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RESEARCH ARTICLE

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Differential performance of selected Sudano-Sahelian plant species for ecological restoration

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Abstract

This study compares the performances of six indigenous (*Acacia albida*, *Acacia nilotica*, *Acacia senegalensis*, *Balanites aegyptiaca*, *Tamarindus indica*, *Ziziphus spina-christi*) and one exotic (*Azadirachta indica*) tree species for the reforestation of a degraded soil (hardé) in the Far North Region of Cameroon. Seedlings were transplanted from the enviroprotect nursery (Maroua) to Gawel ReviTec (revitalization technology) sites (GW1, GW2) in May 2015. A subset of trees from biosoil plots was monitored at 26, 38 and 50 months after transplantation. Survival rate, height, stem diameter and growth volume were measured and revealed lower values at GW2 than at GW1 in general. *A. indica* and *A. nilotica* performed better, with respective survival rates of 78 and 67% at GW1, against lower than 50% at GW2 for all species, the highest (45%) accounting for *A. nilotica*. Stem diameter (91 and 87 cm), height (318 and 308 cm) and growth volume (33 and 42 m^3) were higher for *A. nilotica*, followed by *A. indica* (stem diameter: 90 and 83 cm; height: 248 and 278 cm; growth volume: 20 and 20 m^3), respectively, at GW1 and GW2. These results suggest *A. indica* and *A. nilotica* as the most successful and indicated species for the reforestation of hardé soil.

KEYWORDS
afforestation, Cameroon, exotic tree species, hardé soil, indigenous tree species, soil degradation, soil restoration

Abstract

Cette étude compare les performances de six espèces d'arbres indigènes (*Acacia albida*, *Acacia nilotica*, *Acacia senegalensis*, *Balanites aegyptiaca*, *Tamarindus indica*, *Ziziphus spina-christi*) et une espèce exotique (*Azadirachta indica*) pour le reboisement d'un sol dégradé (Hardé) dans la région de l'Extrême-Nord du Cameroun. Les plants ont été transplantés de la pépinière d'Enviro-Protect (Maroua) aux sites de Gawel ReviTec (technologie de revitalisation) (GW1, GW2) en mai 2015. Un sous-ensemble d'arbres provenant de parcelles de BioSoil a été contrôlé 26, 38 et 50 mois après la transplantation. Le taux de survie, la hauteur, le diamètre des tiges et le volume de croissance ont été mesurés et ont révélé des valeurs plus faibles à GW2 qu'à GW1 en général. *A. indica* and *A. nilotica* ont obtenu de meilleurs résultats, avec des taux de survie respectifs de 78 et 67 % à GW1, contre moins de 50 % à GW2 pour toutes les espèces, le taux le plus élevé (45 %) étant celui de l'espèce *A. nilotica*. Le diamètre des tiges (91 et 87 cm), la hauteur (318 et 308 cm) et le volume de croissance (33 et 42 m^3) étaient plus élevés pour l'espèce *A.*

nilotica, suivie de l'espèce *A. indica* (diamètre des tiges : 90 and 83 cm ; hauteur : 248 and 278 cm ; volume de croissance : 20 et 20 m^3), respectivement, à GW1 et GW2. Ces résultats proposent *A. indica* et *A. nilotica* comme les espèces les plus efficaces et les plus indiquées pour le reboisement des sols de Hardé.

1 | INTRODUCTION

Sub-Sahara Africa, especially the Sahel, is experiencing a constantly growing environmental degradation characterised with some 500 millions ha of degraded soils (Batjes, 2001; Lal & Stewart, 2019). This may even be an underestimate, since the database is not too reliable. Heavy degradation in the Southern Sahel may lead to bare and crusted soil, called hardpan soils or 'hardé', caused by overgrazing (Blay et al., 2004; Tchida et al., 2022). 'Hardé' is unable to sustain agricultural or even pastoral activities and is subject to heavy erosion because of lack of vegetation (Adams et al., 2014; Mainam et al., 2003; Mvondo-Awono et al., 2013).

In Cameroon, about 32% of the national territory has been reported to be degraded and is undergoing soil deterioration, with an increasing tendency (Adams et al., 2014; Bai et al., 2008). In the Far North region, overgrazing and deforestation may lead to the formation of hardé soil (Brabant & Gavaud, 1985; Gavaud, 1971; Peltier, 1993). In the area of Maroua more than 10% are of this type (Blay et al., 2004; Tchida et al., 2022; Tsozué et al., 2014).

Besides improvement of the soil quality by appropriate soil salvage methods, careful selection of tree and shrub species that tolerate hardé soils is important in the rehabilitation of ecosystem services of soil in arid rangelands, for increased productivity (Chazdon, 2008; German et al., 2006; Taddese, 2001). Therefore, in the degraded Sudano-Sahelian savannah ecosystem of the Far North, several ambitious reforestation programmes were initiated by the Cameroon Government (MINEPDED, 2012) and NGOs like the 'Green-Sahel' operation in 2008, to revitalise these degraded lands and convert them step by step into more productive lands.

To help efficiently combatting soil degradation and desertification, the soil and vegetation environmentalists partners of KeKo–Kesel, Koehler and Associates Biologists and the Centre for Environmental Research and Sustainable Technology (UFT) at the University of Bremen developed an ecological approach of revitalization technology called ReviTec (Koehler & Warrelmann, 2007). This technology is based on experience from long-term ecological research (Koehler & Melecis, 2010).

Since 2012, ReviTec has been applied to sites near Salak, Boula and Gawel in the Far North of Cameroon, all suffering from hardé soil. ReviTec is an ecological approach implemented within the partnership between the Universities of Ngaoundéré (Cameroon) and Bremen (Germany; Alifa et al., 2020; Kesel et al., 2006). It aims at combatting soil degradation and desertification by supporting natural processes of soil and vegetation development (assisted natural regeneration, Chazdon et al., 2022), by improving soil porosity and water infiltration and by fostering above and below-ground biodiversity (Danra Djackba et al., 2019; Koehler et al., 2006). The ultimate goal is to develop soil ecosystem services, such as fertility, water retention, erosion control and carbon sequestration.

The ReviTec implementation in the Gawel sites in June 2014 included the planting of selected tree species, fencing and guarding by the local community (department Diamaré, Far North region; Ngakou et al., 2015). ReviTec has been designed as a bottom-up approach, based on the integration of scientific and local knowledge (see also Thor West et al., 2020). So, the approach incorporates indigenous knowledge concerning the plant species as well as traditional soil and water conservation measures (such as bunds, earth dikes, small dams, half-moons, Zaï or planting holes), mineral, organic and biological soil amendments and direct-seeding mulch-based cropping systems (DMC) (Tsozué et al., 2014).

The identification of tree species being best adapted to the harsh conditions in the Sudano-Sahelian savannah has been realised, however, with limited effect up to now (Samaké et al., 2011; Savadogo et al., 2020). High survival rates and good growth performance are essential for the reforestation of degraded soil and hardé in particular, rehabilitating the region-specific ecosystem services and traditional use values. The introduction of non-native tree species is controversially discussed to avoid introduction of invasive species (Brundu et al., 2020). Despite their slow growth rates (Otieno et al., 2001), indigenous species have proved successful in environmental rehabilitation because of their adaptation to local conditions (Sinha, 1997). The use of mainly exotic tree and shrub species in environmental rehabilitation has not given due consideration to the adaptability of such species to local conditions, and neither has it considered survival rates (Olukoye et al., 2003). Thus, the growth performance and survival rates of plant species should be important criteria in assessing the suitability of tree and shrub species towards environmental rehabilitation (Olukoye et al., 2003).

This paper focuses on an assessment of the performance of both exotic (one) and indigenous (six) tree and shrub species for reforestation of hardé soils in the Far North of Cameroon over four years after planting. The growth performances of exotic and indigenous tree and shrub species were assessed in terms of survival rate, height, stem diameter and growth volume of the seven tree species over the period of investigation.

2 | MATERIALS AND METHODS

2.1 | Study area

Our study area is located in the Far North region of Cameroon in the Gawel community (subdivision Ndoukoula, department Diamaré with Maroua as capital; Figure 2). The area belongs to the Sudano-Sahelian

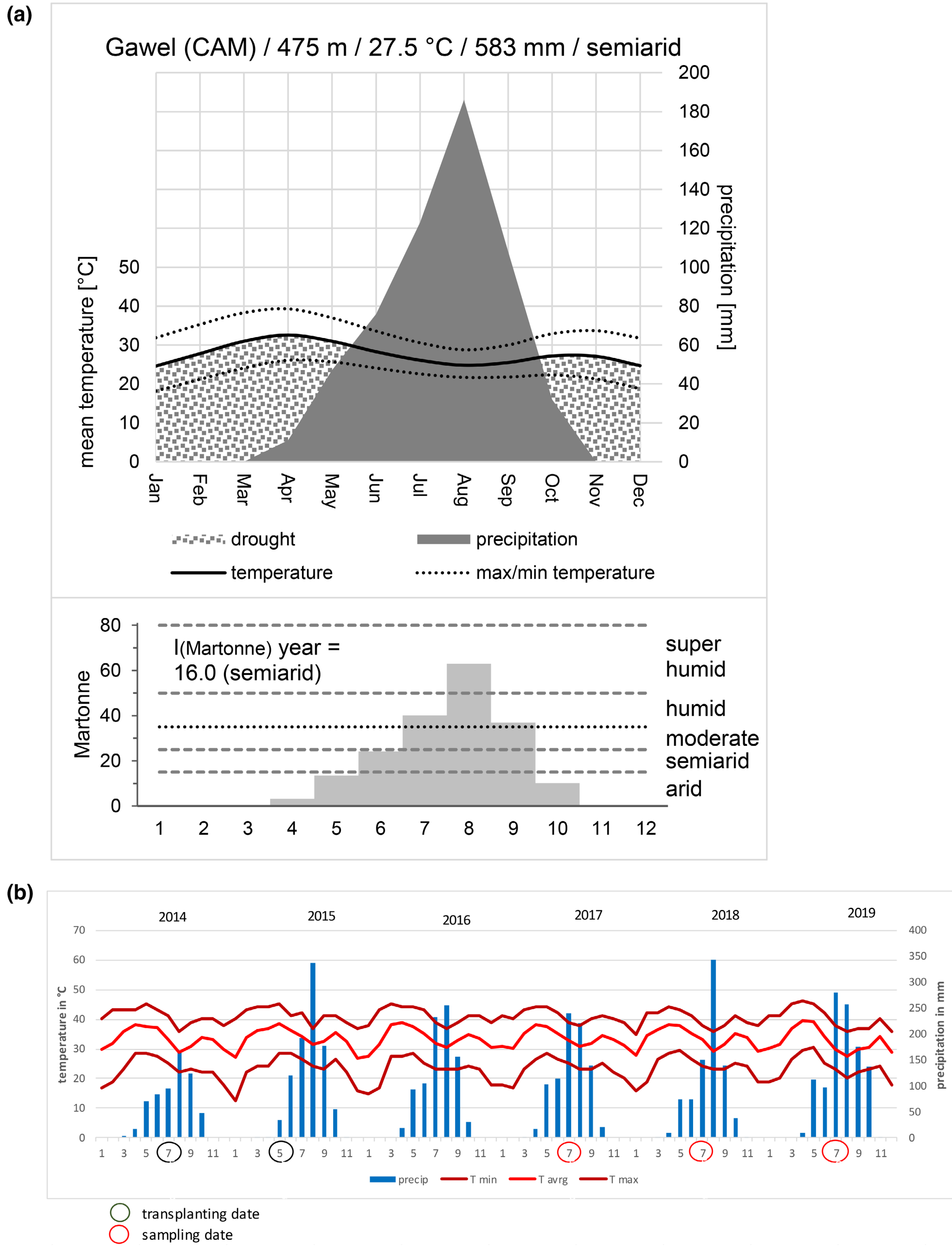

FIGURE 1 (a) Climate diagram after Walter & Lieth and aridity index after De Martonne for Maroua region (long-time average 1991–2021) and (b) Weather data, 2014–2019 (averages for daily mean, minimum, maximum and sum of precipitation, per month); transplanting dates and sampling dates are indicated by circles on the x-axis (months).

agroecological zone, governed by a semi-arid climate with mean annual rainfall of 583 mm and a mean annual temperature of 28°C. According to the aridity index of De Martonne (1926), the dry season lasts from October to May (I < 25) and the rainy season from June to September (I > 25) (Figure 1a; https://en.climate data.org/afrique/cameroun/%20far-north/gawel-901914/, accessed Oct. 2022). The temperature data for the period of the study (2014–2018) are for Maroua airport, retrieved from https://tcktcktck.org/cameroon/far-north/maroua/january-2014#t5, where minima and maxima are available (accessed Nov. 2022). Because the precipitation data from this source are low by factor 2.5; we took the precipitation data from https://en.climate-data.org/africa/cameroon/far-north/maroua-52884/ (accessed Nov. 2022; Figure 1b).

2.2 | Set up of ReviTec site

The investigations were carried out on the two experimental sites Gawel 1 (GW1; 10°24′22.03″ N, 14°06′12.75″ E, 475 m asl; 5.8 ha) and Gawel 2 (GW2; 10°23′24.69″ N, 14°05′12.62″ E, 492 m asl; 32.6 ha) (Figures 2 and 3). With support of the GIZ/ProPSFE (Maroua), a ReviTec measure was tested for the rehabilitation of highly degraded lands with hardé soil. GW2 is separated by a road from the adjacent Sahel Vert reforestation site.

The ReviTec approach includes consultation and capacity building with stakeholders, which was achieved with extensive exchange with honorary citizens of the Gawel community. A memorandum of

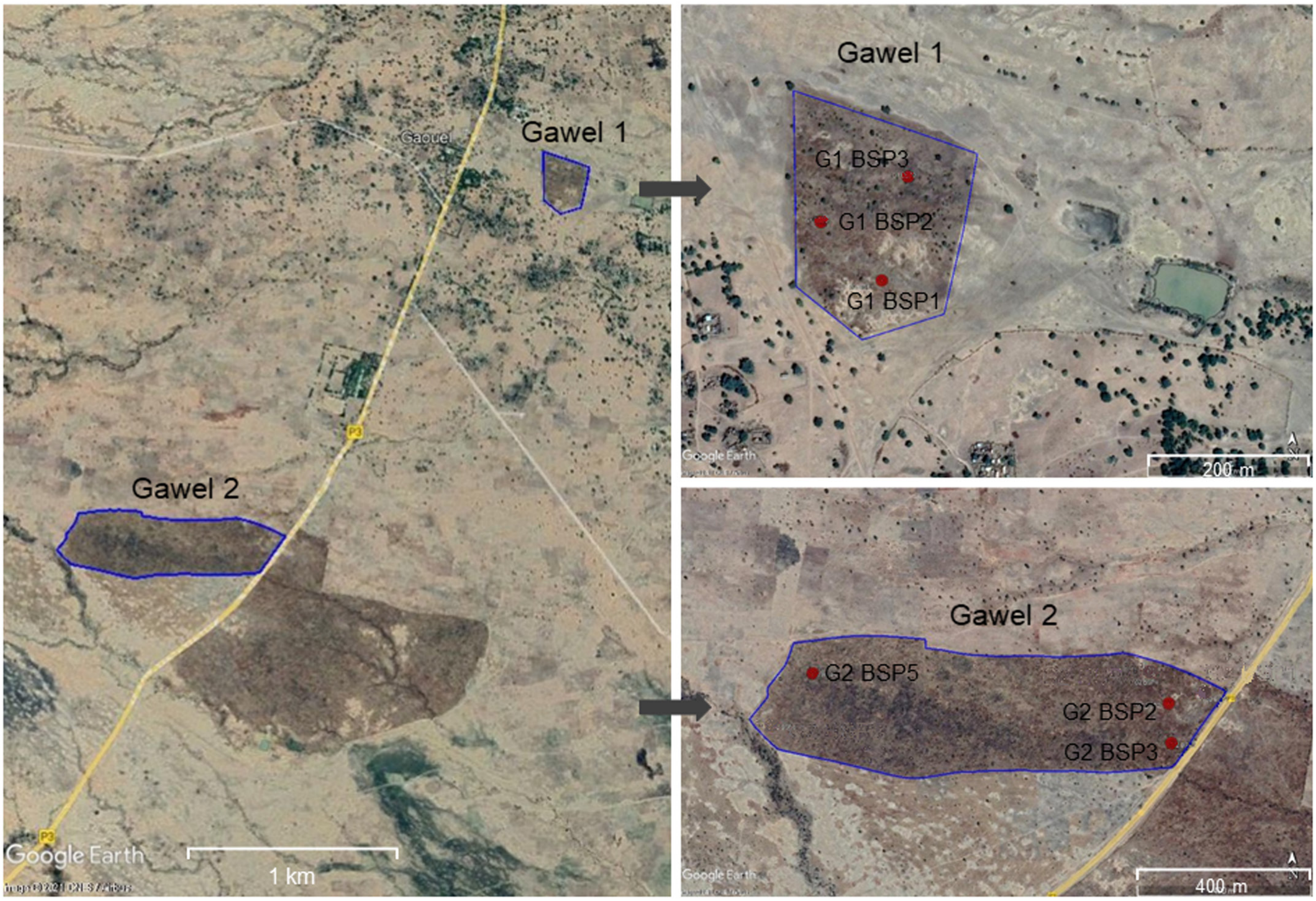

FIGURE 2 Gawel 1 and Gawel 2 sites and the six BioSoilPlots (BSP). Source: Google Earth, Image (c) 2021, CNS/Airbus (Tchida et al., 2022).

understanding was signed between the community and GIZ/ProPSFE (Maroua). Technically, some 5100 biodegradable bags (coffee bags from jute) were filled with 30 L of mixtures of (1) loamy sand, (2) ground cow dung, (3) compost, (4) charcoal (biochar) and (5) EM bokashi (1,2,3: enviroprotect, Maroua; 4: GIZ; 5: GIC Sondason, Bafoussam; Boubakari, 2014). Local grass seed was spread by hand just under the top fabric. With these bioactivated bags ReviTec structures were built: half-moons (demi-lunes), bunds and islands. In the initial phase, the bags protect the substrate against erosion. When rains start, the growing sod takes over erosion control, while the bags are degraded (approx. within 3 months). Under the bags, the roots grow into the moistened hardé and improve soil porosity with all its positive consequences (Kesel, personal communication). The site was fenced with steel wire and dry thorn-bush. Site implementation was finished in June 2014 (Figure 3a).

2.3 | Plant species used

Eighteen tree species belonging to the genera Acacia, Anogeissus, Azadirachta, Balanites, Cassia, Khaya, Parkia, Prosopis, Sclerocarya, Tamarindus and Ziziphus were planted in July 2014 and May 2015 (Table 1). The trees are known to be helpful in restoring degraded ecosystems (Reisman-Berman et al., 2019). Also, it is intended to provide after approx. 5 years firewood from pruning and enable agroforestry. As the trees, the seeds of the two grass species are from local sources. They have direct use values, such as fodder and house thatching (Aronson et al., 1993; Castro et al., 2002; Gupta et al., 1981; Maestre et al., 2001). For the scientific names of Acacia, we follow Worldwide Wattle (2022).

The trees were raised in the nursery of enviroprotect, Maroua. The substrate was inoculated with mycorrhizal fungi by adding some spoonfuls of soil from a nearby forest, presumably containing spores of the fungi. At planting, the saplings were four months old. A total of 21,423 trees was planted in July 2014. Because of loss of a large number of trees due to drought, replantation was effectuated in 2015 in the soil improved by one year of ReviTec application.

To investigate the potential of seven tree species in the re-forestation of hardé soil at Gawel, six indigenous and one exotic tree species were selected (nomenclature according to Table 1): *Acacia albida*, *Acacia nilotica*, *Acacia senegalensis*, *Balanites aegyptiaca*, *Tamarindus indica* and *Ziziphus spina-christi* (all indigenous) and *Azadirachta indica* (exotic).

2.4 | Monitoring

A detailed monitoring was set up to address the objectives of the study. BioSoilPlots (BSPs) allow to study repeatedly individual trees

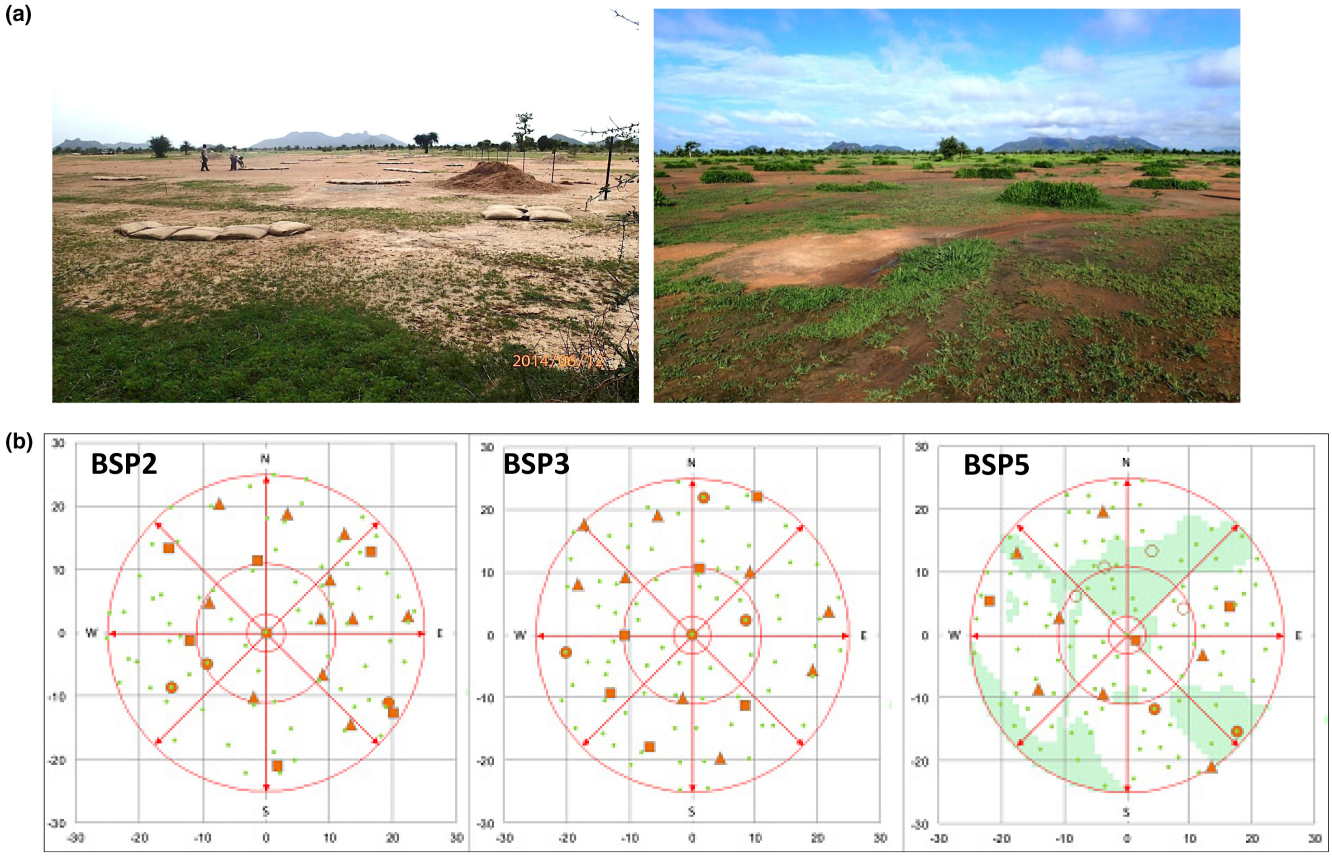

FIGURE 3 (a) Gawel 2 in April and June 2014 before tree planting (Photos: Ngakou) and (b) The BioSoil plots studied: BSP 2–5 from GW2 (Tchida et al., 2022).

TABLE 1 List of the planted species with scientific names, synonyms and common names.

	Names used (synonyms, scientific names)			Scientific names of synonyms		
	Species	Author	Code	Species	Author	Common names
1	*Acacia albida*	Delile	Aa	*Faidherbia albida*	(Delile) A. Chev.	Apple-ring acacia
2	*Acacia nilotica*	(L.) Willd. ex Del	An	*Vachellia nilotica*	(L.) P.J.H. Hurter & Mabb.	Gum arabic tree
3	*Acacia senegal*	(L) Willd.	As	*Senegalia senegal*	(L.) Briton	Sudan gum
4	*Balanites aegyptiaca*	(L.) Delile	Ba			Egyptian balsam
5	*Tamarindus indica*	L.	Ti			Tamarind
6	*Ziziphus spina-christi*	(L.) Desf.	Zs			Christ thorn jujube
7	*Azadirachta indica*	A. Juss.	Ai			Neem
8	*Acacia gerardii*	Benth.		*Vachellia gerrardii*	(Benth.) P.J.H. Hurter	Red thorn
9	*Acacia polyacantha*	Willd.		*Senegalia polyacantha*	(Willd.) Seigler & Ebinger	White thorn
10	*Acacia seyal*	Delile		*Vachellia seyal*	(Delile) P.J.H. Hurter	Red acacia
11	*Acacia sieberiana*	DC.				
12	*Anogeissus leiocarpus*	(DC) Guill and Perr				African birch
13	*Cassia siamea*	Lam.		*Senna siamea*	(Lam.) H.S. Irwin & Barneby	Siamese cassia
14	*Khaya senegalensis*	(Desr.) A. Juss.				Senegal mahogany
15	*Parkia africana*	R. Br.		*Parkia biglobosa*	(Jacq.) R. Br. ex G. Don	Clapperton's parkia
16	*Prosopis africana*	(Guill. & Perr.) Taub.				African mesquite
17	*Sclerocarya birrea*	(A. Rich.) Hochst.				marula
18	*Ziziphus jujube*	Mill.		*Ziziphus mauritiana*	Lam.	Indian jujube
19	*Brachiaria brizantha*	(A.Rich.) Stapf		*Urochloa brizantha*	(Hocht. Ex A.Rich.) R. Webster	Pallisade grass
20	*Pennisetum pedicellatum*	Trin		*Pennisetum pedicellatum*	Trin	Desho grass

Note: 1–7: species included in the analyses. 8–18: species planted but not monitored. 19–20: grasses in ReviTec structures.

TABLE 2 Trees selected for monitoring at the BSP 1–3 of GW1 and GW2, respectively.

	GW1		GW2	
	installed	monitored	installed	monitored
BSP 1				
Acacia albida	10	7	10	7
Acacia nilotica	8	7	13	7
Acacia senegal	10	7	12	7
Balanites aegyptiaca	11	7	8	7
Tamarindus indica	9	7	14	7
Ziziphus spina-christi	9	7	9	7
Azadirachta indica	8	7	17	7
BSP 2				
Acacia albida	11	7	10	7
Acacia nilotica	11	7	19	7
Acacia senegal	8	7	10	7
Balanites aegyptiaca	9	7	10	7
Tamarindus indica	10	7	16	7
Ziziphus spina-christi	12	7	10	7
Azadirachta indica	9	7	9	7
BSP 3				
Acacia albida	10	7	11	7
Acacia nilotica	8	7	22	7
Acacia senegal	19	7	8	7
Balanites aegyptiaca	9	7	12	7
Tamarindus indica	12	7	9	7
Ziziphus spina-christi	11	7	8	7
Azadirachta indica	9	7	10	7
Total	213	147	247	147

Note: Six trees are indigenous and one exotic (Neem, marked bold). For species names see Table 1.

of a specified plot in the long term. The method was adapted after the basic design principles for the ICP Forests Monitoring Networks (Ferretti et al., 2010). A BSP consists of three circular subplots, delimited by circles of increasing radius: inner circle (3 m radius, 28 [30] m^2), middle circle (11 m radius, 380 [400] m^2) and large circle (25 m radius, 1963 [2000] m^2; [for practicability, rounded values are commonly used]; Figure 3b). These subplots are further partitioned in sectors. The BSPs include ReviTec structures. Each BSP is marked with a steel rod with a number plate welded on it, that is driven into the soil providing retrieval of the plot over years. GPS coordinates are determined. The BSPs are distributed more or less regularly over the site, by representing the relevant vegetation, including several tree species and covering about 10% of the surface of the site. For our study, six BSPs were used (3 at each of the two sites, Figures 2 and 3b).

2.5 | Sampling

For the measurements, 49 trees were randomly selected in each of the BSPs, representing replications, resulting in a total of 147 trees per site being monitored at every sampling date (Table 2). For the analyses, t_0 is the second transplantation of trees from the nursery to the ReviTec sites in May 2015. We sampled in July 2017, July 2018 and July 2019, which corresponds to 26, 38 and 50 months after transplantation (MAT). July is the middle of the rainy season (Figure 2) when the vital plants are green and have their full potential.

2.6 | Measurements

Parameters of the monitored trees (Table 3) were survival, height, stem diameter and growth volume. They were measured at each of the sampling dates. (1) Survival rate was calculated as the proportion of trees alive after a given time since planting (Bayen et al., 2015; Bognounou et al., 2010), using the following equation: SR (%) = N(alive)/N(planted at t_0) × 100. SR: survival rate in %; N: number of trees; t_0: May 2015; (2) Tree height in cm was determined with a clinometer and trigonometry; (3) Stem diameter in cm was measured at 30 cm above ground with a Vernier calliper; (4) Growth volume as an indicator for the overgrown space as a simple roughness parameter was calculated as described by Kesel (2013): GV (m^3) = (($d_1 + d_2$)/4)2 × π × h, where, GV is the growth volume expressed in m^3, d_1 is crown diameter north–south (m), d_2 is crown

TABLE 3 Survival rates (%; arithmetic mean and standard deviation, maxima in bold).

Site	Species	Time after transplantation (months) 26	38	50	p-value
GW1	Aa	9.5 ± 1.6e	9.5 ± 1.6e	9.5 ± 1.6d	1.00
	An	67.4 ± 3.2b	67.4 ± 3.2b	67.4 ± 3.2b	1.00
	As	20.3 ± 2.8d	20.3 ± 2.8d	20.3 ± 2.8c	1.00
	Ba	23.8 ± 2.6d	23.8 ± 2.6 cd	23.8 ± 2.6c	1.00
	Ti	17.8 ± 1.9d	2.2 ± 1.0f	2.2 ± 1.0e	0.05**
	Zs	48.1 ± 3.2c	27.8 ± 2.7c	24.1 ± 1.6c	0.03**
	Ai	88.2 ± 1.7a	77.8 ± 2.0a	**77.8 ± 2.0a**	0.06
	p value	<0.0001****	<0.0001****	<0.0001****	
GW2	Aa	7.4 ± 2.4c	7.4 ± 2.4de	7.4 ± 2.4c	1.00
	An	49.5 ± 2.0a	49.5 ± 2.0a	**44.7 ± 3.0a**	0.19
	As	42.9 ± 2.2a	42.9 ± 2.2b	42.9 ± 2.2a	1.00
	Ba	9.1 ± 3.9c	6.1 ± 2.6e	6.1 ± 2.6c	0.40
	Ti	12.4 ± 1.6c	12.4 ± 1.6d	12.4 ± 1.6c	1.00
	Zs	28.2 ± 3.0b	28.2 ± 3.0c	28.2 ± 3.0b	1.00
	Ai	27.3 ± 2.0b	23.6 ± 1.6c	23.6 ± 1.6b	0.06
	p value	<0.0001****	<0.0001****	<0.0001****	

Note: For species names see Table 1; all species indigenous, except Ai (exotic). Different letters indicate significant differences of the means of the tree species at $p < 0.05$ (ANOVA). Bold: maximum after 4 years.

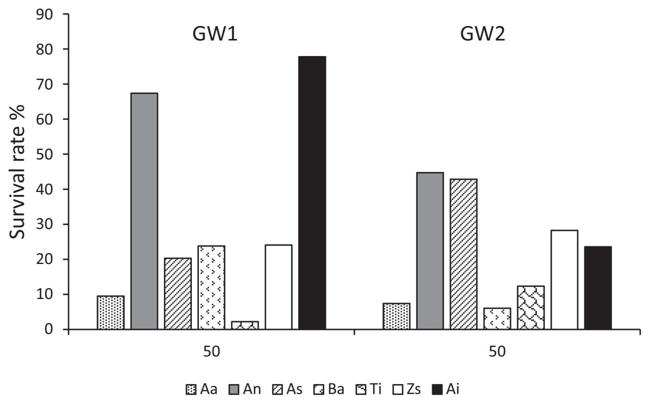

FIGURE 4 Survival rate of the seven selected tree species at MAT 50 (for species code see Table 1).

diameter west–east (m) and h is the plant height (m). The crown diameter was measured with a diameter tape (D-tape).

For each of the 7 tree species, means were calculated for each of the three BSPs ($n = 3$). The data shown are means for the 3 BSPs. The increment in height, stem diameter and growth volume is the difference of the respective parameters of two successive monitoring campaigns. For this section, we have included dead trees in our measurements.

2.7 | Statistical analysis

Data were analysed separately for survival, height, stem diameter and growth volume. Test of distribution followed by analysis of variance (ANOVA) were conducted using the XLStat version 2016 (Addinsoft, 2016) with the following model of analysis: $Y_{ijk} = u + S_i + Y_j + e_{ijk}$, where Y_{ijk} is the dependent variable (e.g. height), u is the overall mean, S_i is the effect of species, Y_j is the effect of year, and e_{ijk} is the random error. Statistical differences between the means of the tree species were assessed using the Tukey Range test.

3 | RESULTS

3.1 | Survival rate

After four years (MAT 50) the number of surviving trees declined from 147 on each of the sites to 47 and 35 on GW1 and GW2, respectively. The survival rates (SR) for the seven tree species selected for analyses specify the lower survival on GW2 (Figure 4). Survival rates of more than 60% are documented for *A. nilotica* and *A. indica* on GW1 with the other species being below 25%. On GW2, two Acacia species (*A. nilotica* and *A. senegal*) show highest survival rates of more than 40%.

The more detailed analysis of the survival in time documents a decrease by more than 50% of trees alive in the first two years after planting (MAT 26) on both sites (Figure 5). Notable exceptions are *A. indica* (SR = 91%) and *A. nilotica* (survival rate = 67%) at GW1. Survival rates of less than 10% were documented for *A. albida* on both sites and for *B. aegyptiaca* and *T. indica* on GW2 and GW1, respectively. Mortality generally did not increase too much in the two years from MAT 26–50. The difference between the two sites is particular striking for *A. indica* (SR = 77/24%, GW1/GW2, respectively). *Z. spina-christi* performed similarly on the two sites (SR = 24/29%, GW1/GW2, respectively).

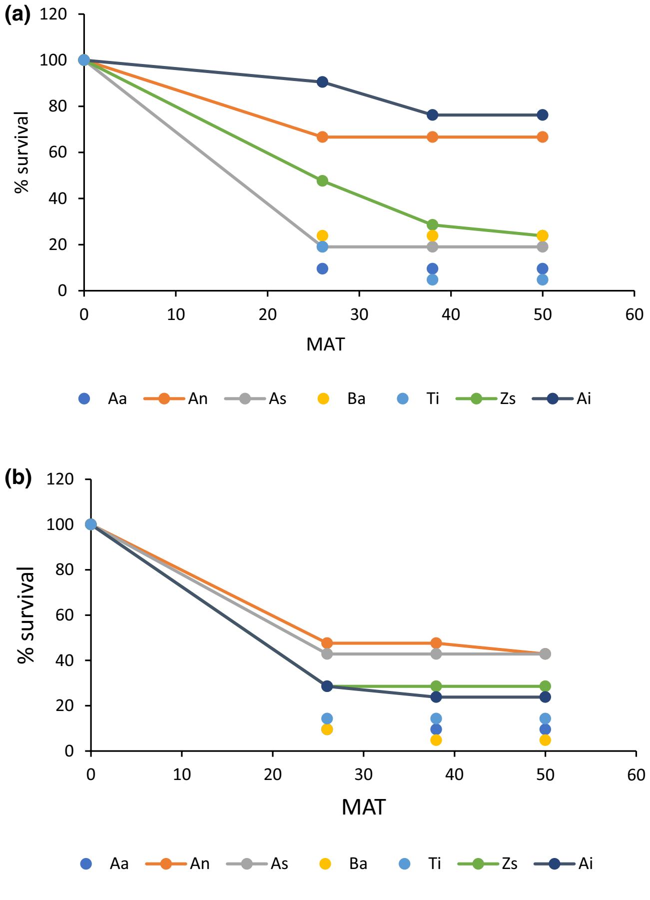

FIGURE 5 Survival rate (%), (a) GW1 and (b) GW2. MAT: months after transplantation. For species code see Table 1; all species indigenous, except Ai (exotic).

Pair-wise comparisons for species survival showed that there was a significant difference ($p<0.05$) among species at different monitoring dates at both sites. The survival rate of *A. indica* was highly and significantly greater ($p<0.0001$) at MAT 26, 38 and 50 compared with that of all the other tree species at GW1 site, while for *A. nilotica* the significant difference ($p=0.001$) was observed at MAT 38 and 50. *A. nilotica* showed highly significant difference ($p<0.0001$) between MAT 26, 38 and 50 compared with all other species at GW2 site, but for *A. senegalensis*, no significant difference was observed at 26 MAT ($p=0.07$) and 50 MAT ($p=0.95$).

Pair-wise comparisons for survival rate between months after planting showed that there was no significant difference ($p>0.05$) for almost all tree species at different planting dates at both sites, except for *T. indica* ($p=0.05$) and *Z. spina-christi* ($p=0.03$) at GW1.

3.2 | Height

Tree growth in the observation period was considerable at both sites, particularly for *A. nilotica* and *A. indica*. *B. aegyptiaca* performed worst (Table 4). Mean tree heights were significantly different ($p<0.05$) between all species within a monitoring date. *A. nilotica* significantly ($p<0.0001$) increased in height more than all other tree species at both sites. The pair-wise comparisons of the heights of each tree species indicate significant differences ($p<0.0001$) between all monitoring periods.

The increments in height from one monitoring to the next are strongest in the first two years until MAT 26 and less pronounced

TABLE 4 Height (cm; arithmetic mean and standard deviation, maxima in bold).

Sites	Species	Time after transplantation (months) 26	38	50	p-value
GW1	*Aa*	53.7±2.5e	58.0±2.2f	63.3±1.6e	<0.0001****
	An	239.2±2.1a	275.8±3.3a	**318.3±2.5a**	<0.0001****
	As	172.8±1.4b	180.5±3.7d	185.3±2.6d	<0.0001****
	Ba	26.7±2.9f	37.2±3.1g	41.2±3.4f	<0.0001****
	Ti	112.6±1.6d	195.2±0.5c	195.4±0.7c	<0.0001****
	Zs	149.1±0.8c	170.7±1.2e	182.7±1.9d	<0.0001****
	Ai	176.7±3.8b	233.4±3.2b	247.7±2.8b	<0.0001****
	p value	<0.0001****	<0.0001****	<0.0001****	
GW2	*Aa*	83.1±0.5e	109.7±1.0e	124.1±3.9d	<0.0001****
	An	212.1±0.6a	267.0±3.6a	**308.4±4.6a**	<0.0001****
	As	149.8±0.5b	175.5±3.8c	195.8±2.8c	<0.0001****
	Ba	33.2±2.2g	40.9±1.9g	51.7±0.4g	<0.0001****
	Ti	59.3±1.6f	68.8±0.5f	81.1±0.1e	<0.0001****
	Zs	123.9±1.8e	138.4±3.3d	154.1±5.8d	<0.0001****
	Ai	142.1±0.9c	216.6±1.1b	272.6±1.1b	<0.0001****
	p value	<0.0001****	<0.0001****	<0.0001****	

Note: For species names see Table 1; all species indigenous, except Ai (exotic). Different letters indicate significant differences of the means of the tree species at $p<0.05$ (ANOVA). Bold: maximum after 4 years.

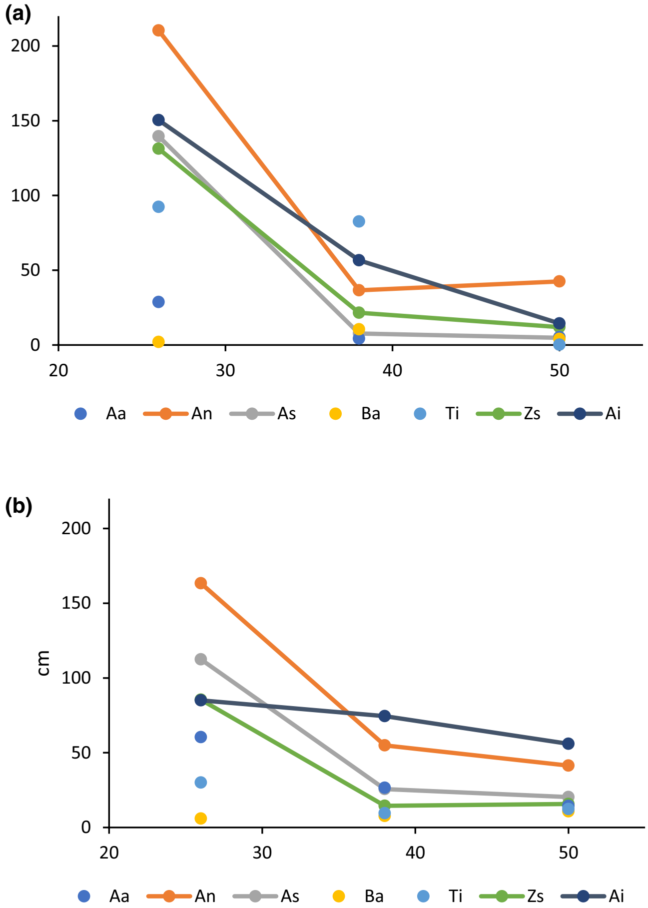

FIGURE 6 Height increment (cm) from one monitoring date to the next, (a) GW1 and (b) GW2. As Figure 5.

on GW2 than on GW1, which is in part due to higher trees planted at GW2 (Figure 6).

3.3 | Stem diameter

On both sites, the highest values were observed for *A. nilotica*, closely followed by *A. indica*. At each MAT, mean stem diameter of *A. nilotica* was significantly higher ($p<0.0001$) than that of all other tree species at GW1 (Table 5). A similar result but not significant ($p=0.999$) was observed between *A. nilotica* and *A. indica* at MAT 50. The pair-wise comparisons of each tree species between months after transplantation indicated a significant difference ($p<0.0001$) between all the monitoring periods for each species (Table 5).

The increments of mean stem diameter are very similar at GW1 and GW2, with highest values in the initial growing phase until MAT 26 and a tendency of increase from MAT 38–50 (Figure 7).

3.4 | Growth volume

Only for three species (*A. nilotica*, *A. indica*, *Z. spina-christi*), growth volume increases considerably within the period of investigation (Table 6). The differences between the two sites are generally comparably low. Only *Z. spina-christi* grew much slower on GW2 than on GW1.

The growth volumes between almost all species at the same monitoring date were significantly different ($p<0.05$). Comparison

TABLE 5 Stem diameter (cm; arithmetic mean and standard deviation, maxima in bold).

		Time after transplantation (months)			
Sites	Species	26	38	50	*p*-value
GW1	*Aa*	7.2±0.6f	8.5±0.3f	11.3±0.5e	<0.0001****
	An	54.1±2.3a	72.0±3.0a	**91.1±3.9a**	<0.0001****
	As	41.3±1.6b	44.7±1.9c	52.3±3.1c	<0.0001****
	Ba	10.6±0.4e	12.9±1.7e	18.3±0.8d	<0.0001****
	Ti	35.6±1.0c	44.4±2.7c	48.0±5.1c	<0.0001****
	Zs	30.1±1.5d	39.1±1.8d	61.0±1.9b	<0.0001****
	Ai	43.0±2.9b	63.6±2.9b	89.6±2.1a	<0.0001****
	p value	<0.0001****	<0.0001****	<0.0001****	
GW2	*Aa*	16.9±0.5d	26.4±4.2d	32.8±3.1c	<0.0001****
	An	52.0±4.9a	70.6±4.2a	**87.2±4.5a**	<0.0001****
	As	27.2±2.9c	36.0±3.6c	45.6±4.7b	<0.0001****
	Ba	7.1±0.6e	9.4±1.1f	10.1±0.3e	<0.0001****
	Ti	14.8±2.4d	20.6±3.0e	23.4±2.7d	<0.0001****
	Zs	14.8±2.9d	19.0±2.2e	28.6±1.9c	<0.0001****
	Ai	38.3±2.8b	59.9±0.5b	83.4±0.7a	<0.0001****
	p value	<0.0001****	<0.0001****	<0.0001****	

Note: For species names see Table 1; all species indigenous, except Ai (exotic). Different letters indicate significant differences of the means of the tree species at $p<0.05$ (ANOVA). Bold: maximum after 4 years.

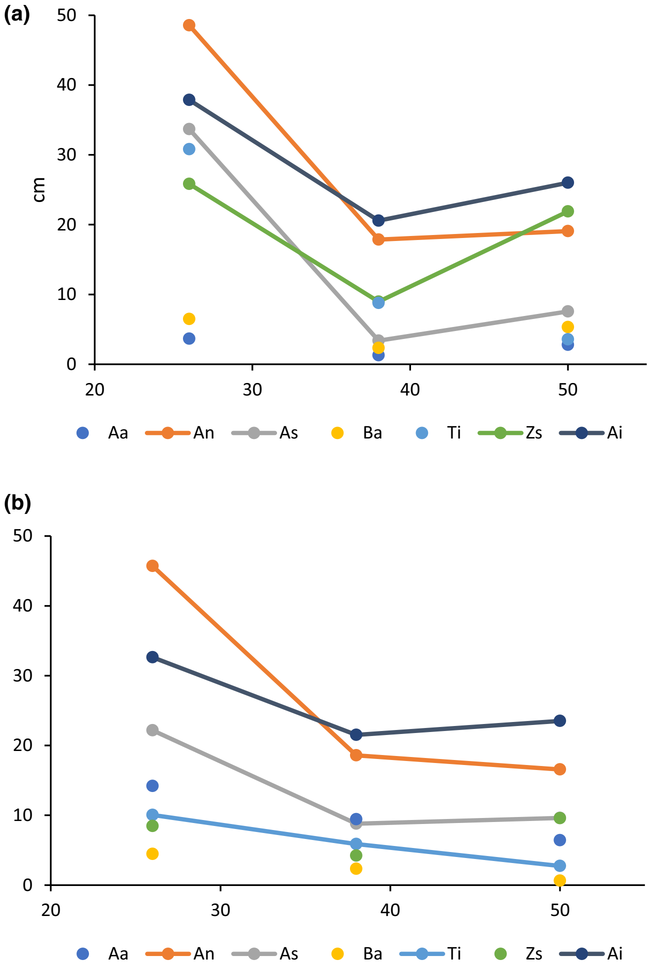

FIGURE 7 Stem diameter increment (cm) from one monitoring date to the next, (a) GW1 and (b) GW2. As Figure 5.

of growth volume of each tree species between monitoring dates revealed significant differences ($p < 0.0001$) between almost all species.

Some increments of growth volume decrease after MAT 26 with a tendency to increase to MAT 50. Only *A. senegal* performs similarly at both sites (Figure 8).

3.5 | Correlations

For re−/afforestation, trees with good survival rate and good growth performance should be selected. The linear regressions show that survival rate is only little correlated with the growth parameters (Table 7). The goodness-of-fit (R^2) is highest for height and diameter, when a 2nd grade polynomic model is chosen also for height and GV. If growth volume is regarded as the most important parameter from the applied point of view, the correlation with diameter may be good enough to justify easily measured diameter as a good proxy.

4 | DISCUSSION

4.1 | Methodology

Results presented in this communication and in previous one (Tchida et al., 2022) document the effectiveness of ReviTec, which combines both traditional approaches (planting pit [Zai, Tassa], bund, etc.) and insights from log-term succession research (Koehler & Melecis, 2010). In contrast to planting pit technologies,

TABLE 6 Growth volume (m^3; arithmetic mean and standard deviation, maxima in bold).

		Time after transplantation (months)			
Sites	Species	26	38	50	*p*-value
GW1	*Aa*	0.2±0.1d	1.1±0.1e	1.6±0.3d	<0.0001****
	An	16.2±2.4a	23.2±2.9a	**32.9±2.1a**	<0.0001****
	As	4.6±0.1c	5.5±0.1d	6.6±0.1c	<0.0001****
	Ba	0.7±0.1d	1.3±0.2e	1.9±0.1d	<0.0001****
	Ti	0.3±0.0d	0.4±0.0e	0.6±0.1d	0.04
	Zs	4.8±0.6c	12.3±0.4c	19.9±0.8b	<0.0001****
	Ai	13.9±0.8b	15.8±1.8b	20.0±2.4b	<0.0001****
	p value	<0.0001****	<0.0001****	<0.0001****	
GW2	*Aa*	0.8±0.0de	2.5±0.0d	3.6±0.0d	<0.0001****
	An	14.8±2.4a	33.7±2.9a	**42.0±3.1a**	<0.0001****
	As	4.5±0.9c	6.4±0.2c	8.8±0.8c	<0.0001****
	Ba	0.2±0.1e	0.6±0.1ef	0.8±0.1e	<0.0001****
	Ti	0.2±0.0e	0.4±0.0f	0.5±0.1e	<0.0001****
	Zs	2.1±0.1d	2.4±0.1de	4.2±0.7d	<0.0001****
	Ai	9.1±0.0b	15.4±0.0b	19.8±0.0b	<0.0001****
	p value	<0.0001****	<0.0001****	<0.0001****	

Note: For species names see Table 1; all species indigenous, except Ai (exotic). Different letters indicate significant differences of the means of the tree species at $p < 0.05$ (ANOVA). Bold: maximum after 4 years.

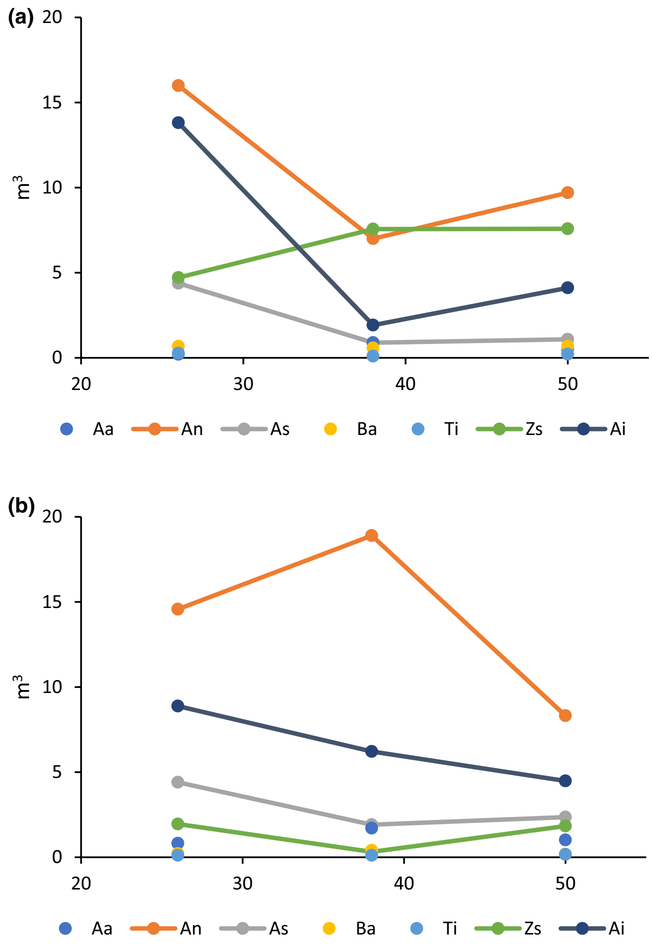

FIGURE 8 Growth volume (m^3) from one monitoring date to the next, (a) GW1 and (b) GW2. As Figure 5.

ReviTec allows contouring for the retention of surface water run-off and does not require digging, an advantage particularly on hard ground.

The advantages of BSPs have been reported by several studies conducted in the framework of monitoring forest development (Ferretti et al., 2010; Tchida et al., 2022). They are the precondition for precise readings over several years. It is possible to monitor a site even decades after its installation.

4.2 | Survival rate

As our results show, young, planted trees have great difficulty in developing. Most often we can see the young trees planted, even carefully protected from the wandering animals, enjoy a year then vegetate and finally die (Savadogo et al., 2020). Different factors affected the survival of plants in the ReviTec sites. During the dry season, water stress may be lethal (Tchida et al., 2022). However, in this locality as in the Sahel, permeable soil is 50 cm or more below the ground (Savadogo et al., 2020). Thus, Zida et al. (2008) add that evaporation at the high prevailing temperatures (45 to 55°C) as well as the long dry season of 7 to 9 months, make watering of saplings inefficient and costly, with the risk of salination (van der Wijngaart et al., 2019; Vengosh, 2003).

Bio-irrigation of nursing shrubs may have a potential (https://globalwater.osu.edu/bio-irrigation-for-the-african-sahel/, accessed Dec. 2022), which has been addressed in the ReviTec context by Koehler et al. (2006). The nurse plant concept (Castro et al., 2002) responds to the fact, that abiotic factors of the environment have a

TABLE 7 Regression models of survival rate (SR) with growth parameters (height, stem diameter, growth volume GV).

		GW1	GW2
SR	height	$y = 37.303x + 116.86$, $R^2 = 0.0751$	$y = 41.094x + 41.689$, $R^2 = 0.598$
SR	diameter	$y = 17.781x + 22.292$, $R^2 = 0.1939$	$y = 0.9741x + 10.407$, $R^2 = 0.3743$
SR	GV	$y = 0.4594x + 37.088$, $R^2 = 0.0905$	$y = 0.4739x - 34.711$, $R^2 = 0.3866$
height	diameter	$y = 0.2807x - 24{,}644$, $R^2 = 0.8953$	$y = 0.2857x - 64.484$, $R^2 = 0.9094$
height	GV	$y = 0.09x - 54.436$, $R^2 = 0.6437$	$y = 0.1272x - 99.767$, $R^2 = 0.7863$
height	GV	$y = 0.0005x^2 - 0.0577x + 26.809$, $R^2 = 0.7737$	$y = 0.0007x^2 - 0.0959x + 37.309$, $R^2 = 0.9346$
diameter	GV	$y = 0.3194x - 46.039$, $R^2 = 0.7136$	$y = 0.4377x - 68.533$, $R^2 = 0.8363$
diameter	GV	$y = 0.0031x^2 + 0.0372x - 0.0335$, $R^2 = 0.7639$	$y = 0.4377x - 68.533$ $R^2 = 0.8363$

profound effect on the well-being and distribution of organisms and the function of ecosystem (Muoghalu, 2003).

Mycorrhization and hardening in the nursery may be mandatory to achieve high survival rate (Corsini et al., 2022). However, the mycorrhiza is in large parts species specific and respective research and cultures are needed. Planting before the rainy season is necessary, seemingly trivial, but often not observed.

Vegetative rehabilitation yielded results both in the Sahelian and others degraded areas in the world in terms of species survival (Mulizane et al., 2005). The significant differences in survival rates among all tree species suggest that their level of adaptation to 'hardé' conditions was not the same.

The strong difference in survival rates between the two sites is in contrast to the development of herbaceous vegetation, which is in general similar on GW1 and GW2 (Tchida et al., 2022). The differences in the performance of the trees at the two sites cannot be attributed to differences in clay content (which is spatially very variable) nor pH (Tchida et al., 2022).

In our study, native *A. nilotica* and exotic *A. indica* performed best. This result is in line with revegetation results of iron mines in Minas Gerais state in Brazil, where both native and introduced species performed well (Griffith & Toy, 2001). However, *A. indica* did not seem to maintain its survival performance at GW2, where it was reduced compared with the one of GW1. This could be explained by the fact that these trees are poorly adapted to drought, clay and lateral superficial soils and do not tolerate flooding even temporarily, thus are sensitive to herbaceous competition (Gautier et al., 2002). Similarly, Hautdidier et al. (2002) added that despite the very fast growth of neem (*A. indica)* compared to local species, their survival rate unfortunately drastically dropped, which could confirm their reduced growth on compacted soils.

The ReviTec structures supported survival only indirectly by improving the sites in total. To benefit from their ameliorating functions (e.g. improvement of water retention, softening the hardé; Tchida et al., 2022) the 2014 planting immediately after ReviTec implementation was premature and the planting in 2015 was only done in some cases directly in the structures.

4.3 | Growth parameters

Diameter as well as height were found to be the most independent fitting variables to predict the biomass. Growth volume is an integrative parameter, qualifying it as the most important of those measured. It includes an indication of availability of litter, leaves for browsers and twigs for coppicing and use in pyrolytic cooking stoves.

In the present study results showed an increase in mean height, stem diameter and growth volume for all selected species. Moreover, the correlation analyses revealed a good correlation between these three growth parameters. This may result in a decrease in runoff and soil loss (Tchida et al., 2022), since previous research showed that the root structure becomes more complex with maturity (Reubens et al., 2007) resulting in a greater protective function in terms of soil erosion. ReviTec structures seemed to have been suitable for tree growth. Similar result was observed by Ponce-Rodríguez et al. (2019) who highlighted the importance of the effect of Stone Bunds on the growth of vegetation. According to Klik et al. (2017), the areas near the Stone Bunds offer better conditions for the development of the vegetation due to the retention of solids and the accumulation of mulch (organic matter, litter, etc.) which is dragged towards the Stone Bunds.

Our study has shown that *A. nilotica* and *A. indica* additionally to good survival also had the best performance in terms of mean height, stem diameter and growth volume on both studied sites. The difference was highly significant from one monitoring period to another, indicating fast growth. Fast growing and developing plant species perform better in terms of soil stabilisation (Andreu et al., 1998; Reubens et al., 2007) and help to ameliorate microclimate and reduce its fluctuation. This creates potential for rapid restoration of degraded lands through the accumulation of organic matter and for future development of mixed stands that combine fast-growing exotics and naturally regenerated native species (Otsamo, 2000) and for the use of the above-mentioned nurse plants. Hautdidier et al. (2002) stated that on the flooded planosols in the rainy season, the local species have proven to be generally more efficient. The most convincing results was obtained for acacias (*A. nilotica* in particular), whereas only neem gave relative satisfaction as the only exotic species.

Unlike other exotic species, *A. indica*, fits better into this habitat which is not its own in respect to the dramatically changing environmental conditions from dry to rainy season (pronounced drought, flooding). Other exotic species with commercial benefits, such as *Eucalyptus spp.* and *Prosopis spp.*, pose an ecological risk because of their allelopathic traits (Reisman-Berman et al., 2019). Such trees release phytotoxic compounds into the environment, e.g. volatile oils in *E. camaldulensis* (Verdeguer et al., 2009) or water-soluble phenols in *P. juliflora* (Al-Humaid & Warrag, 1998). These metabolites can strongly inhibit the germination of other plant species (Inderjit & Callaway, 2003) or even the germination and establishment of congeneric species (Inderjit et al., 2008), counteracting to the concept of assisted natural regeneration.

5 | CONCLUSION

According to our monitoring, only one native and one exotic species performed really well on the sites suffering from hardé and treated with ReviTec. From our findings, we conclude that research and development of nursery conditions and planting regime is needed, particularly in respect to hardening, mycorrhization, timing of planting to benefit from the improvements caused by ReviTec structures. Then more species may prove to be suitable for effective assisted natural regeneration.

The combination of survival rate, height, stem diameter and growth volume provides a four-dimensional indicator of species suitability. The highest values in all four indicators were documented for *A. nilotica* at GW2, giving an indication for the good adaptation of native species to the conditions of the site. Correlation analyses show that for practical reasons stem diameter may be a good proxy for, for example growth volume. In spite of being exotic, *A. indica* also performed very well, despite of its low survival rate at GW2. Both species could be recommended for soil restoration of hardé in the Gawel agroecosystem.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data are available on request due to restrictions, for example privacy or ethical. The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the non-existence of a link at the moment.

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REFERENCES

Adams, S., Tchinda, D., & Mambo, O. (2014). *Evaluation du reboisement à grande échelle dans la Région de l'Extrême-Nord: quelles leçons tirées (Final Report)*. MINFOV, MINEPDED, GIZ.

Addinsoft, XLSTAT. (2016). Data Analysis and Statistical Solution for Microsoft Excel, 2016.

Al-Humaid, A. I., & Warrag, M. O. A. (1998). Allelopathic effects of mesquite (*Prosopis juliflora*) foliage on seed germination and seedling growth of bermudagrass (*Cynodon dactylon*). *Journal of Arid Environments*, *38*, 237–243.

Alifa, A., Megueni, C., Haouvang Laba, C., Kesel, R., & Oumar, M. O. (2020). Restoration of soil physical parameters by an ecological revitalization technology (ReviTec) in Maroua, far region, Cameroon. *International Journal of Advanced Research in Biological Sciences*, *7*(3), 139–151. https://doi.org/10.22192/ijarbs.2020.07.03.017

Andreu, V., Rubio, J. L., Gimeno-Garcia, E., & Linares, J. V. (1998). Testing three Mediterranean shrub species in runoff reduction and sediment transport. *Soil and Tillage Research*, *45*, 441–454.

Aronson, J., Floret, C., Floc'h, E., Ovalle, C., & Pontanier, R. (1993). Restoration and rehabilitation of degraded ecosystems in arid and semi-arid lands. I. A view from the south. *Restoration Ecology*, *1*(1), 8–17. https://doi.org/10.1111/j.1526-100x.1993.tb00004.x

Bai, Z. G., Dent, D. L., Olsson, L., & Schaepman, M. E. (2008). Global assessment of land degradation and improvement 1. Identification by remote sensing. GLADA report 5, version November 2008, 78.

Batjes, N. H. (2001). Options for increasing carbon sequestration in West African soils: An exploratory study with special focus on Senegal. *Land Degradation & Development*, *12*(2), 131–142. https://doi.org/10.1002/ldr.444

Bayen, P., Lykke, A. M., & Thiombiano, A. (2015). Success of three soil restoration techniques on seedling survival and growth of three plant species in the Sahel of Burkina Faso (West Africa). *Journal of Forestry Research*, *27*(2), 313–320. https://doi.org/10.1007/s11676-015-0159-0

Blay, D., Bonkoungou, E., Chamshama, S., & Chikamai, B. (2004). *Rehabilitation of degraded lands in sub-Saharan Africa: Lessons learned from selected case studies* (101). IUFRO-SPDC, FORNESSA.

Bognounou, F., Thiombiano, A., Oden, P. C., & Guinko, S. (2010). Seed provenance and latitudinal gradient effects on seed germination capacity and seedling establishment of five indigenous species in Burkina Faso. *Tropical Ecology*, *51*(2), 207–220.

Boubakari, S. (2014). *Rapport de stage* (p. 15). Internal document GIZ/ProPSFE.

Brabant, P., & Gavaud, M. (1985). *Soils and earth resources of northern-Cameroon (north and far-north provinces): Mapping scale: 1:500000 north: Maroua-Kousseri south: Garoua* (Vol. *103*, 285). ORSTOM.

Brundu, G., Pauchard, A., Pyšek, P., Pergl, J., Bindewald, A. M., Brunori, A., Canavan, S., Campagnaro, T., Celesti-Grapow, L., & Dechoum, M. d. S. (2020). Global guidelines for the sustainable use of non-native trees to prevent tree invasions and mitigate their negative impacts. *NeoBiota*, *61*, 65–116.

Castro, J., Zamora, R., Hodar, J. A., & Gomez, J. M. (2002). Use of shrubs as nurse plants: A new technique for reforestation in Mediterranean Mountains. *Restoration Ecology*, *10*(2), 297–305. https://doi.org/10.1046/j.1526-100x.2002.01022.x

Chazdon, R. L. (2008). Beyond deforestation: Restoring forests and ecosystem services on degraded lands. *Science*, *320*(5882), 1458–1460. https://doi.org/10.1126/science.1155365

Chazdon, R. L., Julio, A., Oliveira, M., Calmon, M., Pinto, A., Darvin, E., & Pereira, B. (2022). *The role of assisted natural regeneration in accelerating Forest and landscape restoration: Practical experiences from the field. Practice kiiNote*. WRI Brasil.

Corsini, D., Vigevani, I., Oggioni, S. D., Frangi, P., Brunetti, C., Mori, J., Viti, C., Ferrini, F., & Fini, A. (2022). Effects of controlled mycorrhization and deficit irrigation in the nursery on post-transplant growth and physiology of *Acer campestre* L. and *Tilia cordata* mill. *Forests*, *13*, 658.

Danra Djackba, D., Nukenine, E. N., & Koehler, H. (2019). Soil Gamasina from savanna and ReviTec site of Ngaoundéré (Adamawa, Cameroon): Abundance and species diversity. *Soil Organisms*, *90*, 187–198.

De Martonne, E. (1926). Aréisme et Indice d'Aridité. *Comptes Rendus Académie des Sciences*, *181*, 1395–1398.

Ferretti, M., Fischer, R., Mues, V., Granke, O., & Lorenz, M. (2010). Basic design principles for the ICP forests monitoring networks. Manual part II. In UNECEICP Forests Programme Co-ordinating Centre (Ed.), *Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests* (22). UNECE ICP Forests Program Co-ordinating Centre. http://www.icp-forests.org/Manual.htm

Gautier, D., Hautdidier, B., Ntoupka, M., Onana, J., Perrot, N., & Tapsou, T. (2002). *Technical file of trees useful to farmers of northern Cameroon. Tree charactéristics, what is used for by farmers, what would be their utility* (125). IRAD (Cameroon), CIRAD (France).

Gavaud, M. (1971). «Harde» soil of Nord-Cameroon (halomorph soils, leached soils, planosoils, hydromorph soils). Setting up of references. *Bull. ORSTOM*, *2*, 55–88.

German, L. A., Kidane, B., & Shemdoe, R. (2006). Social and environmental trade-offs in tree species selection: A methodology for identifying niche incompatibilities in agroforestry. *Environment, Development and Sustainability*, *8*(4), 535–552. https://doi.org/10.1007/s10668-006-9054-3

Griffith, J. J., & Toy, T. J. (2001). Evolution in revegetation of iron-ore mines in Minas Gerais state, Brazil. *Unasylva*, *207*, 9–15.

Gupta, J. P., Aggarwal, R. K., & Raiky, N. P. (1981). Soil erosion by wind from bare sandy plain in western Rajasthan. *Indian Journal of Arid Environments*, *4*, 15–20.

Hautdidier, B., Ntoupka, M., Njiti, C., Tapsou, T., & Dawang, M. (2002). *Un bilan des essais forestiers et agroforestiers du Nord-Cameroun* (112). Institut de la Recherche Agronomique, Centre de Maroua.

Inderjit, S., & Callaway, R. M. (2003). Experimental designs for the study of allelopathy. *Plant and Soil*, *256*, 1–11.

Inderjit, S., Seastedt, T. R., Callaway, R. M., Pollock, J., & Kaur, J. (2008). Allelopathy and plant invasions: Traditional, congeneric, and biogeographical approaches. *Biological Invasions*, *10*, 875–890. https://doi.org/10.1007/s10530-008-9239-9

Kesel, R. (2013). *ReviTec Maroua: Monitoring report august and December 2012* (24). KeKo–Kesel Koehler & partner.

Kesel, R., Koehler, H., & Heyser, W. (2006). ReviTec®, a modular approach of ecological restoration to combat degradation and desertification. *SER-Newsletter*, 1–2.

Klik, A., Schürz, C., Strohmeier, S., Demelash, N. M., Ziadat, F., Schwen, A., & Zucca, C. (2017). Impact of stone bunds on temporal and spatial variability of soil physical properties: A field study from northern Ethiopia. *Land Degradation and Development*, *29*, 585–595. https://doi.org/10.1002/ldr.2893

Koehler, H., Heyser, W., & Kesel, R. (2006). The ecological technology ReviTec® in combating degradation: Concept, first results, applications. In J. Gao, M. Veste, B. Sun, & W. Beyschlag (Eds.), *Restoration and stability of ecosystems in arid and semi-arid regions Beijing* (pp. 288–303). Science Press.

Koehler, H., & Melecis, V. (2010). Long-term observations of soil mesofauna. In F. Müller, C. Baessler, H. Schubert, & S. Klotz (Eds.), *Long term ecological research: Between theory and application* (pp. 203–220). Springer.

Koehler, H., & Warrelmann, J. (2007). *Further development of the revitalization technology ReviTec for degraded soil (project report RevitTal05 No. FV 172)* (84). University of Bremen.

Lal, R., & Stewart, B. A. (Eds.). (2019). *Soil degradation and restoration in Africa* (1st ed.). CRC Press. https://doi.org/10.1201/b22321

Maestre, F. T., Bautista, S., Cortina, J., & Bellot, J. (2001). Potential of using facilitation by grasses to establish shrubs on a semiarid degraded steppe. *Ecological Applications*, *11*(6), 1641–1655. https://doi.org/10.2307/3061085

Mainam, F. J., Zinck, A., & Ranst, E. V. (2003). Variations in the soil properties and crop characteristics due to soil erosion at plot scale in the semi-arid zone of Cameroon. *Cirad- Prasac*, 5.

MINEPDED (2012). *National biodiversity strategy and action plan – Version II* (p. 169). MINEPDED.

Mulizane, M., Katsvanga, C. A. T., Nyakudya, I. W., & Mupangwa, J. F. (2005). The growth performance of exotic and indigenous tree species in rehabilitating active gold mine tailings dump at Shamva mine in Zimbabwe. *Applied Sciences & Environmental Management*, *9*(2), 57–59.

Muoghalu, J. I. (2003). Priority parameters: Abiotic and biotic components. In I. I. Hilary & L. D. Jon (Eds.), *Environmental monitoring. In: Encyclopedia of life support system (EOLSS)*. Eolss Publishers. http://www.eolss.net. Accessed 29 Apr 2021

Mvondo-Awono, J. P., Boukong, A. L., Mvondo-Zé, A. D., & Beyegue-Djonko, H. (2013). Rétablissement de la capacité de production de sorgho (*Sorghum bicolor* [L.] Moench) d'un vertisol dégradé dans la région de l'Extrême Nord du Cameroun. *Biotechnologie, Agronomie, Société et Environnement*, *17*, 56–63.

Ngakou, A., Kesel, R., Mambo, O., & Koehler, H. (2015). ReviTec®, a sustainable approach for combatting desertification: A case study from northern Cameroon. 6th international conference on biotechnology of the Egyptian Society of Environmental Sciences (ESES): Genetics, biotechnology and sustainable development in safe environment. 2–4 February 2015, Ismaila, Egypt.

Olukoye, G. A., Wamicha, W. N., & Kinyamario, J. I. (2003). Assessment of the performance of exotic and indigenous tree and shrub species for rehabilitating saline soils of northern Kenya. *African Journal of Ecology*, *41*(2), 164–170. https://doi.org/10.1046/j.1365-2028.2003.00430.x

Otieno, D. O., Kinyamario, J. I., & Omenda, T. O. (2001). Growth features of *Acacia tortilis* and *Acacia xanthophloea* seedlings and their response to cyclic drought stress. *African Journal of Ecology*, *39*, 126–132.

Otsamo, R. (2000). Secondary forest regeneration under fast-growing forest plantations on degraded Imperata cylindrica grasslands. *New Forests*, *19*(1), 69–93. https://doi.org/10.1023/a:1006688022020

Peltier, R. (1993). *Les terres Hardé: caractérisation et réhabilitation dans le bassin du lac Tchad* (p. 121). CIRAD-Forêt.

Ponce-Rodríguez, M. d. C., Prieto-Ruíz, J. Á., Carrete-Carreón, F. O., Pérez-López, M. E., Muñoz-Ramos, J. d. J., Reyes-Estrada, O., & Ramírez-Garduño, H. (2019). Influence of stone bunds on vegetation and soil in an area reforested with *Pinus engelmannii* Carr. in the forests of Durango, Mexico. *Sustainability*, *11*, 18–5033. https://doi.org/10.3390/su11185033

Reisman-Berman, O., Keasar, T., & Tel-Zur, N. (2019). Native and non-native species for dryland afforestation: Bridging ecosystem integrity and livelihood support. *Annals of Forest Science*, *76*, 114. https://doi.org/10.1007/s13595-019-0903-2

Reubens, B., Poesen, J., Danjon, F., Geudens, G., & Muys, B. (2007). The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: A review. *Trees*, *21*, 385–402.

Samaké, O., Dakouo, J. M., Kalinganire, A., Bayala, J., & Koné, B. (2011). *Régénération naturelle assistée – Gestion des arbres champêtres au Sahel. ICRAF, Technical Manual No. 16*. World Agroforestry Centre.

Savadogo, P., Ky-Dembele, C., & Carsan, S. (2020). *Reussir la plantation des arbres au Sahel*. Manuel Technique. World Agroforestry (ICRAF/WCA/SAHEL).

Sinha, R. K. (1997). Towards ecological regeneration, biodiversity conservation and environmental restoration of the Thar Desert ecosystem in India. *Desertification Control Bulletin*, *30*(28), 36.

Taddese, G. (2001). Land degradation: A challenge to Ethiopia. *Environmental Management*, *27*(6), 815–824. https://doi.org/10.1007/s002670010190

Tchida, P. B., Ngakou, A., Kesel, R., & Koehler, H. (2022). Changes in the Physico-chemical properties of degraded soils in response to the ReviTec approach applied at Gawel (far-North Cameroon). *Sustainability*, *14*(1), 324. https://doi.org/10.3390/su14010324

Thor West, C., Benecky, S., Karlsson, C., Reiss, B., & Moody, A. J. (2020). Bottom-up perspectives on the re-greening of the Sahel: An evaluation of the spatial relationship between soil and water conservation (SWC) and tree-cover in Burkina Faso. *Land*, *9*, 208.

Tsozué, D., Bertrand, R. H., Louleo, J., & Nghonda, J. P. (2014). Local initiatives of land rehabilitation in the Sudano-Sahelian region: Case of hardé soils in the far north region of Cameroon. *Open Journal of Soil Science*, *4*, 6–15. https://doi.org/10.4236/ojss.2014.41002

van der Wijngaart, R., Helming, J., Jacobs, C., Delvaux, P. G., Hoek, S., & Gomez y Paloma, S. (2019). *Irrigation and irrigated agriculture* *potential in the Sahel: The case of The Niger River basin*. Publications Office of the European Union.

Vengosh, A. (2003). 9.09 – salinization and saline environments. In H. D. Holland & K. K. Turekian (Eds.), *Treatise on geochemistry* (pp. 1–35). Pergamon.

Verdeguer, M., Blazquez, M. A., & Boira, H. (2009). Phytotoxic effects of Lantana camara, *Eucalyptus camaldulensis* and *Eriocephalus africanus* essential oils in weeds of Mediterranean summer crops. *Biochemical Systematics and Ecology*, *37*, 362–369.

WorldWide Wattle ver. 2. (2022). Published on the Internet at: www.worldwidewattle.com [Accessed Oct 2022].

Zida, D., Tigabu, M., Sawadogo, L., & Odén, P. C. (2008). Initial seedling morphological characteristics and field performance of two *Sudanian savanna* species in relation to nursery production period and watering regimes. *Forest Ecology and Management*, *255*(7), 2151–2162. https://doi.org/10.1016/j.foreco.2007.12.029

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