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Effects of organic amendment on early growth performance of *Jatropha curcas* L. on a severely degraded site in the Sub-Sahel of Burkina Faso

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Abstract The aim of this study was to evaluate the effect of organic amendment on the germination and growth patterns of *Jatropha curcas* L. on completely barren and degraded land in the Sahelian area of Burkina Faso. Prior to the field trials, laboratory germination tests were undertaken to explore the impact of different pre-treatments on germination of *Jatropha* seeds. Seeds soaked in water for 24 h had the highest mean rate of germination (86%) while seeds that were pre-treated with sulphuric acid did not germinate. The results of the field experiment showed that plant growth and biomass development were significantly enhanced by organic amendment compared to the control. With direct seeding, 20% of the plants treated with organic manure survived after 2 years, while all seedlings of the control plot perished. In the plantations, 30% of the untreated seedlings remained alive whereas only 5% of the plants survived with amendment. The trials in unfenced plots were decimated by livestock grazing and trampling 2 months after the beginning of the experiment. This emphasizes the need to protect *Jatropha* plants at an early stage of their development from roaming animals. Organic amendment attracted humivorous termites, which were destructive to the seedlings. The use of pesticides may be necessary to control this problem. When directly seeded, plants of the control plots demonstrated poor growth and became rapidly diseased, further accelerating their decline. The low survival rates (5–30%) and meagre seedling performance, even for the amended plots, may be an indication that *Jatropha* is unsuited to severely degraded lands like the *zippelé*, and cannot be expected to give good yields and the claimed environmental and socio-economic benefits. However, we recommend that the performance of *Jatropha* on the *zippelé* should be further tested with other soil and water conservation techniques (half-moon, tillage, etc.) that have been shown to enhance crop production and yield on degraded lands in the Sahelo-Sudanian zone of West Africa. The impact of seed provenance on the outcome of this study is unknown. Therefore, further experiments should embrace seeds from different sources, including genotypes that are more adapted to dry conditions and might therefore show improved performance.

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Introduction

Land degradation is a global environmental problem that threatens the survival of more than 250 million people living in the drylands of the developing world. A total of more than 1 billion people, mostly in Sub-Saharan countries, are at risk (FAO 2011). Large areas of the Sahelo-Sudanian zone of Burkina Faso are seriously degraded as a result of various factors including drought, climate change, human impacts (unsuitable soil management, deforestation, overgrazing, use of marginal lands for agricultural purposes, etc.) and an exponential population growth that accentuates the pressure on the fragile and reduced land resources (Omotayo and Chukwuka 2009; Paré et al. 2010).

In 1990, about 25% of the land area of Burkina Faso was considered to be severely degraded (Shapiro and Sanders 2002) and at least 50% of the total land area of the country was classified as highly to very highly vulnerable to degradation (Rasmussen et al. 2001). This degradation is mainly human induced and mostly affects the Sahelian zone of the country (Müller and König 2005) where more than 90% of the population depends exclusively on land resources for their livelihood (INSD 2008; Leenders 2006; Sop et al. 2010).

The most common manifestation of land degradation in the Sahelo-Sudanian zone of Burkina Faso are the famous *zippelés*, as they are called in the local Mooré language. These are white-surfaced lands with encrusted soils, partially or totally barren and unproductive, and which can cover patches of several acres. The soil of such expanses is known to have a weak infiltration capacity, nutrient imbalance, reduced biodiversity and a very low to zero primary production (Sawadogo et al. 2008). When the soil has became encrusted and sterile for agricultural production, it is generally abandoned by land-users in favour of new agricultural territories in remaining savannahs. But an increasing population on ever-diminishing land resources has amplified awareness of the urgent need to curtail further degradation and restore the productivity of already degraded lands (Mando et al. 1999). Since these degraded systems are highly unlikely to recover by natural successional processes alone, their restoration has become an urgent necessity in the Sahelo-Sudanian area as well as other parts of Burkina Faso. Despite the well known effects of fallows on the restoration of soil fertility, rapid population growth leading to shortage of suitable cropland represents an obstacle to the widespread use of this practice (Ayoola and Adeniyan 2006; Schlecht et al. 2006). In order to address the situation, land-users of the Sahel have been developing, since many decades, a number of soil and water conservation techniques such as half-moons, zaï systems, stone strips and mulching, to reclaim marginal and degraded barren lands for agricultural production (Fatondji et al. 2009; Roose et al. 1993; Sidibe 2005; Zougmore et al. 2003). Political authorities, NGOs and development agencies have also shown great concern about land degradation and have, in past years, encouraged rehabilitation through bioreclamation programs based on the use of reputedly drought-resistant *Acacia* species.

In the past few years, increasing prices and declining reserves of fossil fuels, together with the recognition that climate change is being driven by rising CO_2 emissions, have focused global attention on the need to reduce fossil-fuel dependence and promote renewable energy sources such as biofuels. This has attracted the attention of decision-makers, project managers and farmers to *Jatropha curcas* L., a multifaceted species which is believed to provide potential environmental and economic benefits. Indeed, it has been claimed that *Jatropha* can be used for biofuel production, enhancement of rural development, and reclamation of marginal and degraded lands in (semi-)arid regions, without competing with food production or depleting natural carbon stocks and ecosystem services (Divakara et al. 2009; Fairless 2007; Francis et al. 2005; Maes et al. 2009). Marginal lands are defined here as being of poor quality for agricultural use, and not generally utilized for crop cultivation (King et al. 2009).

The contributions of *Jatropha* to environmental protection are widely acknowledged. It can act as a nutrient pump for the rehabilitation of degraded lands. The taproots of *Jatropha* extract minerals that have leached down through the soil profile and return them to the surface through leaf fall (Brittaine and Lutaladio 2010). In a case study in India, Ogunwole et al. (2008) observed that the cultivation of *Jatropha* increased macro-aggregate turnover in degraded soils, enhanced the recovery of the soil structure and showed considerable potential to increase carbon sequestration rates. Soulama (2008) reported that soils under *Jatropha* hedgerows in Tikaré (Burkina Faso) showed high amounts of organic carbon compared to neighbouring soils, confirming the importance of *Jatropha* for carbon sequestration.

In Burkina Faso, the promising characteristics of *Jatropha* (i.e. production of green fuel, reclamation of marginal and wastelands, conservation or restoration of soil fertility and enhancement of socio-economic development in rural areas) have created a business boom around this small shrub among farmers, start-ups and community groups. Unfortunately unsustainable practices such as the use of core agricultural land or the removal of savannah vegetation for *Jatropha* cultivation (Sop, personal observation), create worrying concerns over this "*Jatropha* fever" in the country. Despite this heightened interest in *Jatropha*, research on its cultivation and propagation in the Sudano-Sahelian area in Burkina Faso is scarce. The aim of this paper is two-fold: (i) to report on the impact of some pre-treatments on *Jatropha* germination; and (ii) to describe the effects of organic amendment on the growth parameters and survival rate of *Jatropha* on a degraded site in the Sub-Sahelian zone of Burkina Faso.

Materials and methods

Materials

Shrub species studied

Jatropha curcas L. (hereafter *Jatropha*), or purging nut, is a tropical multipurpose perennial shrub or small tree that normally reaches a height of 3–5 m but can also attain 10 m in favourable soil conditions. It belongs to the family Euphorbiaceae and is endemic to South America (Achten et al. 2010b; Brittaine and Lutaladio 2010; Ye et al. 2009). *Jatropha* can live for up to 50 years, fruiting annually for more than 30 years, and is believed to easily withstand drought conditions (Francis et al. 2005). It is also believed to be well adapted to arid and semi-arid climates thanks to its physiological mechanism for drought resistance (Zhang et al. 2008). *Jatropha* is also alleged to be pest resistant, inedible to domestic herbivores and possessing of medicinal properties. All parts of the plant are used for various purposes.

Jatropha seeds contain 30–35% essential oil that is easily extracted through simple and cheap technology. This oil can be used for biodiesel production or directly in adapted diesel engines as well as in stoves and lamps. It can also be used in large static running engines like pumps, mills and generators, especially in rural and remote areas. The oil from *Jatropha* can also serve for the production of biocides (e.g. insecticides, molluscicides, fungicides and nematicides), fertilizers and biogas (Achten et al. 2008). The cultivation of *Jatropha* in rural areas could therefore contribute to the improvement of the livelihoods of marginal communities by creating income-generating activities.

Jatropha is believed to be able to grow on a large range of soils, probably preferring sandy and gravelly well-drained and aerated soils. The plant is said to be well adapted to marginal soils with low nutrient levels and to be able to survive in very poor, dry soil conditions considered unsuitable for agriculture (Achten et al. 2008).

Experimental site description

The trials were conducted on an experimental site in Baporé (N 13°33′34.4″, W 02°20′40.1″), situated 8 km south-east of Ouahigouya in the Northern Province of Yatenga. Phytogeographically, the experimental site is part of the Sub-Sahelian sector (Fontes and Guinko 1995). The climate is of Sahelian type with two contrasting seasons: a long dry season from October to May and a short rainy season from June to September. Mean annual precipitation from 1979 to 2008 was 622 mm, while mean temperatures for the same period reached 29°C. Daily temperatures are subject to high fluctuations ranging from 25°C in December–January to more than 40°C in April–May (Fig. 1).

The soil on the site is classified as Leptic-Luvisol (WRB 2006). It is shallow, compact, crusted and whitish at the surface due to water and wind erosion, and ferruginous with plenty of gravel at the surface. The ferruginous crust is at a depth of 40 cm. The soils are known as *zippelés* in the Mooré language and are characterized by a very poor permeability that

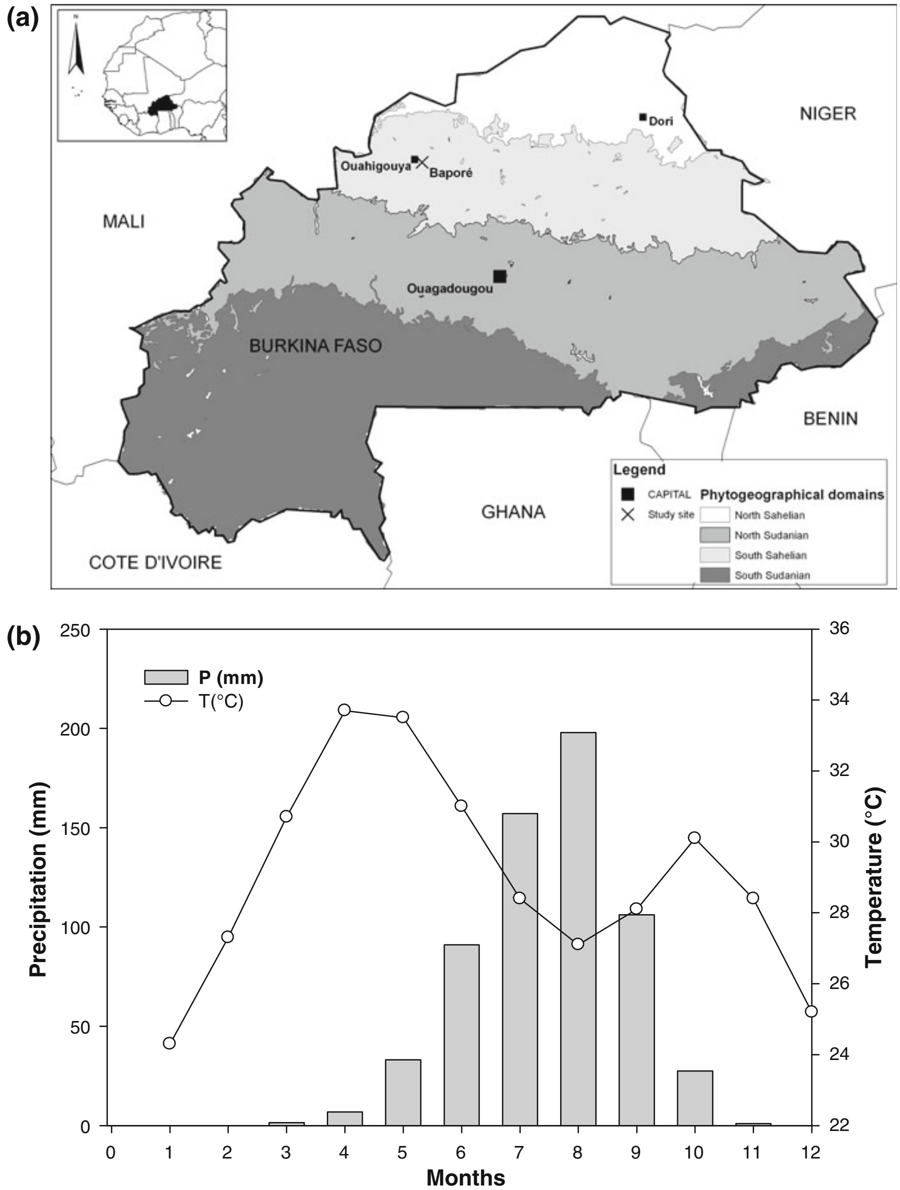

Fig. 1 (**a**) Phytogeographic domains and situation of the experimental site on a degraded land at Baporé in Northern Burkina Faso; (**b**) Mean rainfall (mm) and mean temperatures record (°C) for the weather station of Ouahigouya, near the study site, between 1979 and 2008

prevents water infiltration and increases run-off (Roose et al. 1993; Sawadogo et al. 2008). The study site was used in the past for agricultural production and has been, in recent years, exploited instead as extensive pastures for roaming livestock and cattle.

Soil sampling was carried out prior to the commencement of the trials. We dug three soil profiles on the experimental site, following a diagonal transect. The soil profiles were shallow and comprised two layers (A: 0–15 cm, B: 15–35–40 cm). The analysis of the soil samples from the experimental site was conducted by the National Soil Bureau (BUNASOL) in Ouagadougou. The results of the analysis showed that the soils were acidic (pH = 4.5) and poor in nitrogen and phosphorus. The Cation Exchange Capacity (CEC) was also very low. The soil characteristics of the study site are given in Table 1.

The vegetation at the site of Baporé was very poor. It was characterized by a patchy herbaceous carpet, dominated by therophytes mainly from the family Poaceae. Woody plants were absent and the surrounding vegetation mostly consisted of an open

Table 1 Physical and chemical characteristics of soil profiles of the experimental site on a degraded land at Baporé in Northern Burkina Faso (mean ± SD)

Parameters	Soil profile	
	A-horizon	B-horizon
Clay (%)	26.44 ± 6.58	32.88 ± 3.57
Fine silt [2–20 µm] (%)	17.13 ± 1.61	15.81 ± 0.63
Coarse silt [20–50 µm] (%)	18.95 ± 3.41	12.84 ± 1.26
Fine sand [50–200 µm] (%)	26.25 ± 5.24	27.11 ± 2.06
Coarse sand [200 µm to 2 mm] (%)	11.24 ± 3.50	11.37 ± 2.38
Useful available water (%)	12.00 ± 1.08	13.69 ± 2.06
Soil pH (H_2O)	5.10 ± 0.15	5.04 ± 0.13
Soil pH (KCl)	4.15 ± 0.25	4.49 ± 0.20
Organic matter (g kg^{-1})	10.72 ± 0.10	12.02 ± 2.12
Carbon (g kg^{-1})	7.27 ± 1.37	8.12 ± 1.74
Nitrogen (g kg^{-1})	0.60 ± 0.07	0.64 ± 0.05
Phosphorus (cmol kg^{-1})	2.25 ± 0.73	1.92 ± 0.45
Potassium (cmol kg^{-1})	28.00 ± 2.28	21.05 ± 3.03
Sum of exchangeable bases (cmol kg^{-1})	2.88 ± 0.61	3.27 ± 0.39
Cationic exchange capacity (cmol kg^{-1})	4.56 ± 0.93	5.15 ± 0.71

shrubby savannah with *Acacia senegal*, *Cassia sieberiana*, *Combretum micranthum*, *Combretum glutinosum* and *Guiera senegalensis*, as dominant woody species.

Methods

Germination test in the laboratory

The experiment was carried out at the Laboratory of Phytopathology (Laboratoire de Phytopathologie) of the University of Ouagadougou. The *Jatropha* seeds used in this study were provided by the National Tree Seed Centre of Ouagadougou (Centre National de Semences Forestières) and were approximately 6 months old. The seeds originated from the locality of Guéguéré (11°8′N, 3°11′W) in the Province of Loba situated in the south-west region of Burkina Faso. Phytogeographically, the region belongs to the South-Sudanian sector with a rainy period of 6 months or more, generally from April to October (ClimateDiagrams 2009). The mean rainfall at the nearest meteorological station of Gaoua was 1,055 mm, with a mean temperature of 27.5°C.

Prior to the germination experiments in the laboratory, all seeds were subjected to one of the following pre-treatments in order to identify that giving the best germination success:

- T_1: Control (no treatment);
- T_2: Soaking of seeds in tap water for 24 h;
- T_3: Immersion of seeds in sulphuric acid (H_2SO_4) for 30 min, followed by soaking in tap water for 24 h; and
- T_4: Soaking of seeds in tap water for 48 h.

Five replicates of 20 seeds each were placed in plastic germination boxes containing sterilized sand as the germination medium. The boxes were kept moist at all times and were maintained at room temperature (25–28°C). A seed was considered to have germinated after the radicle emerged from the seed coat. The number of germinated seeds was recorded daily for 30 days, with seedlings being progressively transplanted into plastic bags for the nursery. At the end of the experiment (after 30 days) the percentage of seeds that had germinated was recorded.

Direct seeding and planting in the experimental site

Experimental design: The experimental design employed for the direct seeding and planting was a randomized complete block design with four replicates. The plant spacing was 1.5 m, with 2 m between rows. The total area of the experimental site was 4,000 m^2 with the *Jatropha* plant density being 3,000 seedlings/ha. The experimental site was divided into two parts: one for the direct seeding and the other for the planting of the seedlings from the nursery. The experimental site was fenced to protect the plants from roaming animals. Additionally, we established the same experimental design outside the exclosure, with the only aim to monitor the effect of roaming animals on the *Jatropha* plants.

All field experiments started in July 2008, during the rainy season. No irrigation was practised and the only source of water for the plants was rainfall. Trials involved two treatments, T_0: control (no amendment) and T_1: amendment with animal manure.

Direct seeding: Three weeks prior to the sowing, pits of 20 cm × 20 cm × 20 cm were prepared at the site (in the 1.5 m × 2 m grid described above). This was done to break up the superficial crust of the *zippelé* and to turn over the compacted soil, creating conditions for plant growth. Pits of the amended treatment were filled with 500 g of animal manure mixed with soil, while that of the control treatment were filled only with soil.

The sowing was done on 14 July 2008. Seeds that were pre-soaked for 24 h in tap water were superficially sown in the prepared pits, at a depth of less than 1 cm. Two seeds were sown in each pit but after germination only one seedling was randomly selected for the measurement of the growth parameters.

The following parameters were recorded:

- number of seeds germinated, recorded every 2 days until no further germination was noticed, the final germination rate being calculated after 3 weeks;
- total number of leaves produced, recorded weekly for a period of 5 months (20 weeks);
- shoot length (cm), measured every week during 2 months and then monthly for 24 months;
- basal diameter (mm) of seedling, measured monthly with a caliper during 24 months;
- plant survival rate (in %), assessed monthly over 2 years; and
- signs of pest or disease attack on seedlings, monitored from 3 months after the beginning of the trials.

Plantations: Plants were grown from seed and raised in the nursery for 3 months (from May to July). Seeds that completed germination during the laboratory experiment were transferred in polyethylene bags (25 cm × 12 cm), containing sand, soil and compost in equal proportions.

The seedlings from the nursery were planted in pits of 30 cm × 30 cm × 40 cm. The spacing was identical to the pits for the seedlings, i.e. 1.5 m between pits and 2 m between rows. Pits of the soil amendment plot were filled with a mixture of 500 g of animal manure and soil, while the pits of the control plot were filled only with soil (no addition of animal manure). Observations on the plantations were carried out every month from July 2008 until August 2010, recording the following parameters:

- plant height (cm);
- basal diameter (mm); and
- survival rate (%).

The edibility of Jatropha

To test the widespread assumption that *Jatropha* is not edible for livestock, we established the same experimental design inside and outside the exclosure, i.e. with both direct sowing and planting of *Jatropha* seedlings. Information on any browsing and trampling by animals was recorded every 2 days during the first month after germination and every week during the second and third months.

Assessment of species diversity on the experimental site

Prior to the experiment we listed all the plant species occurring on the experimental site. Each year in the same month (August), we conducted a complete vegetation assessment on the control and the amended plots, separately. The aim of this exercise was to monitor any new species appearing on the experimental site during the trials.

Statistical analysis

Each of the above described experiments was analyzed separately.

The germination rates in the laboratory and field, as well as the survival percentages of the direct seeding and plantations were arcsine-transformed prior to the analysis of variance. However, the normal (untransformed) values were used for

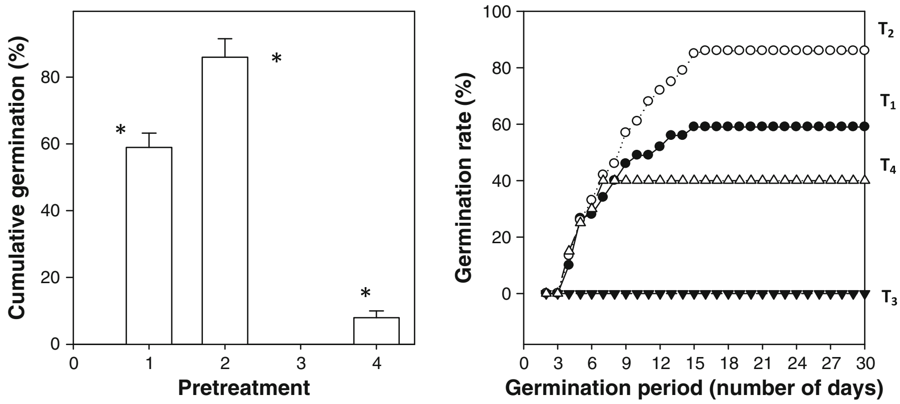

Fig. 2 Effect of the four pre-treatments on the germination of *Jatropha* seeds in the laboratory (duration 30 days) in Burkina Faso: *1* T_1 (control—no pre-treatment); *2* T_2 (soaking in tap water for 24 h); *3* T_3 (30 min immersion in H_2SO_4 + soaking for 24 h); *4* T_4 (soaking in tap water for 48 h). *Error bars* represent the standard deviation of the mean. $*P < 0.002$ (Kruskal–Wallis test, Mann–Whitney pair-wise comparisons)

graphing, carried out with Sigma plot (Systat Soft Inc. 2006).

Pre-treatment and treatment means (in the laboratory and at the site, respectively) were compared using the Kruskal–Wallis test (Quinn and Keough 2002) combined with post-hoc Mann–Whitney pair-wise comparisons. This analysis was performed with the freeware program PAST (Hammer et al. 2001). The influence of independent factors (treatment and time) on the growth parameters of the seedlings of both direct sowings and plantations was computed with a repeated measures ANOVA, using SPSS 16.

Results and discussion

Effects of pre-treatments on seed germination

Germination in laboratory

Pre-treatment had a significant effect on *Jatropha* seed germination ($P < 0.002$). Seeds soaked in water for 24 h (T_2) had the highest mean germination percentage (86%). This was significantly different from the control seeds (T_1). The latter had a mean germination rate of 59%, and indicates a good germination capacity of *Jatropha* seeds if moisture requirements are met. *Jatropha* seeds pre-treated with acid (T_3) did not germinate at all and seeds soaked in water for 48 h (T_4) had a very poor germination (5%) (Fig. 2).

The data showed that seeds soaked in tap water for 24 h germinated faster than seeds of the control and achieved their maximum germination within 12 days. Pre-soaking of seeds for 24 h clearly achieved the highest germination rate of *Jatropha* compared to other treatments. This is in line with other studies (Carels 2009; Heller 1996; Henning 2002). Achten et al. (2008) reported a germination rate of up to 96% after the seeds were pre-soaked in cow-dung slurry for 12 h, while H_2SO_4 did not enhance germination.

Germination in the field

The germination rate of seeds sown in the field was 80% in the control plot and 82.5% in the plot treated with organic amendment. This was in line with the results that we obtained in the laboratory and might be an indication that organic amendment has no impact on *Jatropha* seed germination.

The germination rates observed in this study, both in the laboratory (86%) and field, were nevertheless lower than that of the National Seeds Centre (92%), from where our *Jatropha* seeds were obtained. This difference is probably due to storage time, which has been shown to negatively impact *Jatropha* seed viability (Kumar et al. 2009; Ratree 2004).

Effect of organic treatment on growth patterns of direct sowings and plantations

The results presented and discussed here are all from the exclosure. The trials on the unfenced area were all destroyed by animals a few weeks after they were set up.

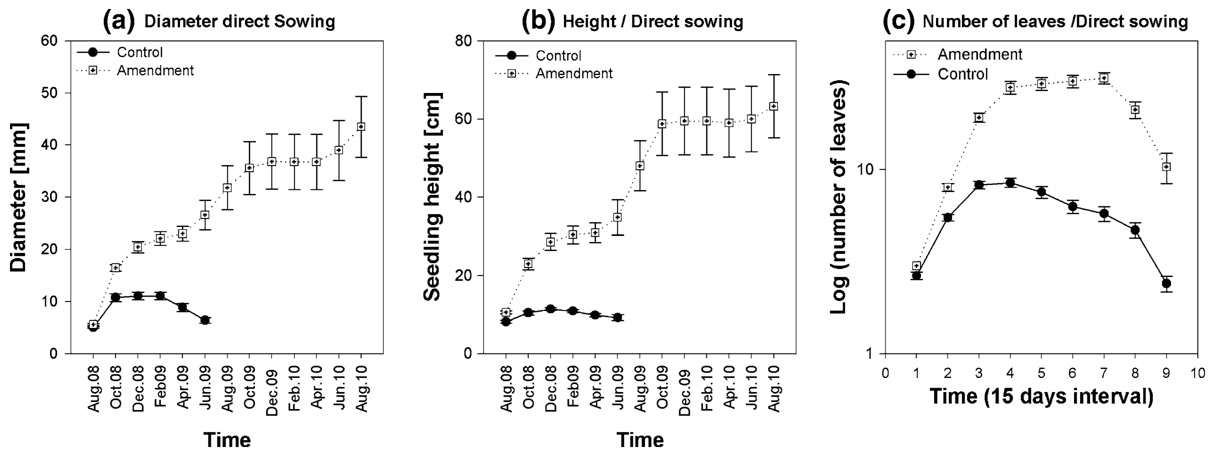

Fig. 3 Growth parameters of shoots from direct seeding of *Jatropha*, under control and amendment, on a degraded land at Baporé in Northern Burkina Faso. *Error bars* represent the standard deviation of the mean. (**a**) mean plant diameter (mm); (**b**) mean plant height (cm); and (**c**) mean number of leaves

Growth parameters

Figures 3 and 4 presents the growth trends of *Jatropha* under different treatments. Results of the ANOVA are presented in Table 2. All the measured parameters (plant height and diameter, and number of leaves produced) showed significant differences between the control and amended plots. Organic manure stimulated plant growth for both direct seeding and plantations. Several studies have reported similar improvement of *Jatropha* growth and development with organic amendment in various parts of the plant's distribution range (Kumar and Sharma 2008).

The number of leaves of *Jatropha* planted under organic amendment increased continuously from the beginning of the trials until the 13th week, and then reached a plateau before drastically decreasing (Fig. 3c). The seedlings began to shed their leaves slowly at first, but more rapidly as soon as the drought period commenced. This was also observed by Achten et al. (2010a). The leaf shedding is related to the deciduous character of *Jatropha* and is an intrinsic mechanism to reduce transpiration in order to withstand the drought period (Kumar and Sharma 2008). It has been observed that *Jatropha* has the ability to develop a particular type of leaf equipped with a special architecture that helps the plant to

Fig. 4 Growth parameters of plants of *Jatropha* from plantations, under control and amendment, during 24 months, on a degraded land at Baporé in Northern Burkina Faso. *Error bars* represent the standard deviation of the mean. (**a**) Plant diameter (mm); and (**b**) Plant height (cm)

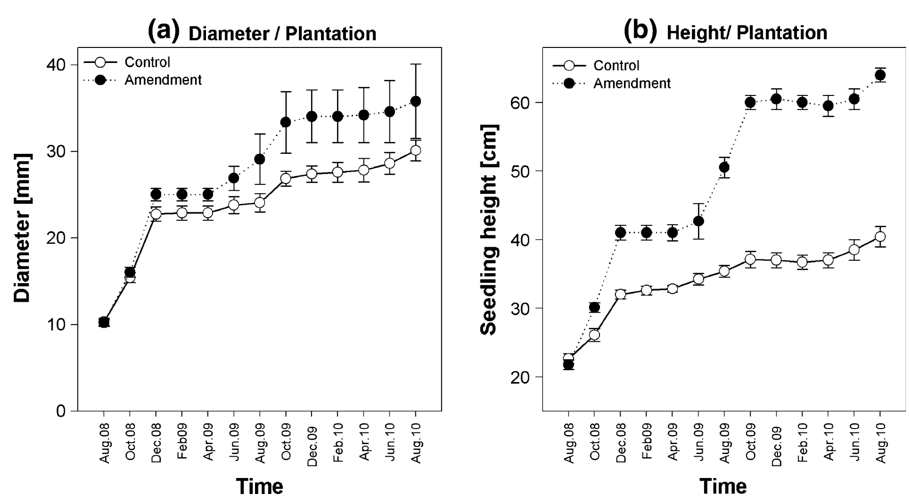

Table 2 Results of the multivariate analysis of the factor effects on the studied growth. Parameters of *Jatropha curcas* on a degraded land at Baporé in Northern Burkina Faso. The significance level is giving for each parameter

Category	Growth parameters	Effect	Source of variation		
			df	*F*	*P*
Direct sowing	Diameter	Treatment	1	181,622	0.000
		Time	4	254,205	0.000
		Treatment * time	4	36,592	0. 000
	Height	Treatment	1	223,595	0.000
		Time	4	17,509	0.000
		Treatment * time	4	8,914	0.000
	No. of leaves	Treatment	8	145,333	0.000
		Time	1	398,919	0.000
		Treatment * time	8	53,117	0.000
Plantation	Diameter	Treatment	1	8,543	0.004
		Time	3	269,429	0.000
		Treatment * time	3	2,398	**0.076**
	Height	Treatment	1	33,61	0.000
		Time	3	133,396	0.000
		Treatment * time	3	21,839	0.000

Bold value means not significant

withstand the dry season (Zhang et al. 2008). This might explain the little peak recorded at the 14th week (Fig. 3c), prior to the decline of the number of leaves. The leaves shed from a *Jatropha* plant form mulch around the base of the plant, which in turn enhances termite activity in the soil around the root-zone and improves the fertility of the soil (Kumar and Sharma 2008).

The growth performance and biomass development under organic amendment are consistent with the findings of Francis et al. (2005) who reported that *Jatropha* responds better to organic amendment than mineral fertilizer on degraded soils in India. Sawadogo et al. (2008) and Bayen (2010) observed, in a soil restoration experiment in Northern Burkina Faso, that organic amendment improves the growth parameters and yield per hectare of sorghum. Indeed, the degraded *zippelé* are generally characterized by an impoverished soil structure and reduced nutrient availability. The effect of soil organic matter on soil productivity through the supply of plant nutrients, the enhancement of Cation Exchange Capacity, the improvement of soil aggregation, and soil and water retention is well acknowledged (Ayuke 2010; Fatondji et al. 2009; Roose et al. 1993). Organic matter from animal manuring supports various soil biological processes by being a substrate for decomposing organisms and ecosystem engineers, such as earthworms and termites, which play an important role in soil structure formation, organic matter decomposition and nutrient mineralization in the immediate vicinity of the rooting zone of the crops (Ayuke 2010; Fatondji et al. 2009; Roose et al. 1993). Organic amendment provides nutrients such as C, N, P and K to degraded soils, and these are essential for seedling growth and biomass development. Freschet et al. (2008) found that the duration and magnitude of the effect of amendment was a function of the amount of manure initially applied. They observed that the residual effect of manure input rapidly decreases between the first and fifth year after corralling.

The directly seeded control plants had slow growth (Fig. 3b) and achieved their maximum development within a month, which corresponds to the rainiest period in the study area. Afterwards, the seedlings showed no further growth and progressively declined. At the onset of the dry season, the leaves of the control plants turned yellow and started falling whereas those of amended plants remained green and were not shed (Fig. 3c). Several weeks after the rainy period, the seedlings under organic amendment kept on growing in terms of height, diameter and number of leaves, albeit slowly and before tailing off (Fig. 3a–c). The seedlings of the plantations demonstrated the same trend. The mean diameter and mean height of the amended seedlings from the plantations differed significantly ($P < 0.004$ and $P < 0.001$, respectively) to that of the control (Table 2).

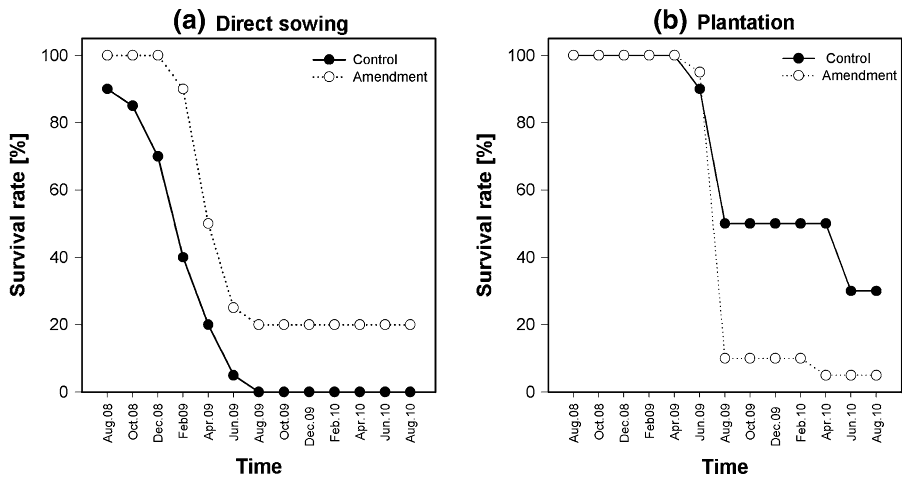

Fig. 5 Survival rate of *Jatropha curcas* individuals under control and organic amendment treatment 2 years after establishment on a degraded land at Baporé in Northern Burkina Faso: (**a**) direct seeding and (**b**) plantation

Although the growth rate was higher under organic amendment, the plants maintained a similar diameter trend in the control plots.

The interaction between time (age of seedlings) and treatment [time × treatment], as well as the time factor alone, had a significant impact on the height, diameter and number of leaves of seedlings from direct seeding (see Table 2). For the plantations, the time × treatment interaction significantly affected the seedling height ($P = 0.00$) but not basal diameter ($P = 0.076$). The factors time and treatment, taken individually, significantly influenced the plant height and diameter (Table 2).

Impact of organic amendment on the survival rate

Within the period of 24 months, organic amendment showed a contrasting and inconsistent pattern on seedling survival (Fig. 5). With direct seeding (Fig. 5a), 20% of the individuals survived in amended plots, while all individuals of the control plots were dead just 1 year after the sowing. Figure 5 shows that between March and May, which is the peak of the dry season in the Sahelian area, with particularly high temperatures (see Fig. 1b), more than 50% of individuals of both amended and control plots were decimated. This applied equally to the direct seeding and the plantations.

Contrary to the direct seeding (Fig. 5a), the control plantations (Fig. 5b) had a significantly higher ($P < 0.05$) survival rate (30%) than the amendment plantations (5%). This poor result might be an indication that *Jatropha* may not absolutely thrive on severely degraded lands such as the *zippelés*, as repeatedly claimed in the literature (Achten et al. 2008; Carels 2009; Fairless 2007; Kumar et al. 2009; etc.). The poor survival rate (5%) of the plants in the amended plantation is possibly due to termites, which attacked the seedlings starting with the roots, especially during the dry season (Sop, personal observations). The dominant termite types in the Sahel are the Macrotermitinae, which are the most important soil fauna in the semi-arid tropics due to their crucial role in nutrient cycling. However, these termites are also capable of causing a loss of over 70% organic amendment mass in the soil within 1 year, under the Sahelian conditions (Mando and Brussaard 1999). As for the direct seeding, the highest plant mortality (more than 50% of individuals in both the control and amended plots) occurred during the second half of the dry season (March–May). This questions the alleged ability of *Jatropha* to withstand long periods of drought, as repeatedly alleged by several authors (Achten et al. 2010a, b; Heller 1996; Jongschaap et al. 2007). One of the explanations for the limited growth and the poor survival rate may be the source of the seeds used for the experiments. The seeds were harvested in a region with more moderate climatic conditions (more than 6 months of rainy season, 1,055 mm mean rainfall) compared to the harsh environment of the Sahel with its unpredictable rainfall and extreme temperatures. A plausible hypothesis is that a seed genotype from a dry area may have led to a more positive result. This is supported by the fact that more than 50% of the seedlings died during the dry season; the genotype used may not have been adapted to drier areas like the Sahel.

The better survival rate recorded in the control plantations (Fig. 5b)—although with a poorer growth performance than in the amended plantations—suggests that it is the compacted soil structure of the zippelés, rather than their nutrient status, which might be the most significant impediment to plant growth and development on these soils. The pits of the plantation may plausibly have improved the soil structure and moisture levels and stimulated the growth of *Jatropha*. That directly seeded plants under control conditions remained dwarf and died less than a year after planting, supports this thesis. In a study on eroded and compacted soils in Ethiopia, Amede et al. (2011) argued that the main constraint on plant growth and efficient use of available nutrients was not nutrient deficiency, but rather low soil water holding capacity.

Impact of roaming animals on *Jatropha* plantations

Three months after the establishment of the trials no individual of *Jatropha* sown or planted outside the exclosure survived. Seedlings were trampled, or bitten off by roaming animals (cattle, sheep or goats). However, most of the time broken plant parts were discarded rather than eaten, suggesting that *Jatropha* is not palatable to livestock, as emphasized by previous research (Achten et al. 2008; Carels 2009; Jongschaap et al. 2007; Kumar and Sharma 2008). In the Sahelian environment, an open pastureland with freely wandering animals much of the year, this result highlights the need to protect the young shoots of *Jatropha* in the early stages of their development. Otherwise, *Jatropha* plantations are likely to be subject to massive destruction by roaming grazers.

Impact of organic amendment on species diversity

Two years after the establishment of the trials, we observed that organic amendment promoted the appearance of numerous herbaceous (12) and ligneous species (four) that were absent on the experimental site at the beginning of the trials (data not shown). This finding is consistent with previous such results in the Sahelian area of Burkina Faso documented by Bayen (2010), Conedera et al. (2010) and Sawadogo et al. (2008).

Conclusion and recommendations

The aim of this experiment was to study the effect of organic amendment on growth patterns of *Jatropha* cultivated on the barren and degraded lands (*zippelé*) that are frequently found in the landscape of the Sudano-Sahelian area of Burkina Faso.

Our results have shown that the growth parameters of *Jatropha* were significantly enhanced by the application of organic amendment on the *zippelé*. Amendment promoted the development of new herbaceous and ligneous species on the experimental site, but also attracted large termites that caused irreversible damage to the seedlings (roots and stem destruction). However, the poor growth and survival rate of *Jatropha curcas*—even in the amended plots—rather suggest that, on degraded soils like the *zippelé*, this plant might not be able to accumulate enough biomass in order to provide all the socio-economic and environmental benefits widely claimed in the literature (carbon sequestration, growth on poor soils, oil production, drought-resistance, etc.).

In this study we used cattle manure for organic amendment as it is easily available to the Sahelian populations. The performance of *Jatropha* on the *zippelé* should also be tested using other soil and water conservation techniques, such as half-moon and tillage, which have been shown to enhance crop production and yield on degraded lands in the Sahelo-Sudanian zone of West Africa (see Sidibe 2005; Zougmore et al. 2003). The effects of seed provenance on the outcome of the study are unknown and should also be investigated. Since the seeds used came from a different phytogeographical zone experiencing different climatic conditions from that of the experimental site, it is possible that seeds adapted to the dry conditions of the Sahel may have given better growth and survival rates. Further studies should therefore take into consideration the variation of seed source(s) and genotypes on studying the performance of *Jatropha curcas* in the Sahelian area of Burkina Faso.

Because of the damage caused by termites, the use of pesticides from the beginning of the plantings or sowings needs to be seriously considered, as being recommended by a number of authors (Achten et al. 2008; Heller 1996; Henning 2002). However, any economic and ecological implications should be taken into account in such decisions. Our results also demonstrated a high mortality of *Jatropha* seedlings during the first dry season after the plantings, suggesting that more research might be necessary to confirm the alleged resistance of *Jatropha* to drought in the Sahelian area of Burkina Faso. Finally, the catastrophic results obtained in the unprotected plots highlight the need for the *Jatropha* shoots to be protected from wandering animals in the first life stages of the plants.

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