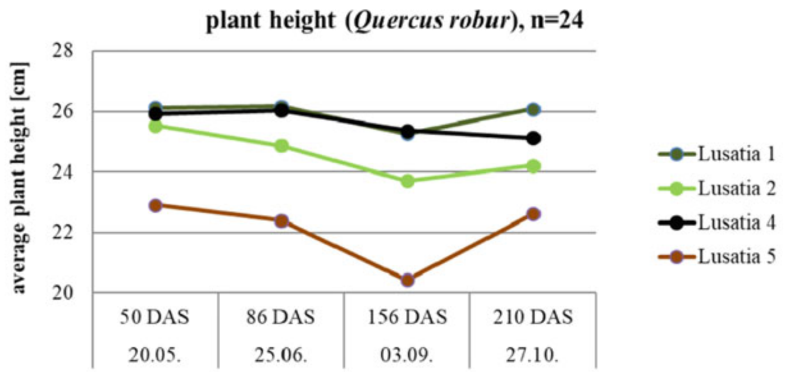
In summary, it can be stated that the growth characteristics of *Betula pendula* as well as *Pinus sylvestris* could be significantly improved by the use of the soil amelioration products E and K3. However, in order to be able to make reliable statements on the effect of the soil amelioration products on the development of *Quercus robur*, a longer observation period is required.

In summary, it can be stated that component K3 is an effective soil amelioration product for vegetation establishment on the rehabilitation sites of Lower Lusatia. In contrast to the pure quaternary sands, the application of component K3 increases the degree of coverage sixfold and the phytomass production. In addition, the growth of the *Trifolium* seed can be promoted in a targeted manner. It is, therefore, possible to achieve protection against aeolian transport after only 5 months.

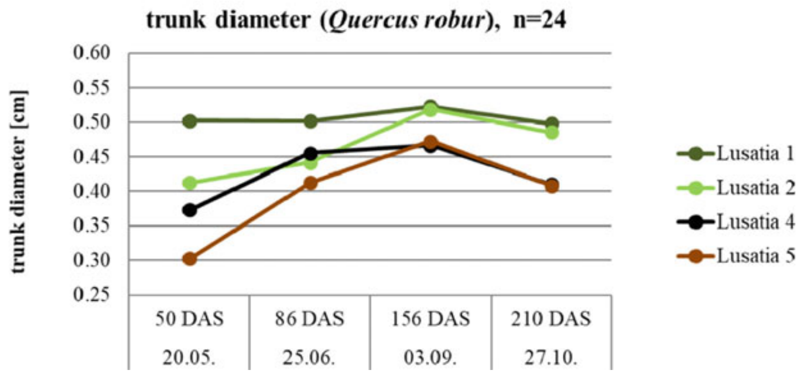
16.3.3 Reduction of Fluvial Transport Processes and Security of Yields in the Kalahari

In addition to a rapid establishment of vegetation, growth under dry conditions is also important in

Fig. 16.14 **a** Plant height of *Quercus robur* during one vegetation period (n = 24), DAS-days after seeding. **b** Trunk diameter of *Quercus robur* during one vegetation period (n = 24), DAS-days after seeding



(a) Plant height of *Quercus robur* during one vegetation period (n=24), DAS-days after seeding.



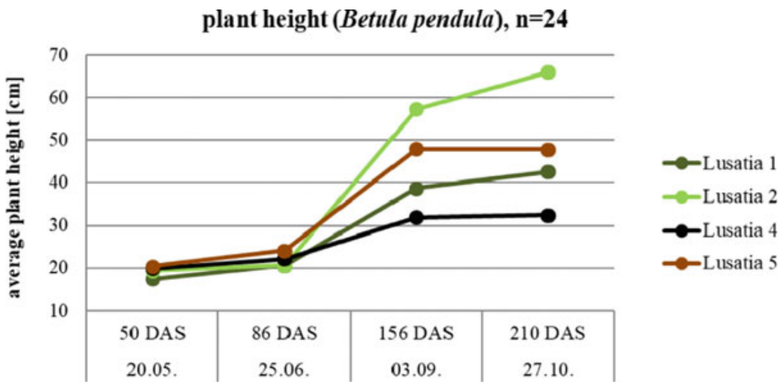
(b) Trunk diameter of *Quercus robur* during one vegetation period (n=24), DAS-days after seeding.

view of the fluctuating rainfall amounts and their temporal distribution.

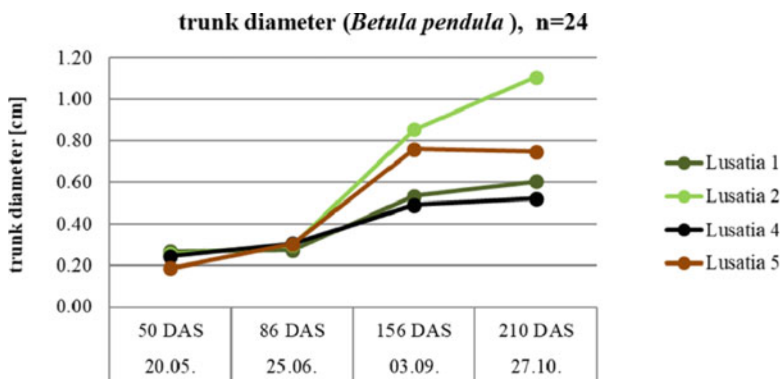
The field trials in the South African Kalahari are based on results obtained in container trials in Germany (Münzel 2019). Here, the growth of wheat plants on sand substrates was monitored under controlled conditions using the components K3 and K4. The results show a positive effect of the soil amelioration products, which was expressed in height growth, biomass, and cover during the vegetative phase, even under intense drought stress (Münzel 2019).

Based on these results, components K3 and K4 were introduced at the beginning of the 2018 rainy season in areas of a thorn savannah in the southern part of the Kalahari, in the wider surroundings of Vergeleë (North-West Province,). The predominant soil type is an oxisol with an average pH of 5.5. The region is characterized by annual rainfall of around 450 mm. However, these vary greatly annually and mostly fall within 4 months, mostly as heavy rainfall. However, the total precipitation that fell during the study period (January 2019 to 10 April 2019) was only 98 mm. Air temperatures varied between 25 and 39 °C (de Wet 2020, oral communication).

Half of the experimental plots were not irrigated (Kalahari 1, 2, 3). On the other half, the irrigation amounted to 121 mm, which is about 50% of the local good practice (Table 16.6). Due to the low rainfall during the 2018/19 rainy season, even for the region, no yield was recorded on the trial plots without supplementary irrigation. Especially in December, in the initial phase of vegetation development, it was too dry, so that the maize seed dried out on all three trial



(a) Plant height of *Betula pendula* during one vegetation period (n=24)



(b) Trunk diameter (below) of *Betula pendula* during one vegetation period (n=24)

Fig. 16.15 **a** Plant height of *Betula pendula* during one vegetation period (n = 24). **b** Trunk diameter (below) of *Betula pendula* during one vegetation period (n = 24)

Table 16.6 Added amount of soil amelioration products to test areas in the Kalahari

plot	Component K3 [% vol.]	Component K4 [% vol.]	NPK	Irrigation amount
Kalahari 1	0.0	0.0	According to good professional practice	0.0
Kalahari 2	5.0	0.0	0.0	0.0
Kalahari 3	0.0	0.0	0.0	0.0
Kalahari 4	0.0	0.0	According to good professional practice	50% According to good professional practice
Kalahari 5	5.0	0.0	0.0	50% According to good professional practice
Kalahari 6	5.0	0.3	0.0	50% According to good professional practice

plots. Therefore, only the three irrigated plots (Kalahari 4, 5, and 6) could be evaluated.

Due to the destruction by animals on the field with K3, the evaluation of the first sowing is limited only to the comparison between the NPK variant and the combined use of the two soil amelioration products K3 and K4. A comparison of all variants is only possible for the reseeding (second sowing, Table 16.7).

The growth success, measured by the number of developed plants, indicates an increase in the number of plants due to the application of the soil amelioration products. In the first sowing, 50% of the plants with NPK fertilizer grew successfully, with the use of the components K3 and K4 there were 50% more (Table 16.7). The second sowing also showed similar results. Compared to the NPK fertilization variant, the growth height of the maize plants could be increased by up to 20 cm when mixed with the soil amelioration products K3 and K4. The use of the organic component K3 alone resulted in maize plants that were 5 cm taller on average compared to the NPK variant.

The positive effect of the soil amelioration products was also shown by the total above-ground biomass. Over 100% more yield was achieved compared to the NPK fertilization. The addition of the water-storing component K4 led to a further improvement in harvest success (Fig. 16.16). In terms of the number of harvested cobs, the maize plants with the addition of both components produced the best harvest results (Table 16.7). The number of cobs doubled compared to conventional management with NPK fertilizer.

16.4 Conclusion

The work carried out provides trend statements for the possibilities of using the developed soil amelioration products. Through their application, a greening of mining tailings can be achieved. Under extreme aridity of a thorn savannah, a soil cover with relevant yields can be achieved with a low supplementary irrigation. It is therefore not necessary and economically advisable to resort to mineral fertilizers and intensive irrigation measures. It can be assumed that the applied soil amelioration products can be effective for up to five years. This was confirmed by subsequent on-site inspections in South Africa. This takes ecological and economic sustainability into account. The practical relevance of the results can be found in the savings in operating costs as well as in irrigation and fertilizer quantities and in the overall labor input.

If the soil has lost its natural polyfunctionality or extreme soil properties prevail, one has to specifically determine the composition and dosage of soil amelioration products. As already mentioned at the beginning, there is no single universally effective soil amelioration product or sole method of agrotechnical treatment. The global use of the developed components of soil amelioration products represents an important step for the sustainable use of our vital resource

Table 16.7 Parameter of maize plants as a function of soil improvement

plot	Kalahari 4 (NPK fertilizer)	Kalahari 5 (K3)	Kalahari 6 (K3 and K4)
Number of plants (first/second sowing)	31 von 60/10 von 30	15 von 60/14 von 30	47 von 60/17 von 30
Average height (first/second sowing))	105 cm/61 cm	94 cm/66 cm	126 cm/74 cm
total biomass (first/second sowing)	10.0 kg/0.5 kg	3.1 kg/1.1 kg	26.2 kg/2.4 kg
number of pistons	19	3	40

Fig. 16.16 Maize plants harvesting in the Kalahari (plot with 5% K3 and K4)

soil. In the future, the demands on soil will increase as the speed of change and the degree of interaction increase and new challenges arise, too. Therefore, increased attention should be paid to this resource in order not to "lose the ground under our feet" (Münzel and Blumenstein 2012).

The information presented so far provides the basis for decision-making on measures to optimize site-specific management, re-vegetation of extreme sites, and crop cultivation in drylands. In the future, the number of components should be expanded by further new developments of soil amelioration products. Thus, the synergy of science and practice provides an important contribution to the adaptation of agriculture to contemporary climatic challenges.

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