Tropical Ecology **51**(2): 207-220, 2010 ISSN 0564-3295
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Seed provenance and latitudinal gradient effects on seed germination capacity and seedling establishment of five indigenous species in Burkina Faso

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Abstract: The present study sought at estimating seed germination capacity and seedling establishment of five Combretaceae species. Five replicates of 20 seeds of *Anogeissus leiocarpa*, *Combretum aculeatum*, *C. micranthum*, *C. nigricans* and *Pteleopsis suberosa* were submitted to germination test according to seed provenance and along latitudinal gradient. Seedling plantation test concerned 25 seedlings per species and per site. Seed provenances affect only the germination capacity of *C. aculeatum* (P = 0.008). Latitudinal gradient influenced the germination parameters of all the species except *P. suberosa* (P = 0.009). The seedling capacity of establishment varied between species, along latitudinal gradient and between control and uncontrol plots (P < 0.001). *A. leiocarpa*, *C. aculeatum*, *C. micranthum, C. nigricans* are potentially usable in vegetation recovery program.

Resumen: El presente estudio intentó estimar la capacidad de germinación de las semillas y el establecimiento de las plántulas de cinco especies de Combretaceae. Cinco réplicas de 20 semillas de *Anogeissus leiocarpa*, *Combretum aculeatum*, *C. micranthum*, *C. nigricans* y *Pteleopsis suberosa* fueron sometidas a una prueba de germinación de acuerdo con la procedencia de las semillas y a lo largo del gradiente latitudinal. La prueba con la plantación de plántulas involucró a 25 plántulas por especie y por sitio. La procedencia de las semillas sólo afectó la capacidad de germinación de *C. aculeatum* (P = 0.008). El gradiente latitudinal influyó sobre los parámetros de germinación de todas las especies excepto de *P. suberosa* (P = 0.009). La capacidad de establecimiento de las plántulas varió entre especies, a lo largo del gradiente latitudinal y entre parcelas controladas y no controladas (P < 0.001). A. *leiocarpa*, *C. aculeatum*, *C. micranthum*, *C. nigricans* tienen potencial de ser utilizadas en un programa de recuperación de la vegetación.

Resumo: O presente estudo procurou estimar a capacidade de germinação das sementes e estabelecimento de plântulas de cinco espécies de Combretaceae. Cinco repetições de 20 sementes de *Anogeissus leiocarpa*, *Combretum aculeatum*, *C. micranthum*, *C. nigricans* e *Pteleopsis suberosa* foram submetidos a teste de germinação de acordo com a proveniência das sementes e ao longo do gradiente latitudinal. O teste de plantação das plântulas foi constituído por 25 plântulas por espécie e por local. A proveniência das sementes afectou apenas a capacidade de germinação da *C. aculeatum* (P = 0,008). Quanto ao gradiente latitudinal verificou-se que influenciou os parâmetros de germinação de todas as espécies, excepto a *P. suberosa* (P = 0,009). A capacidade de estabelecimento das plântulas variou entre espécies, ao longo do gradiente latitudinal e entre os controlos e parcelas sem controlo (P <0,001). A *A. leiocarpa*, a *C. aculeatum, C. micranthum* e *C. nigricans* são potencialmente utilizáveis em programa de recuperação de vegetação.

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Key words: Combretaceae, germination capacity, growth rate, plantation, restoration, survival rate.

Introduction

Tropical dry forests are the most threatened of tropical terrestrial ecosystems (Murphy & Lugo 1986) and have been extensively converted into agricultural land, pasture, secondary forests and savanna (Khurana & Singh 2000, 2001; Vieira & Scariot 2006). The vegetation recovery is often very slow and unpredictable because of complex interactions among propagules as well as site and climatic conditions. Stand regeneration depends on an abundant and viable seed supply, a suitable medium for seed germination, favourable environmental condition and capacity for sprouting, layering or suckering of some species (Kozlowski 2002). In dry and semi-arid areas, natural regeneration is often slow and unpredictable in maintaining mature forest that could provide forest products and services required by increasing population. The highly variable precipitation, frequent dry periods and the losses of seed and young seedlings are major barrier of seedling establishment in natural regeneration (Guariguata *et al.* 2000; Leck 1995; Osunkoya 1994). Hence, greater emphasis on several concurrent strategies will be needed, specifically regarding artificial regeneration pathways with particular emphasis on seed biology, response of tree and genotype to environment stresses. Because of economic limitations for the conservation of tropical forests and the restoration of degraded woodlands, assisting natural regeneration seems the most reliable option (Hardwick *et al.* 1997; Honu & Dang 2002). In Burkina Faso, the management of State forest requires selective tree cutting of the merchantable standing volume over a 20 years rotation (Bellefontaine *et al.* 2000). The harvested stands are mainly left to regenerate naturally, but in some cases this is supplemented by direct seed sowing (Soto Flandez 1995). But direct seeding has frequently failed (Kaboré 2004) due to limited moisture availability, fire and various disturbances (Fensham *et al.* 2003; Marod *et al.* 2002; McDonald *et al.* 2003; McLaren & McDonald 2003a, b; Menaut *et al.* 1995). Therefore, the current approach of woodlands restoration is to consider plantation of seedling as an alternative in order to assist and accelerate the natural regeneration process. All over the world, the priority task of seedling out-planting is to stabilize the ecological situation of cultivated regions which is threatened by impoverishment and detrimental effects on the environment. Many studies were undertaken to assess the germination capacity (Kambou 1997; Ouedraogo *et al.* 2006; Thiombiano *et al.* 2003; Thiombiano 2005; Zida *et al.* 2005; Zida 2007) and the establishment capacity of out planting seedlings (Thiombiano 2005; Zida 2007; Zida *et al.* 2008) of indigenous species in Burkina Faso. But studies about seed germination capacity according to seed provenance and along latitudinal gradient; and out-planted seedlings establishment along the latitudinal gradient are scarce or non-existent. As the purpose of sylviculture is to provide good and services to population, the choice of suitable ecological and socio-economic species is of paramount importance. This situation calls for indepth study of artificial regeneration to help to make decisions about restoration programs and conservation strategies.

In this study, we investigated five Combretaceae species, *Anogeissus leiocarpa* Guill. & Perr. *Combretum aculeatum* Vent., *C. micranthum* G. Don, *C. nigricans* Leprieur ex Guill. & Perr. and *Pteleopsis suberosa* Engl. & Diels. Their ecological magnitude and their importance in pharmacopeia, fuelwood, raw material for house building, handicraft, manufacturing of agriculture tools, utensils, and furniture are well known (Arbonnier 2002; Bognounou *et al.* 1975; Germano *et al.* 1998; Nacoulma/Ouedraogo 1996; Thiombiano 2005). The objectives were, (i) to estimate seed germination capacity according to seed provenance and also according to latitudinal gradient; (ii) to estimate establishment capacity of out-planted species along a latitudinal gradient. Latitude is not ecologically meaningful, but correlates with variation in ecologically meaningful variables such as climate and spatial heterogeneity (Osborne 2000; Gough and Field 2007). Practitioners increasingly talk about geographic gradients that vary with latitude, rather than effects of latitude. However, the term “latitudinal” is convenient, widespread and theory neutral, hence its continued use. We hypothesized that the high loss of seedlings between germination and establishment may be reduced by the production of seedlings in nursery followed by their outplanting.

Materials and methods

Study sites

The study was carried out along latitudinal gradient in Western Burkina Faso, West Africa. The study sites were located at Belehede (14° 06' N and 1° 12' W), Ouahigouya (13° 32' N and 2° 22' W), Diouroum (12° 58' N and 3° 08' W) and Pâ (11° 35' N and 3° 14' W) (Fig. 1). Phytogeographically, the study sites are located in the following sectors defined by Fontes and Guinko (1995). The vegetation type at all sites is a tree/bush savanna with a grass layer dominated by the annual grasses and forb species. Species of Mimosaceae and Combretaceae families dominate the woody vegetation component. The North Sahelian sector's annual rainfall varies between 400 - 500 mm. The number of rainy days per year varies between 30 and 40 days. The most frequently encountered soils at Belehede are solonetz according to the FAO soil classification system (Driessen *et al.* 2001). The vegetation is characterized by Saharian and Sahelian plant species. The South Sahelian sector's annual rainfall varies between 500 - 600 mm. The number of rainy days per year varies between 40 and 50 days. The most frequently encountered soils at Ouahigouya are lithosols. The vegetation is characterized by Saharian, Sahelian and some Sudanian plant species. The North Sudanian sector's annual rainfall varies between 600 - 700 mm. The number of rainy days per year varies between 40 and 70 days. The most frequently encountered soils at Diouroum are lithosols. The vegetation is characterized by Sudanian and some Sahelian plant species. The South Sudanian sector's annual rainfall varies between 800 - 900 mm. The number of rainy days per year varies between 70 and 90 days. The most frequently encountered soils are ferralsols.

Study species and seed provenance

Five species were selected based on their wide ecological distribution and the importance in pharmacopeia, fuel wood, raw material for house building, handicraft, manufacturing of agriculture tools, utensil, and living-room furniture (Arbonnier 2002; Ganaba *et al.* 1998; Kerharo & Adam 1974; Kristensen 2004; Nacoulma/Ouedraogo 1996; Thiombiano 2005). *Anogeissus leiocarpa* is a medium size tree 7 - 18 m with a wide ecological distribution, ranging from the borders of the Sahara up to the

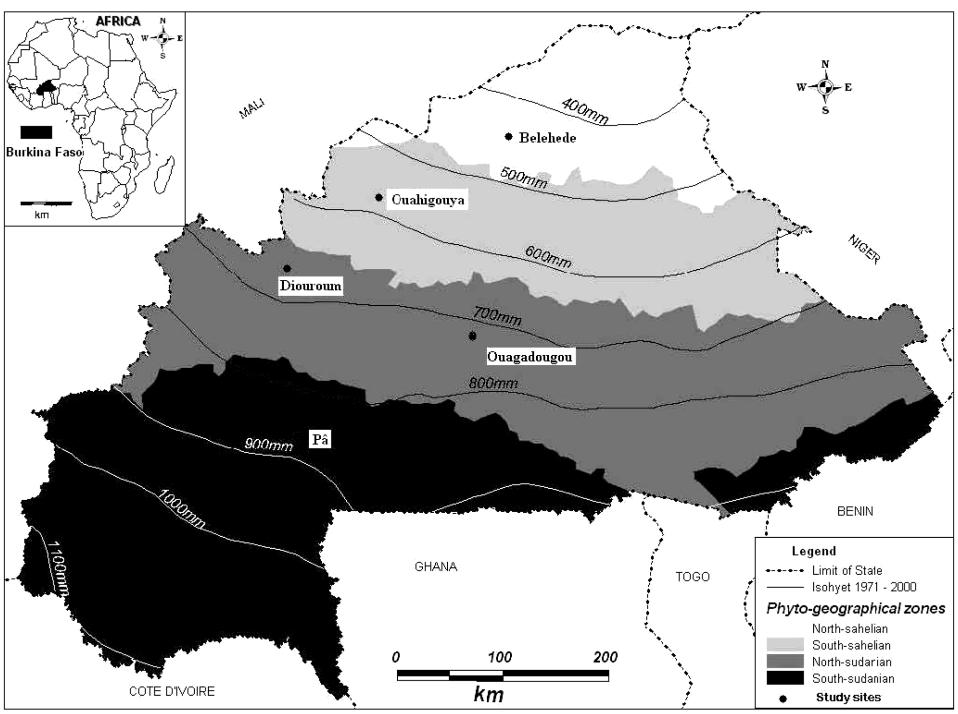

Fig. 1. Phytogeographical map of Burkina Faso with isohyets and location of the study sites.

outlier humid tropical forests. It grows in both Sudanian and Sahelian domains in dry forests, fringing forests and semi-arid savanna areas around swamps, in valleys and forest galleries, where it usually forms pure, dense and closed stands (Thiombiano *et al*. 2006). The seeds were collected from the woodlands of Belehede, Ouahigouya, Diouroum and Pâ. *Combretum aculeatum* is a scrambling shrub up to 0.5 - 4 m in height with virgate branches, or scandent to 8 m. It is found in dry savanna, thickets on dry soils and is sometimes riverine. It grows in Sahelian domain and North Sudanian sector on sandstone, clay, laterite crystalline rocks and skeletal soil. The seeds were collected from the woodlands of Belehede, Ouahigouya and Diouroum. *Combretum micranthum* is a small tree, shrub or liana of 4 m high (attaining up to 10 m under favourable conditions) and may reach a height/length of 20 m by twining around the branches of nearby trees. It grows in the Sahelian domain and the North Sudanian sector. It is a savanna plant, found on dry sites, sandstone, clay, laterite, crystalline rocks, and skeletal soils. It is commonly gregarious and locally abundant, and is often found in pure, dense stands. The seeds were collected from the woodlands of Belehede, Ouahigouya and Diouroum. *Combretum nigricans* is either a tree or a shrub, 4 - 12 m high, with a dense, rounded crown. It grows in South Sahelian sector and Sudanian domain. It is very common, locally abundant and gregarious. It is found in savannah and dry forests of the Guinean and Sudanian regions, usually on loamy or clay soils, but also on sand-stone, sandy or rocky soils. The seeds were collected from the woodlands of Ouahigouya, Diouroum and Pâ. *Pteleopsis suberosa* is a shrub, 4 - 7 m high. It is present in Guinean and Sudanian regions. It grows in Sudanian domain in deciduous woodland and wooded grassland on clay soils, sandstone and sandy or rocky soils. The seeds were collected from the woodlands of Diouroum and Pâ.

Seed collection and processing

Seeds were collected from ten dominant or codominant trees of each species with clear bole, well developed crown and abundant seeds on each site in December 2005 (*A. leiocarpa*, *C. aculeatum*, *C. micranthum* and *C. nigricans*) and February 2006 (*P. suberosa*) according to their phenology. The selected trees were at least 100 m apart from each other to ensure maximum genetic variation within the population. The seeds were reaped directly from the trees at the time of natural dispersal and transported in the Laboratory of Biology and Ecology of the University of Ouagadougou for processing and germination tests. Physical damage on seeds was assessed by visual inspection and damaged seeds were discarded to ensure the use of fairly good quality seeds for the study. According to the National Tree Center in Ouagadougou, Burkina Faso, the species of our study do not need any pretreatment to germinate.

Germination experiments

The germination experiments were performed without pretreatments. The first germination test was conducted in February 2006 at the nursery of Ouagadougou University with 28 °C as the mean ambient temperature. Five replicates of 20 seeds from each provenance were sown on the mixture medium of sand, dung and clay in the ratio 1:2:1 respectively, in polythene plastic pots measuring 7.5 × 25.5 cm, which was kept moist. A total of 75 plastic pots (5 replicates × 5 species × 4 provenances [*A. leiocarpa*: 4, *C. aculeatum*: 3, *C. micranthum*: 3, *C. nigricans*: 3, *P. suberosa*: 2]) was used. The germination process was monitored every day for 40 days and germinated seeds were counted when the seedling emerged from the medium. We considered in this study that the germination termination is the emergence of seedling from the substratum because seed germination involves the imbibition of water, a rapid increase in respiratory activity, the mobilization of nutrient reserves and the initiation of growth in the embryo (Fenner & Thompson 2005). The only stage of germination that we can time fairly precisely is it termination (Bewley & Black 1994).

The second germination test was conducted in May 2006 at four different latitudes (Belehede, Ouahigouya, Diouroum and Pâ) in the nurseries of the foresters. The ambient mean temperatures at these locations were 35 °C, 34.2 °C, 32.9 °C and 32.8 °C, respectively. Mixture of seeds from different provenances of each species was tested. Five replicates of 20 seeds of each species were sown at each site. A total of 100 plastic pots (5 replicates × 5 species × 4 latitudes) was used. The seed medium and the monitoring of the germination were as described above. The following parameters were determined: (i) germination capacity (GC) and (ii) mean time to complete germination (MGT).

Seedling growth and transplantation

The mixture of seeds from different provenances of each species was sown directly on the same medium and in the same polythene type of plastic pots used in the germination experiments. Seedlings were grown under partial shade (50 % full sunlight) using locally available grasses for shade at Belehede and tree shade at Ouahigouya, Diouroum and Pâ; and the medium was kept moist during 3 months. After the seedling growth we performed the plantation experiment of the germinated seeds.

P. suberosa did not germinate and was thus excluded from the seedling experiment. To assess the survival and the growth of the seedlings of *A. leiocarpa*, *C. aculeatum*, *C. micranthum* and *C. nigricans*, a sample of 50 seedlings per species were transplanted at open woodland at Diouroum. The choice of Diouroum is based on the fact this latitude is included in the distribution areas of the four species. Two replicates of 25 seedlings were transplanted on August 2006 with 3 m between seedlings in a row and 25 m between rows. The height of the seedlings was recorded before transplantation and monthly for 12 months.

To assess the latitudinal gradient effect on the survival and the growth of the seedlings of *A. leiocarpa* and *C. aculeatum*, a sample of 25 seedlings per species were transplanted at open woodlands at Belehede, Ouahigouya and Pâ. To estimate the effect of water stress and weed competition on the seedlings establishment, two control plots with a sample of 25 seedlings per species were set up at Belehede and Pâ. These plots were protected against big herbivores, the weed was cleared and the plantations were watered once a week during the dry season (October 2006 to May 2007). These tests concerned only two species because of the problem of seedling availability of other species on different sites. The soil characteristics of the planting sites are summed up in Table 1 (BUNASOLS 2002a, b, c, 2006).

The following parameters were determined after transplantation: (i) seedling survival rate (SR) and (ii) seedling annual relative growth rate (RGR).

Data analysis

GC and MGT were calculated by the followings formulas:

$$\text{GC}\,(\%) = \frac{\text{Number of germinated seeds}}{\text{Number of seeds sown}} \times 100$$

$$\text{MGT (days)} = \frac{\sum(t_i \times n_i)}{\sum n_i}$$

Where t_i is the number of days starting from the date of sowing and n_i is the number of seeds germinated at each day (Bewley & Black 1994).

SR and RGR were calculated by the following formulae:

$$\text{SR}\,(\%) = \frac{\text{Number of seedlings alive at the end of the test}}{\text{Number of seedling transplanted}} \times 100$$

$$\text{RGR}\,(\%) = \frac{H_1 - H_0}{H_0} \times 100$$

Where H_0 is seedlings height before transplantation test (August 2006) and H_1 is the height at the end of the test (October 2007).

GC was analyzed with generalized linear models using penalized quasi-likelihood with binomial errors. Seed provenance and species were treated as fixed factors in the experiment undertaken in the nursery of Ouagadougou and the analyses were done separately for each factor. Latitude and species were treated as fixed factors in the experiment undertaken at the four latitudes. SR was analyzed with generalized linear models with binomial errors. Species was treated as fixed factor in the experiment undertaken at Diouroum; latitude and species were treated as fixed factors in the experiment undertaken at the four latitudes; treatment and species were treated as fixed factors in the experiment undertaken at Belehede and Pâ. Generalized linear models with binomial errors were used in order to account for the non-normal errors and the inconstancy of the variance that are associated with proportion and binary data. Penalized quasi-likelihood estimation was used in order to account for over and under-dispersions of proportion data. MGT and RGR were analyzed using linear models with the same categorical fixed factors according to the experiments. These data fulfilled the assumptions of normality and variance homogeneity. All statistical analyses were performed within the R statistical package (R Development Core Team 2006).

The data from the nursery of Ouagadougou and the plantation test of Diouroum were subjected to one-way analysis of variance (ANOVA) and the models can be described very simply by the use of the following linear additive equation:

$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$

Where, Y = Variable being measured (GC and

Table 1. Physical and chemical characteristics of soils at planting sites.

Soil characteristics	Belehede	Ouahigouya	Diouroum	Pâ
Clay fraction (%)	10 - 47	17 - 29	16 - 45	6 - 27
Silt fraction (%)	-	16 - 22	12 - 28	-
Sand fraction (%)	61 - 51	55 - 62	57 - 31	82 - 65
Organic matter (%)	0.5	0.6	0.8	0.66
Nitrogen (%)	0.03	0.04	0.04	0.03
Carbon/Nitrogen (%)	11	12	13 - 10	12 - 11
Assimilable phosphorus (ppm)	1.2	1.2	1.93	2.35
Free potassium (ppm)	142	21	97.31	68
Base sum (meq/100)	3 - 9	4.60 - 5.00	2.62 - 13.78	1.23
CEC (meq/100)	8 - 11	9.20	10 - 12	2.01
Saturation (%)	70	50 - 55	52 - 93	65 - 58
Useful available water (mm)	56 - 78	39.49	53 - 90	36 - 87
pH (H_2O)	6.2	5.60 - 6.00	5.64 - 6.25	6.7 - 5.9
Fertility class	Average	Low	Average	Low

MGT for Ouagadougou or SR and RGR for Diouroum); μ = Mean value of the Y variable; α = Factor effect (species and seed provenance for Ouagadougou or species for Diouroum); ε = Experiment error; i = Factor number (1 = *A. leiocarpa*, 2 = *C. aculeatum*, 3 = *C. micranthum*, 4 = *C. nigricans*, 5 = *P. suberosa* and 1 = Belehede, 2 = Ouahigouya, 3 = Diouroum, 4 = Pâ); j = Replicate number.

The data from latitudinal germination and plantation tests were subjected to two-way ANOVA and the models can be described very simply by the use of the following linear additive equation:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

Where, Y = Variable being measured (GC and MGT for germination experiment, and SR and RGR for plantation experiment); α_i = Main effect of level i of factor α (species); β_j = Main effect of level j of factor β (latitude); $(\alpha\beta)_{ij}$ = Interaction term between α_i and β_j; ε_{ijk} = Experiment error.

The data from plantation test and control plots were subjected to three-way ANOVA and the models can be described very simply by the use of the following linear additive equation:

$$Y_{ijkf} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} - (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijkf}$$

Where, Y = Variable being measured (SR and RGR); α_i = Main effect of level i of factor α (species); β_j = Main effect of level j of factor β (latitude); γ_k = Main effect of level j of factor γ (treatment); $(\alpha\beta)_{ij}$ = Interaction term between α_i and β_j; $(\alpha\gamma)_{ik}$ = Interaction term between α_i and γ_k; $(\beta\gamma)_{jk}$ = Interaction term between $\beta_{j.}$ and γ_k; $(\alpha\beta\gamma)_{ijk}$ = Interaction term between α_i, $\beta_{j.}$ and γ_k; ε_{ijkf} = Experiment error.

The car package was used to perform the ANOVA using the type III sum of squares for non-orthogonal design in the plantation experiment. The gplots package was used to perform graphs.

Results

Seed provenance effect on seed germination parameters

In the nursery of Ouagadougou, GC varied significantly among species (Fig. 2a, $F_{4, 70}$ = 241.650, P < 0.001). The seeds of *P. suberosa* did not germinate. *C. aculeatum* had the highest GC (97 %) and *A. leiocarpa* the lowest one (2 %). MGT was significantly different among species (Fig. 2b, $F_{4, 70}$ = 10.746, P < 0.001). The seeds of *A. leiocarpa* had the lowest MGT (6 days) and *C. nigricans* the highest one (13 days).

GC of *C. aculeatum* were significantly affected by seed provenance (Fig. 2a, $F_{2, 12}$ = 7.332, P = 0.008). The seeds from Belehede had the lowest GC (91 ± 4) and the ones from Belehede and Ouahigouya had the highest (99 ± 1). However, the seed provenance did not significantly affect GC of *A. leiocarpa*, *C. micranthum*, *C. nigricans* and *P. suberosa* (Table 2, Fig. 2a). On the other hand, the seed provenance did not affect significantly MGT of species (Table 2, Fig. 2b).

Latitudinal gradient effect on seed germination parameters

Under the four latitudes (Belehede, Ouahigouya, Diouroum and Pâ), GC varied significantly within species (Fig. 3a, $F_{3, 80}$ = 4.135, P = 0.009). The latitudinal gradient influenced the seeds GC. Under the same latitude GC was significantly different among the species ($F_{4, 80}$ = 998.994, P < 0.001). *P. suberosa* did not germinate. GC of *C. aculeatum* was not affected by latitudinal gradient (Fig. 3a). However, GC of *A. leiocarpa*, *C. micranthum* and *C. nigricans* varied significantly depending on latitudinal gradient (Fig. 3a, $F_{12, 80}$ = 2.763, P = 0.003). GC of *A. leiocarpa* was twice greater at Pâ (4 %) than at the other latitudes (2 %), while *C. micranthum* had the lowest GC at Pâ (10 %). GC of *C. nigricans* was the lowest at Pâ and Belehede (32 % and 33 %, respectively). The latitudinal gradient had a significant effect on MGT of species ($F_{3, 80}$ = 28.985, P < 0.001). Under the same latitude MGT varied significantly among species ($F_{4, 80}$ = 28.985, P < 0.001). Except *P. suberosa,* MGT of species varied significantly depending on the latitudinal gradient (Fig. 3b, $F_{12, 80}$ = 28.985, P < 0.001). The greatest MGT of species was observed at the site of Belehede.

Performance of out-planted seedlings

Under the same latitude at Diouroum, SR was significantly different among species (Table 3, $F_{3, 196}$ = 18.097, P < 0.001). SR of *C. aculeatum* was the highest (98 ± 2), while *C. micranthum* had the lowest one (36 ± 7). SR of *A. leiocarpa* and *C. nigricans* was medium. RGR was significantly different among species (Table 3, $F_{3, 117}$ = 18.280, P < 0.001). RGR of *A. leiocarpa* was the highest (255 %).

Under the four latitudes, SR of *A. leiocarpa* and *C. aculeatum* was significantly different (Fig. 4a, $F_{3, 267}$ = 9.538, P < 0.001). The latitudinal gradient influenced their SR. The highest SR was met at Ouahigouya (96 % for *A. leiocarpa* and 100 % *C. aculeatum*). Under the same latitude (except at Ouahigouya) SR was significantly

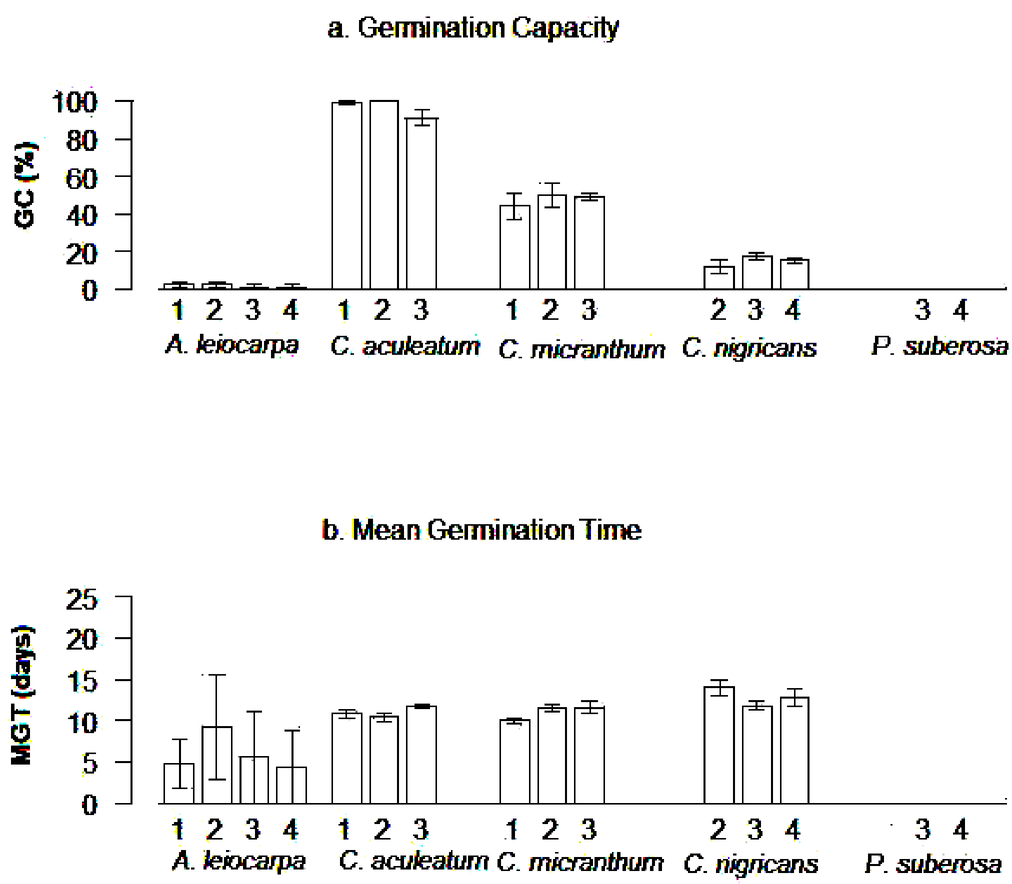

Fig. 2. Effect of seed provenance on the Germination Capacity (Mean ± S.E) and the Mean Germination Time (Mean ± S.E) of five Combretaceae species in Burkina Faso. The sites Belehede, Ouahigouya, Diouroum and Pâ are labeled as 1, 2, 3 and 4, respectively.

Table 2. Effect of seed provenance on five Combretaceae species germination performance in West Burkina Faso. The data were analyzed using one way ANOVA with seed provenance as a fixed factor.

Species	G.C			MTG	
	d.f.	F	P	F	P
A. leiocarpa	3,16	0.259	0.854	0.193	0.900
C. aculeatum	2,12	7.332	0.008	2.44	0.129
C. micranthum	2,12	0.318	0.733	3.556	0.061
C. nigricans	2,12	0.852	0.451	1.75	0.215
P. suberosa	1,8	0	1	-	-

different between the two species ($F_{1,\,267}$ = 18.809, P < 0.001). SR of *A. leiocarpa* varied from 96 % to 32 % and *C. aculeatum* from 100 % to 84 %. On the other hand, under different latitudes RGR was significantly different among species (Fig. 4b, $F_{3,\,203}$ = 17.988, P < 0.001). The latitudinal gradient influenced also their RGR. RGR of *A. leiocarpa* varied from 255 % to 36 % and the *C. aculeatum* one from 173 % to -16 %. The lowest RGR of the two species was met at Pâ.

Under the control and the uncontrol plots, SR of *C. aculeatum* and *A. leiocarpa* were not influe-nced significantly ($F_{1,\,217}$ = 0.384, P = 0.536). The drought of the dry season and the weed compe-tition did not affect their SR (Fig. 5a, Table 4). However, the control effect was significant on their RGR (Table 4). The control effect varied depending on species and latitudinal gradient (Fig. 5b, Table 4). The one year old prote-cted seedlings of *C. aculeatum* produced seeds at Belehede. Watering, weeding and protection imp-roved seedling growth and this effect was greater at Belehede than at Pâ.

Discussion

Large differences in germination capacity and the speed of germination were found between species. This wide range of variation could be partly explained by inter specific differences

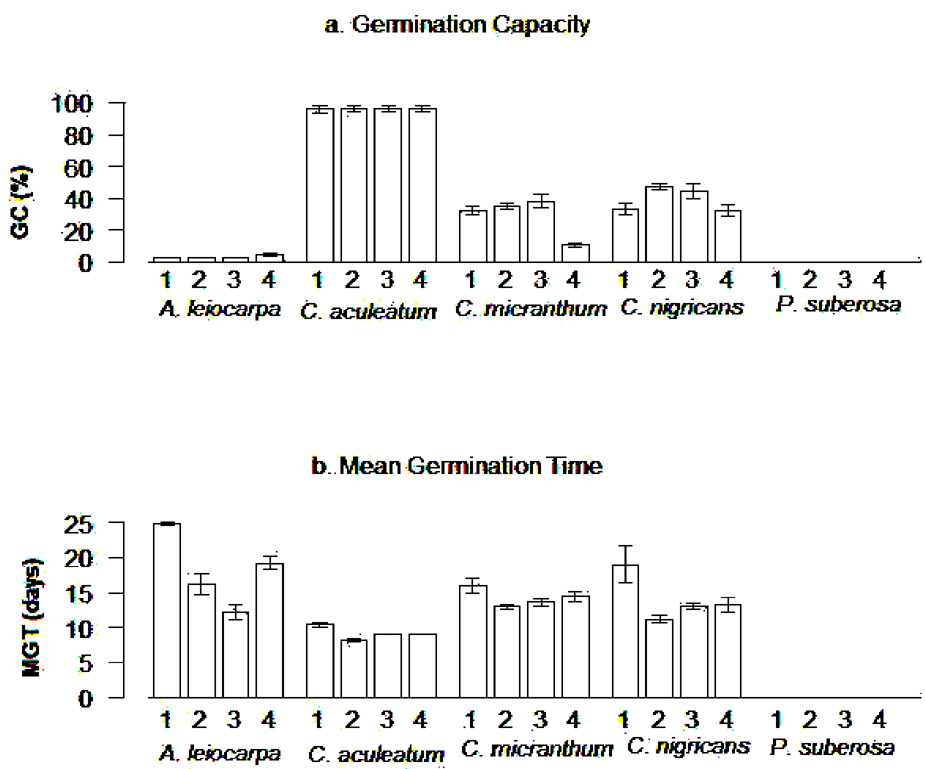

Fig. 3. Effect of latitudinal gradient on the Germination Capacity (Mean ± S.E) and the Mean Germination Time (Mean ± S.E) of four Combretaceae species in Burkina Faso. The sites Belehede, Ouahigouya, Diouroum and Pâ are labeled as 1, 2, 3 and 4, respectively.

Table 3. Survival and growth of four Combretaceae species out-planted seedlings.

Species	Survival rate (%)		Relative growth rate (%)	
	Mean	SE	Mean	SE
A. leiocarpa	56	7_{a}	255	41_{a}
C. aculeatum	98	2_{b}	50	7_{b}
C. micranthum	36	7_{c}	93	16_{b}
C. nigricans	52	7_{a}	77	19_{b}

Species with standard error (SE) followed by the same letter for each parameter is not significantly different at 5 % level using Tukey's HSD test.

between populations due to both environmental and genetic causes (Baskin & Baskin 1998). The no germination of the seeds of *P. suberosa* could be explained by the infertility of the majority of the seeds (Dayamba 2008) and the physical dormancy of the fertile seeds (Baskin & Baskin 1998). Further studies showed that 96 % of the seeds are infertile and the germination capacity of the fertile seeds was 94 % (Bognounou, unpublished data). That could be why the natural regeneration of *P. suberosa* is ensured mainly by asexual regeneration (Bationo 1996; Ky-Dembele *et al*. 2007). GC of *A. leiocarpa* seeds is usually low (Dayamba 2008; Thiombiano *et al*. 2003; Thiombiano 2005). This has been shown to be primarily due to a large proportion of infertile ovules (Kambou & Guinko 1995; Kambou 1997) and the gap is compensated by the production of a huge number of seeds. But the germination capacity can be increased up to 90 % by eliminating the infertile seeds (Sakandé & Sanogo 2007). GC of the seeds of *C. micranthum* and *C. nigricans* were low compared to the finding of previous studies (Dayamba 2008; Thiombiano *et al*. 2003; Thiombiano 2005). In Mali, some authors found 100 % of GC (Sakandé & Sanon 2007a,

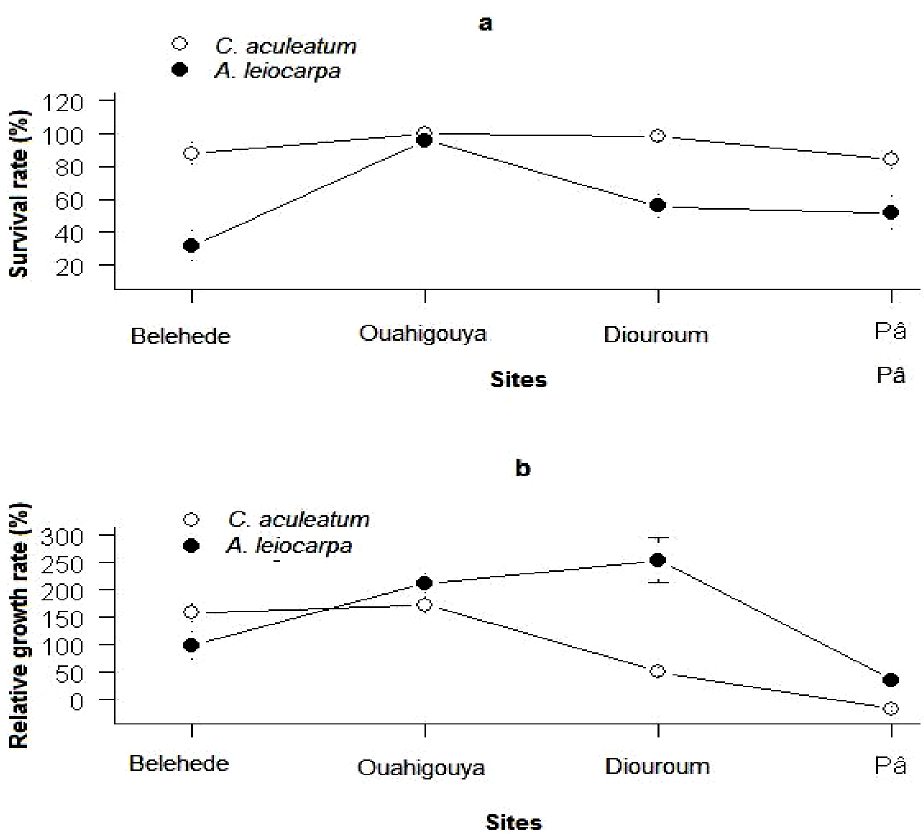

Fig. 4. Effect of latitudinal gradient on out-planted seedlings survival (Mean ± S.E) and relative growth (Mean ± S.E) of two Combretaceae species in Burkina Faso.

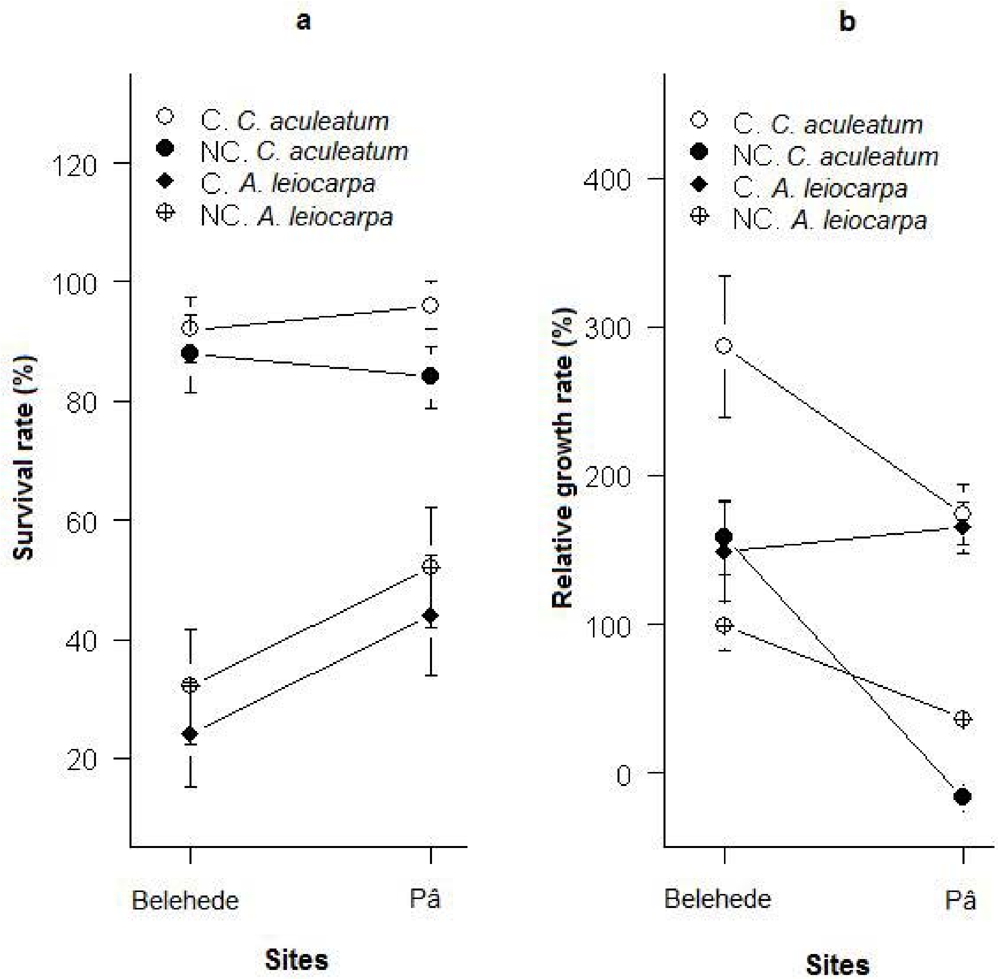

Fig. 5. Effect of watering, weeding and protection on transplanted seedling survival (Mean ± SE) and the relative growth (Mean ± S.E) of two Combretaceae species at two sites in Burkina Faso.

b). The low GC we found could be explained by the early infection of the seeds by insects (Thiombiano 2005). This limitation could be overcome by near infrared reflectance spectroscopy for sorting the sound, empty and insect-damaged seeds (Tigabu & Oden 2002, 2003). On the other hand, if the seed is buried, mortality between germination and emergence is probably quite high (Fenner & Thompson 2005), because buried seedling has to grow in the dark up to the soil surface using its own reserves, and it requires energy not only for extension growth but also for the penetration of the soil itself. GC of *C. aculeatum* is usually excellent (Thiombiano *et al.* 2003; Thiombiano 2005).

Seed provenances have displayed significant difference in GC of *C. aculeatum* only. Some authors (Loha *et al.* 2006) showed a relatively low correlation between seed provenances and their germination parameters. In most plant species, seeds vary in their degree of germinability between and within populations and between and within individuals (Baskin & Baskin 1998; Bischoff *et al.* 2006). Some of this variation can be of genetic origin, but much of it is known to be phenotypic caused by the local conditions under which the seed matured. Although seed provenance did not affect the germination capacity of the species (except *C. aculeatum*), handling seed

Table 4. Effect of latitudinal gradient and control on the survival and the growth of out-planted seedlings of *C. aculeatum* and *A. leiocarpa*. The data were analyzed using three-way ANOVA with latitude, species and control as fixed factors.

Factors	Survival rate (%)			Relative growth rate (%)		
	d.f.	F	P	d.f.	F	P
latitude	1	3.365	0.068	1	0.081	0.776
species	1	38.477	< 0.001	1	17.084	< 0.001
control	1	0.851	0.357	1	2.913	0.090
latitude: species	1	1.263	0.262	1	12.751	< 0.001
latitude: control	1	0.216	0.643	1	5.189	0.024
species: control	1	2.905	0.090	1	4.335	0.0391
Error	218			142		

during collection and processing might cause erratic germination responses (Loha *et al.* 2006). So, the effect of other factors cannot be ruled out. On the other hand, MGT did not vary with the seed provenance. It means that the species has more or less the same germination energy on all the provenances. In reality, allocation of resources to reproduction does not vary greatly within species (Fenner & Thompson 2005).

The latitudinal gradient has displayed significant differences in germination parameters except for *P. suberosa*. The environment effects on seed germination parameters are high. Many studies showed that seeds germination parameters can be markedly influenced by environmental factors such as day length, temperature, light quality, water availability, altitude, latitude, soil nutrient and fire related cues such as heat and smoke (Baskin & Baskin 1998; Bewley & Black 1994; Dayamba 2008; Fenner & Thompson 2005; Khurana & Singh 2000; Loha *et al.* 2006). The spatial heterogeneity, climatic factors and interaction effect could explain the variation of the germination parameters within species. However, seedling for plantation can be produced on all the phytogeographical sectors of the country and that makes the degree of disturbance to the root system during lifting, transportation and planting much low. But, the sorting of sound, insect-damaged and infertile seeds have to be done before seedling production in nursery. However, *P. suberosa* deserves special attention concerning it sexual regeneration mechanism problem. The important feature of sexual regeneration is genetic variability that increases the likelihood of at least some individuals surviving the hazards of natural selection (Fenner & Thompson 2005).

The out-planted seedlings of *C. aculeatum* and *A. leiocarpa* showed the highest survival and growth rate, followed by *C. nigricans* and last by *C. micranthum*. Although these are optimistic results, a multitude of factors influence the establishment of seedling (Baskin & Baskin 1998; Bewley & Black 1994), hence the variation of establishment between and within species (Moulaert *et al.* 2002; Thiombiano *et al.* 2003; Zida *et al.* 2008). Seedling death could occur as a direct result of drought or non-drought stressors, such as herbivores, pathogens and competition exacerbated by drought.

Latitudinal gradient effects were comparably higher on the seedling growth of *C. aculeatum* and *A. leiocarpa* than on their survival. The lowest growth was found at the lowest latitude. This could be explained by the effect of plant cover and the soil characteristics. The plant cover increases with the decrease of the latitude. However, interaction between precipitation, soil depth, and dominant species cover determines the facilitative or competitive role of plant cover (Aide & Cavelier 1994). Seedling growth is reduced under plant cover compare to open area during the rainy season or with supplemental water (Vieira & Scariot 2006) due to low light transmittance affecting the plant growth (Osborne 2000). The survival and the growth of out-planted seedlings of *C. aculeatum* and *A. leiocarpa* are favoured on open area. So, the recommended management would be to use these species on bare soil.

Since water is the major growth-limiting factor in dry areas, survival and growth of out-planted seedlings are expected to be higher in watered than non-watered plots. However, watering, weeding and protection did not affect the survival of the out-planted seedlings of *C. aculeatum* and *A. leiocarpa*. This could be related to the intact root system of container-grown seedlings, which resulted in lower resistance to water flow through the soil-plant-atmosphere continuum (Grossnickle 2005). The degree of disturbance to the root system during lifting, transportation and planting is much lower for container-grown than bare rooted seedlings (Zida *et al.* 2008). Previous studies found also that water supplement does not affect the survival of transplanted seedlings of some tropical woody species (Engelbrecht & Kursar 2003; Zida *et al*. 2007). The plasticity of the species could also be an explanation. On the other hand, watering, weeding and protection favoured the growth of the two species. The decrease of the relative growth of *C. aculeatum* and *A. leiocarpa* on the unprotected plots could be associated with drought, weed competition, shoot dieback, the grazing and sometimes insect attacks (Bosu *et al*. 2006; Moulaert *et al*. 2002; Zida 2007). The recommended management would be weeding around trans-planted seedlings and established seedlings that is not expensive management tool when compared to total cost of common practices used to restore woodlands in tropical zone.

Conclusions

The following conclusions can be drawn from this study:

(1) There is no conclusive evidence that seed provenance influences seed germination capacity. The data, however, provided evidence that production in nursery of *A. leiocarpa, C. aculeatum, C. micranthum* and *C. nigricans* seedlings is possible along the latitudinal gradient with the supplementation of sorting the seed before sowing.

(2) Attention has to be paid to *P. suberosa* which did not germinate at all. Future research should focus on developing and testing methods of vegetative propagation and embryo salvage.

(3) The seedlings of *A. leiocarpa, C. aculeatum*, *C. micranthum* and *C. nigricans* are efficient for plantation. This capacity of seedling establishment confers a high potential for the vegetation recovery of the country. *C. aculeatum* and *A. leiocarpa* could be used on bare soil.

(4) Watering, weeding around the out-planted seedling and the protection against big herbivores enhances seedling growth. The separated effects of these factors could be helpful for the out-planted seedling management.

(5) This study is based on the ecology of natural seed germination and artificial seedling production. The guidelines proposed have not been fully tested as tool of management. Each site in each region may have its own set of suitable management strategies.

Acknowledgments

We acknowledge the financial support from the Swedish International Development Cooperation Agency (SIDA). Thanks are also dues to Sangaré Hassane, Koundaba Alou, Nouma Nalo Albert, Zerbo Moussa and Lamien Donfoui Ignace for help during the entire study period. We thank Issa Ouédraogo for drawing the map. Anonymous reviewers are greatly appreciated for providing valuable and constructive comments on the manuscript.

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