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Does *Jatropha curcas* L. show resistance to drought in the Sahelian zone of West Africa? A case study from Burkina Faso

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Abstract

Land degradation is an environmental problem which weakens agro-silvo-pastoral productivity in Sub-Saharan Africa. The most common manifestation of land degradation is the appearance of denuded land. We carried out an experiment to test the effect of three soil and water conservation techniques on survival and growth of *Jatropha curcas* seedlings transplanted onto two completely denuded lands in the Sahelian and Sudanian zones of Burkina Faso. We implemented an experimental design with three replicates per restoration technique. A total of 174 seedlings were planted in each study site. The results showed that soil water content varied according to the restoration technique used (df = 2; $F = 53.21$; $p < 0.00$) as well as according to study site (df = 1; $F = 74.48$; $p < 0.00$). Soil water content was significantly lower in the Sahel than in the Sudanian zone. Seedling survival rate varied significantly according to technique used (df = 2; $F = 8.91$; $p = 0.000$) and study site (df = 1; $F = 9.74$; $p = 0.003$). Survival rate, diameter and seedling height were highest at the Sudanian site. At the Sahelian site, all seedlings died two years after establishment. These results suggest that *Jatropha curcas* is unsuited to denuded land in the Sahelian zone. Most of the plants died in the Sahel between April and May, which is the peak of the dry season; this may be an indication that Jatropha may not be as drought-resistant as suggested by the prolific literature which has reported on diverse claims surrounding this plant.

1 Introduction

Land degradation is a global environmental problem threatening the survival of more than 250 million people in the arid lands of developing countries (Sop et al., 2012). In dry lands, land degradation and its manifestation are still widespread – jeopardizing livelihoods and sustainable development (Fleskens et al., 2014). In Sub-Saharan Africa, in particular, soil degradation has a strong negative impact on agro-silvo-

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pastoral production (Sidibé, 2005). In the Sudano-Sahelian region of West Africa area, the combined effects of drought, poor soil quality and human impact have resulted in soil degradation due to crusting, sealing and erosion by water and wind (Mando et al., 1999). Land degradation can lead to the formation of bare soils that became encrusted and unproductive (Traoré et al., 2015) and biodiversity loss (Bisaro et al., 2014). In Burkina Faso, one of the most common manifestations of land degradation is the appearance of the "*zippelés*", which, in the local Mooré language, refers to barren, encrusted whitish soil surfaces which have become useless to local people for agro-silvo-pastoral activities (Sop et al., 2012).

The actions to combat desertification and land degradation can be broadly classified as prevention, mitigation and restoration interventions (Zucca et al., 2013). The restoration actions often involve the improvement of vegetation cover through, for example, the (re)introduction of adapted species, the control of invasive species and reforestation (Zucca et al., 2014). Planting trees in degraded lands can stabilize soils, mitigate erosion and increase fertility (Fisher, 1995; Barua et al., 2013) and also increase understory biodiversity (Parrotta, 1992; Parrotta et al., 1997; Zhao et al., 2013; Gilardelli et al., 2013). Published research has addressed several aspects of afforestation (Dubovyk et al., 2014). Lamers et al. (2006) and Khamzina et al. (2006) have evaluated the suitability of selected tree species for afforestation. Khamzina et al. (2008) examined the establishment, irrigation demands, and groundwater uses by tree plantations. Since ever Acacia species have been the most valued plants for reforestation of degraded areas in Sahelian countries due to their renowned capacity to resist to drought and extreme climatic conditions. But in the recent years, the rise of the prices of fossil energy in Burkina Faso and the evidence that CO_2 pollution is the main driver of climate change, have attracted the attention of decision-makers, project managers and farmers to *Jatropha curcas* L., which is believed to be able to provide social, environmental and economic benefits to the poor rural communities in West Africa.

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Jatropha curcas L. (*J. curcas*) is a multipurpose shrub or small tree belonging to the family of Euphorbiaceae with many attributes and multiple uses. The plant is of significant economic importance and is often used in the rehabilitation of degraded lands (Ghost et al., 2007). *J. curcas* (Physic nut) has received increasing interest since the beginning of the 21st century (Fei et al., 2005; Min et al., 2005; Su et al., 2006). The plant has gradually attracted increased interest for biodiesel, and increasing farmer income (Meng et al., 2009).

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). The planting of *J. curcas* is considered to be an effective option for rehabilitating wastelands and improving employment opportunities and livelihoods in rural areas (Achten et al., 2010b). The cultivation of the biofuel crop *Jatropha curcas* L. in Burkina Faso may contribute to ameliorating the soil fertility of severely declining cropland through increased organic matter input and erosion control (Baumert et al., 2014). Recent studies confirmed that *J. curcas* can indeed thrive in arid conditions due to its drought-avoidance strategy (Rao et al., 2012).

Several studies have investigated the performance of *J. curcas* in terms of biomass production, water conservation and drought tolerance under arid conditions (Maes et al., 2009; Achten et al., 2010a). Little research, however, has focused on the ability of *J. curcas* to grow in the marginal soils in of the Sahel (Kagambèga et al., 2011a; Sop et al., 2012). Hence, a gap in our knowledge exists regarding the capacity for adaptation and the growth response of *J. curcas* under Sahelian conditions. If it is possible to convert the barren and unproductive soils of the Sahelian and Sudanian zones of Burkina Faso into productive ones by growing *J. curcas*, it would strengthen local livelihoods and increase their income diversification, at the same time reducing carbon emissions by producing biofuels. Under the constraints of the Sahelian environment, however, it is necessary to put into place soil and water conservation techniques in order to ensure the productivity of such barren soils. These techniques include soil restoration methods such as half-moon, sub-soiling furrows in soil and the zaï (traditional technique used in the Sahel zone for the restoration of degraded and crusted soils) technique (Zougmoré et al., 2003; Ganaba, 2005), all of which have been shown to be efficient in increasing soil water content. We carried out the current study in order to evaluate the efficiency of several soil restoration techniques on the productivity of *J. curcas* on completely barren and denuded soil in two agro-ecological zones in Burkina Faso. More specifically, the research evaluates the survival and growth performance of *J. curcas* under three soil and water conditions (half-moon, zaï and standard plantation).The final goal of this research is to contribute to a better understanding of the ability of *J. curcas* to adapt to harsh climatic environments.

2 Material and methods

2.1 Study areas

The study sites are located at Namoungou (31P 894854 UTM 1331216) in the north Sudanian zone and at Dangadé (30P 807092 UTM 1550839) in the Sahel (Fig. 1). The climate in Namoungou is characterized by a short rainy season lasting from May to September and a long dry season from October to April. The mean annual rainfall over the last 30 years is 822 mm while mean temperatures for the same period reached 28 °C.

In Dangadé, the rainy season lasts from July to September and the dry season from October to June. Rainfall is characterized by an irregular distribution, with a mean precipitation of 467 mm year^{-1}, of which about 90 % falls between July and August. The mean annual rainfall over the last 30 years is 467 mm while mean temperatures for the same period reached 29 °C (Fig. 2).

2.2 Restoration techniques

Three restoration techniques were tested: half-moon, zaï and standard plantation (Fig. 3).

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The half-moon technique is designed to collect surface runoff by excavation of holes on bare and crusted soils with gentle slopes (Zougmoré et al., 2003). In this study, the half-moons were 2 m in diameter, spaced out by 1 m in rows approximately 3 m apart. In each half-moon the water collection area was 3.14 m^2. The area between the half-moons served as the impluvium (the non-cultivated area between half-moons which is used to collect runoff water). The holes, 10–15 cm depth, were dug with a hoe or a pick in order to break through the crusted layer on the soil surface and to collect the runoff water. Excavated earth served to form ridges around the edges of the half-moons.

The zaï is a traditional technique that has been used for centuries in the Sahel zone for the restoration of degraded and crusted soils. The zaï technique involves manually digging holes to collect surface runoff (Roose et al., 1999). In this study, the zaï holes were about 20 cm in diameter, 15 cm deep and separated by 3 m. The excavated soil served to form ridges around the holes. No organic material was used in this experiment.

The standard plantation technique consists of planting seedlings from the nursery in pits prepared with a hoe or a pick. In this study, the holes were 40 cm in diameter, 40 cm deep and 3 m apart. The excavated soil served to form a pile of ground around the holes.

2.3 Plantation

In August 2011, three month-old nursery-raised seedlings were planted in plots in the two study sites using a randomized design with three treatments each with three replicates: (i) HM: half-moon technique, (ii) SP: standard plantation and (iii) Zaï: Zaï technique.

A total of 174 seedlings were planted at each study site. In total, we placed nine plots in each study site. In each plot (14 m × 11 m in size), 20 seedlings each were planted using the zaï and standard plantation techniques and 18 seedlings were planted using the half-moon technique. Fertilizer was not applied during refilling of the pits and the plants were not watered.

2.4 Data collection

2.4.1 Assessment of soil water content

We measured soil moisture gravimetrically for each of the restoration techniques in October 2012 and 2013, during the dry season, at five different depths: 0–10, 10–20, 20–30, 30–40 and 40–50 cm. Three measures, one per replicated block and period were taken at each depth level corresponding to a total of 45 measures for each year. For each depth level, three soil samples were stored in sealed boxes. Samples were oven-dried at 105 °C to enable us to determine a constant measure of weight and water content.

2.4.2 Seedling performance

For each plot, plant height (i.e., the height of the apical meristem above the ground surface) and diameter (i.e., stem diameter at the ground surface) were measured monthly for four months (from December 2011 to April 2014). In September 2011, i.e. one month after the seedlings were planted, we assessed the transplantation losses (i.e., seedling mortality due to the transfer of seedlings from the nursery to the plot). Survival rates were recorded again in December 2011, April, August and December 2012 and 2013 and April 2014.

2.4.3 Statistical analysis

We computed the effects of the independent factors (treatments and sites) on the growth parameters (survival rate, height and diameter) of the seedlings with repeated measures ANOVA, using the JMP 9 program (SAS Institute, 2010). We checked for normality and homogeneity of variance using, respectively, the Shapiro–Wilk test of normality and the Levene test for the homogeneity of variances. Data on survival rate were arcsine transformed to ensure normality. The effect of treatment on soil moisture

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content was performed on the measuring values. Variables with significant differences were compared using Tukey's HSD test at the 5 % level.

3 Results and discussion

3.1 Effect of treatment on soil moisture content

Soil water content (SWC) varied significantly between the restoration techniques (df = 2; $F = 53.21$; $p < 0.00$), but did not vary between depth levels (df = 4; $F = 0.70$; $p = 0.59$). SWC was higher under the half-moon technique and lower under the zaï (Fig. 4). Denuded soils are well known to be characterized by their poor degree of permeability and their low water-storage capacity. The hard outer crust that forms on these soils results in poor water infiltration and ventilation of the horizontal layers (Bayen et al., 2011). Consequently, where there is low rainfall, the seedlings cannot obtain enough water to meet their growth requirements.

Destroying the surface crust by stripping away the surface horizon temporarily improved soil porosity and hence infiltrability (Casenave and Valentin, 1992). A likely reason for our finding that SWC was higher in the plots treated with the half-moon technique than those treated with zaï and standard plantation techniques is that half-moon plots had larger impluvia, causing water to infiltrate the soil more deeply. These results are in accordance with those found by Kagambèga et al. (2011a) in the same study area. Indeed, the most effective way to increase soil productivity in the Sub-Saharan zone is to ensure effective water infiltration and storage in the soil (Lal, 1997). The combined effect of capturing water and allowing for the infiltration of surface runoff makes the half-moon technique the most effective method for improving SWC on degraded soils (Kagambèga et al., 2011a). Soil moisture is vital to the success of revegetation programmes (Banerjee, 1990), because soil moisture plays an important role in promoting root growth of plant seedlings (Li and Chen, 1995). In our study, the pits of zaï and standard plantation collected the surface runoff water, but both had

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a smaller surface area compared to half-moons. This could explain the low SWC and the high and speedy mortality rates of Jatropha when we used these techniques.

SWC also varied significantly between the study sites (df = 1; $F = 73.48$; $p = 0.00$). SWC depends on precipitation rate, and the precipitation was significantly higher in Namoungou, in the Sudanian zone, than in Dangadé, which is located in the Sahel (Table 1).

Improvement of soil water using appropriate water-harvesting techniques is the main condition favoring degraded land rehabilitation. The techniques used in our study (half-moon, zaï and standard plantation) modify the physical characteristics of the soil and increase the infiltration and storage of runoff water (Kagambèga et al., 2011b).

3.2 Effect of treatment on survival rate and seedling growth

Overall, over 33 months the survival rates of the seedlings were 78.57 % in the half-moon treatment and 0 % in zaï treatment (Fig. 5). Most of seedlings died in the first years after planting due to soil condition. These observations are in accordance with those found by Baumert et al. (2014), who reported that in the afforestation systems, most of *J. curcas* trees died in the first years after planting due to soil constraints and lacking management. Seedling growth varied significantly between the treatments, study sites and the interaction of study sites and treatments (Table 2).

J. curcas seedlings showed significantly higher growth and survival rates under the half-moon treatment at both sites than under the two other treatments. It is noteworthy that all of the plants in the Sahel zone, independently of treatment, perished at the latest two years after they were planted. At Namoungou (North Sudanian zone), the survival rate was overall higher than at Dangadé (Sahelian zone). Overall, *J. curcas* seedlings were found to profit more from the effects of the half-moon and standard plantation techniques in the North Sudanian zone. The poor survival rates for seedlings under all of the techniques in the Sahelian zone may be an indication that *J. curcas* is barely able to survive at all on barren areas receiving very low rainfall. Our results corroborate those of Kun et al. (2007), who reported low survival and reproductive rates of *J. curcas*

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in barren areas in the Yunnan Province, Southwest China. The results of our study indicate that the limited water supply in the Sahelian zone may be responsible of the poor performance of *J. curcas* seedlings in all of the restoration techniques tested. The high survival rate obtained for the half-moon technique at the Namoungou site demonstrate that this technique is suitable for increasing and maintaining soil water content over extended periods of time. Figure 3 shows that most of the seedlings died principally during the April–May period, which corresponds to the peak of the dry season in the Sahel. This is an indication that *J. curcas* may not be as drought-resistant as is commonly claimed in the abundant literature that praises this so-called "wonder plant" (Fairless, 2007). In the Sudanian zone, 78 % of seedlings survived from August 2011 to April 2014 under the half-moon treatment, confirming the capability of this technology to improve soil properties and thus plant productivity.

4 Conclusion

The aim of this experiment was to study the effects of three soil and water conservation techniques on the growth parameters and survival rate of *J. curcas* at two denuded sites in Burkina Faso. The growth performance and survival rate of *J. curcas* were significantly higher in the Sudanian area than in the Sahel. Furthermore the half-moon treatment resulted in more than 70 % of seedling survival in the Sudanian zone and none in the Sahel, after 33 months of experiment. Furthermore, our results showed that most of the plants died in the Sahel between April and May, which is the peak of the dry season, therefore suggesting that the nut may not be as drought-resistant as suggested by the very prolific literature praising the productivity of this plant. The success of the Half-moon technique in increasing soil water content promises to make it an efficient afforestation technique in the Sudanian zone. In the Sahel, the mortality of all of the seedlings under all of the treatments, two years after establishment of the plantations, shows that *J. curcas* is not a suitable plant for restoration of degraded lands in that region. On the contrary, we can recommend the use of the species for

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restoration purposes in the Sudanian zone. We have demonstrated that the half-moon technology is the technique best-suited to improve soil water content and ensure the survival of *J. curcas*.

Author contributions. P. Bayen conducted the study, compiled the data, conceived the ideas of this manuscript, conducted the analysis and submitted the first draft: T. K. Sop deepened the ideas of the paper, provided guidance for data analysis and contributed to the writing. A. Thiombiano and A. M. Lykke initiated the project UNDESERT, scientifically supervised the implementation of the research and data collection and provided comments on the manuscript.

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Table 1. Percentage of soil water content (average over all depths) according to site and technique.

Technique	Site	
	Dangadé (Sahelian Zone)	Namoungou (Sudanian Zone)
Half-moon	4.69 ± 0.96^{b}	10.45 ± 2.39^{a}
Zaï	0.6 ± 0.60^{c}	1.52 ± 1.49^{c}
Standard plantation	0.82 ± 0.67^{c}	7.4 ± 1.54^{b}
Average	2.04 ± 2.06	6.46 ± 4.2

Note: means followed by the same letter are not statistically different at $p = 0.05$ tested by Tukey's test.

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Table 2. Summary of the results of the two-way ANOVA investigating the effects of site and treatment on the survival and growth of *J. curcas* seedlings.

Sources of variation	Survival rate			Diameter			Height		
	df	F	p	df	F	p	df	F	p
Site	1	9.74	0.0033	1	133.40	< 0.0001	1	82.61	< 0.0001
Treatment	2	8.91	0.0006	2	27.78	< 0.0001	2	18.54	< 0.0001
Site treatment	2	2.18	0.1247	2	7.78	0.0004	2	13.74	< 0.0001

Note: df: degree of freedom; F: Fisher value; p: significance level

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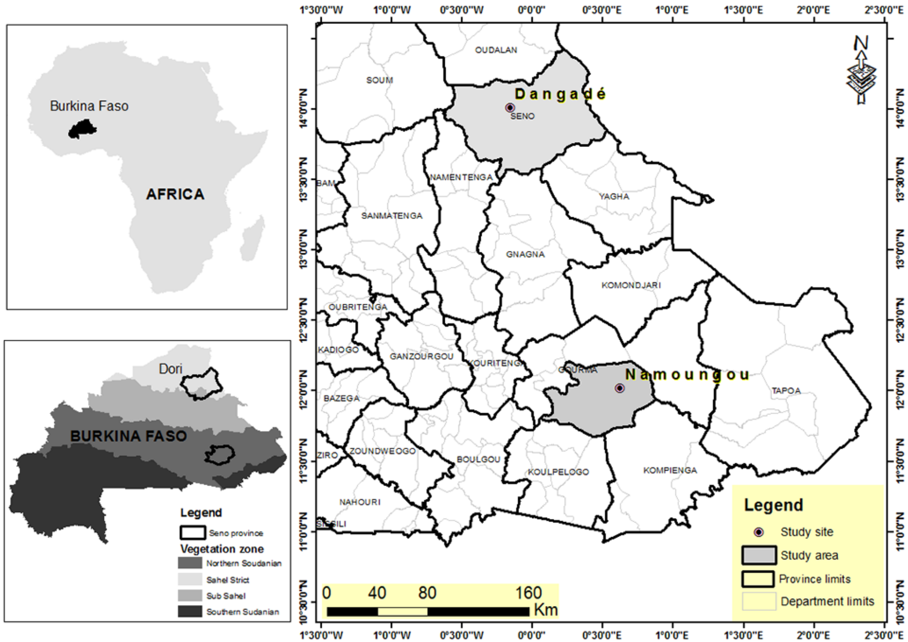

Figure 1. Phytogeographic domains and geographic locations of the experimental sites.

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Jatropha curcas L. performance in the Sahelian Zone of West

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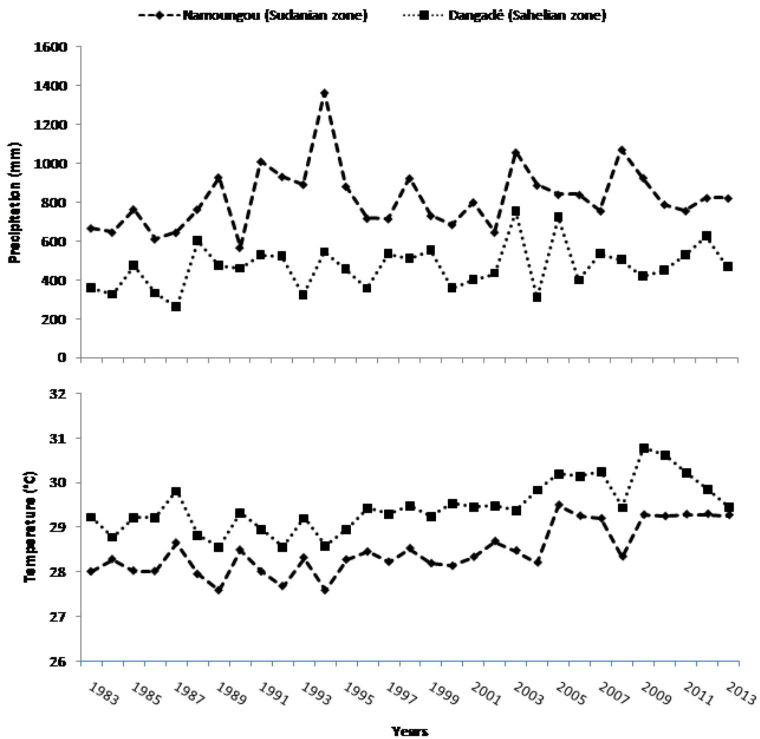

Figure 2. Mean rainfall (mm) and mean temperatures record (°C) for the weather station of Dori (Sahelian zone) and Fada N'Gourma (Sudanian zone), near the experimental sites, between 1983 and 2013.

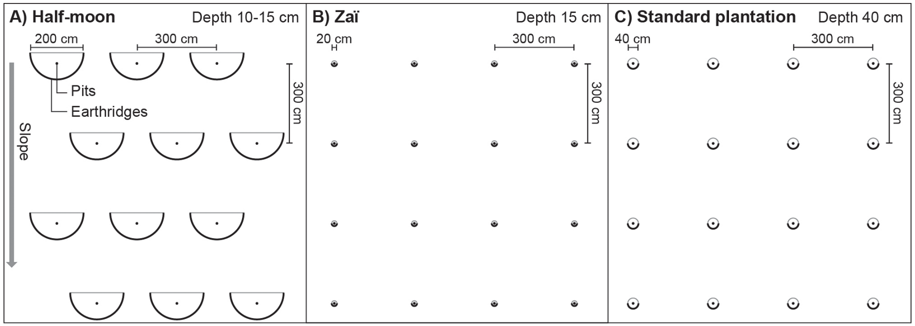

Figure 3. Specifications of restoration techniques.

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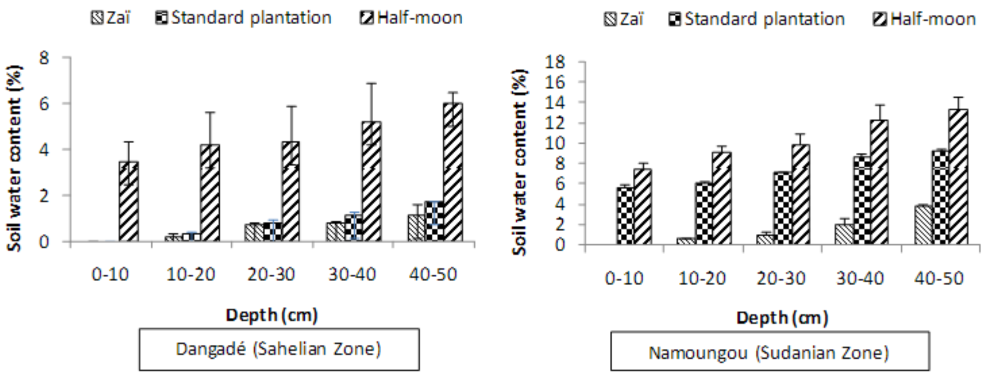

Figure 4. Effect of treatments on soil water content at different depth levels in October 2012 (error bars show the SD).

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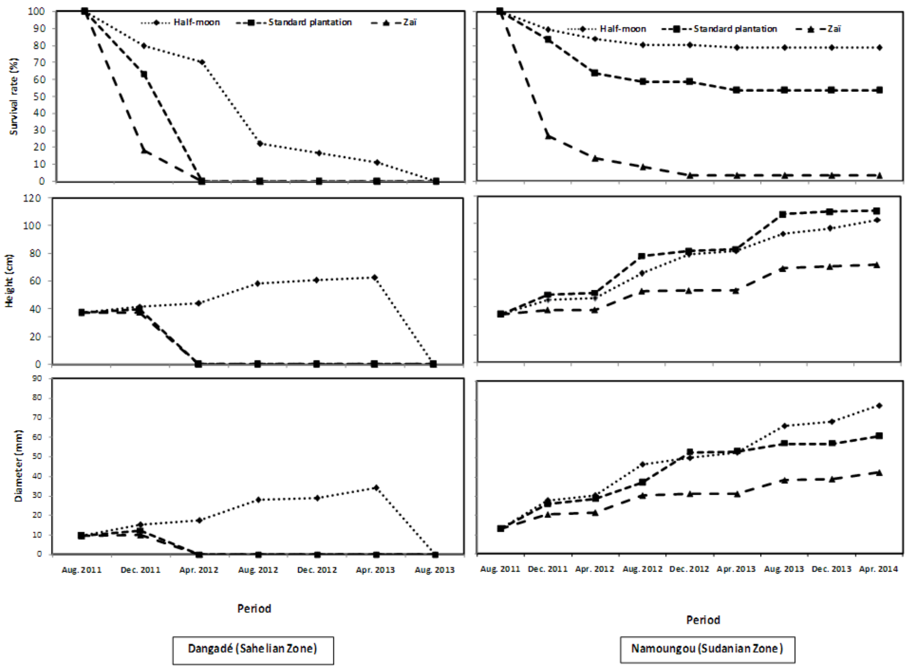

Figure 5. Survival rate and mean growth of seedlings.

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