Exploring Drivers of Invasiveness of the Plant Species *Senna obtusifolia* in Rangelands to Secure Forage Production in West Africa

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Abstract

Rangelands in Sahelian countries are continuously over-grazed decreasing forage resources and causing rapid environmental changes. *Senna obtusifolia* is a less palatable plant species that becomes increasingly invasive. This research explored drivers of its invasiveness in the perspective to propose solutions to secure forage production in the pastoral reserves. Species composition and herbaceous aboveground biomass were assessed in rangelands with different levels of invasion of *Senna obtusifolia* along a climatic and land-use pressure gradient. A greenhouse experiment was conducted to test the competitiveness of this species. The development of *Senna obtusifolia* in rangelands affected significantly forage quantity. Indeed the biomass of the others herbaceous species decreased but not the species richness. The overgrazing of Sahelian rangelands combined to the floristic selection operated by livestock reduced the abundance of fodder species and fostered the expansion of *S. obtusifolia*. Moreover, *S. obtusifolia* had a good germination rate with a rapid growth that made it more competitive. Thus, in the interspecific competition experiment, the aboveground biomass of *S. obtusifolia* was not influenced when associated to legume, grass and perennial grass species respectively. After 3 years of full protection experiment, the abundance of *S. obtusifolia* decreased, hence its invasiveness in rangelands should be supported by the mixed effect of disturbance factors as grazing and drought that lead several plant species to be vulnerable and favor undesirable species expansion. The control of *S. obtusifolia* expansion is conditionned by the reformulation of the land management systems and the promotion of sustainable environmental policies.

Introduction

Changes in climate, land cover, and land use are widely cited as major global change drivers that are particularly important in drylands because they may cause desertification (Maestre et al. 2016). Other factors may also constitute important (but often neglected) influences on ecosystem functioning and, subsequently, on ecosystem service (ESS) provision. After habitat destruction, land invasion by non-native species has become the second most important threat to biodiversity conservation (Vankat & Graham, 2002). In natural ecosystem worldwide, invasive plants have severely reduced the diversity of native flora and fauna, altered ecosystem processes, reduced wildlife habitat, and decreased ecosystem productivity (Reid et al. 2009). Many of these species have also affected rangelands; they continue to invade previously uninfested land at an alarming rate. The global livestock sector is highly dynamic. In developing countries, it is currently evolving in response to a rapidly increasing demand for livestock products (Thornton, 2010). The livestock sector is also the main economic pillar of several countries in West Africa, employing a high percentage of the labor force (Ly et al.2010). However, pastoral activities remain essentially traditional and extensive in these countries (Weber and Horst, 2011). Nutrition of cattle, sheep and goats in livestock farming systems of the Sahelian and Sudanian regions of West Africa is essentially based on the exploitation of naturally occurring herbaceous and ligneous plant species, and crop residues (Zampaligré et al. 2013). Because of their accessibility and availability, natural forages have always and continue to be the essential support for livestock nutrition (Kiema et al., 2014). Unfortunately, African pastoral systems have been under pressure from steady population growth and an expansion of agriculture into grazing lands (Moritz, 1998; Turner and Hiernaux, 2008). The sub-Sahelian and the northern Sudanian zones of West Africa also suffer from variable annual precipitation and increased climate variability combined with high anthropogenic pressure on natural resources, notably crop and range land, natural vegetation and crop residues (Zampaligré et al. 2013).

The high grazing pressure pushes rangeland resilience to its limits (Hiernaux et al. 2016). Sahelian and Sudanian rangelands of West Africa are currently invaded by *Senna obtusifolia*, an herbaceous legume native in tropical Africa and India. It is an annual, fast-growing plant that germinates well even at relatively low water availability (Sy et al. 2001; Anastasia et al. 2014 ; Saidou et al. 2015). In these rangelands, *Senna obtusifolia* (Chinese senna or sicklepod), a less palatable plant species becomes increasingly invasive degrading natural

forage quality. This research aimed to explore drivers of its invasiveness in the perspective to propose solutions to secure forage production in rangeland ecosystems.

Methods and Study Site

This research was conducted in rangelands distributed in the climate sectors of Burkina Faso. In this research, we expected to explore whether the expansion of *S. obtusifolia* in rangelands is related to local topo-edaphic conditions, the presence or absence of competing species, changes in climatic conditions, increased land-use pressure, high rates of local adaptation, or a mixture of these factors. We investigated the ecological performance of *S. obtusifolia* in three different climatic sectors (Sahel, Sudano-Sahel and Sudanian) and under two topo-edaphic conditions (Upland, lowland) and different levels of land-use pressure. Our sampling design established research sites within three different climate zones (Sahel, Sudano-Sahelian and Sudanian zone), to stratify further for land-use type and topographic position, and to collect data in plant communities with different invasion patterns. Here, three levels of invasion by *S. obtusifolia* were considered:

- Plant communities with a minimum invasion level of *S. obtusifolia;*
- Plant communities with an intermediate (medium) invasion level of *S. obtusifolia;*
- Plant communities with a maximum invasion level of *S. obtusifolia*.

Within each climate zone, we sampled in 2 land-use types x 3 locations x 2 slope positions x 3 levels of invasion x 4 plots. In total, 144 vegetation plots with a size of 100 m² were sampled per climate zone.
In each plot, we listed all plant species and visually estimated their ground cover and average height. For *S. obtusifolia*, we recorded variables quantifying population-level performance (density and plot-level biomass) and individual performance (individual biomass) in subplots of 1m². The aboveground biomass from all subplots were separated into two fractions (*S. obtusifolia* and other species). Concomitantly, we tested the effect of full protection on the performance of *S. obtusifolia* in land invasion. Thus, we installed first fenced plots in land totally invaded by *S. obtusifolia* and then monitored annually its density and its biomass from 2017 to 2019. During each floristic campaign, the species composition was listed to determine species richness.
To explore drivers of the invasiveness of *S. obtusifolia*, we performed a greenhouse experiment at the National Center of Forest Seed (CNSF) of Ouagadougou (Burkina Faso). Here, seeds of four herbaceous species (*S. obtusifolia* (legume); *Pennisetum pedicellatum* (annual grass); *Andropogon gayanus* (perennial grass) and *Chameacrista mimosoides* (legume)) were sown per pair in containers under three water regimes. Four competitions treatments were applied (*S. obtusifolia* only, *S. obtusifolia* + *P. pedicellatum* and, *S. obtusifolia* + *Andropogon gayanus*). Each container received a total of 20 seeds. In polyculture, this total were composed of equal numbers of seeds of the participating species. Each competition treatment were submitted to three levels of drought stress (well-watered, moderate drought stress, and severe drought stress). A total of 270 containers with a standard substratum were used. After 90 days, we measured the height and total biomass of each species to quantify the performance of *S. obtusifolia*. Floristic data were submitted to a GLM analysis with Poisson distribution in R software. We used also Anova test to for the comparison of monitoring data. The agressivity index was calculated to measure the strength of competition (See the formula in Roush and Radosevich 1985; Mc Gilchrist and Trenbath 1971). The principle is when two species grow together is a container, the strong competitor (Mekkins and McCarty, 1999).

Results

Ecological performance of Senna obtusifolia under environnemental conditions

Data analysis revealed that the species richness of the herbaceous vegetation and the density of *S. obtusifolia* were influenced significantly by climate zone, land use, topography and the mix-effect of these factors (Table 1). The species richness reached 11.56 ± 4.34 per m² in the Sudanian sector while it was 8.00 ± 3.01 in the Sahel (Table 2). However, the biomass of *S. obtusifolia* differed significantly depending on land use (p=0.019) and on climate zone (p=0.002). In fact, the tallest individuals (112.30 ± 30.26 cm) and the highest biomass (2.25 ± 1.22 kg.m^{-}2) were found in the more humid Sudanian sector of Burkina Faso. While *S. obtusifolia* is almost absent in protected areas, it exhibited a high density in rangelands (86.21 ± 80.10 individual/m²).

Competitiveness of Senna obtusifolia under water regime

The germination test of four species used for interspecific competition showed that the two grass species *Andropogon gayanus* (6 %) and *Pennisetum pedicellatum* (7 %) exhibited low germination rates, while legume species had high germination rates. About 80% of *S. obtusifolia* seeds were found to germinate within six days after sowing. The agressivity index values showed that *S. obtusifolia* was the strong competitor under controlled high-water regime (0.27±0.08) and medium (0.39±0.04) and low water regimes (022 ±0.16).

Table 1. Effect of environmental factors on herbaceous vegetation richness and on *Senna obtusifolia* performance. A GLM analysis with Poisson and Gamma distribution were applied. p-values <0.05 were significant

	Herbaceous species richness	*S. obtusifolia* biomass	*S. obtusifolia* density
Environmental variables	z value (Pr(>|z|))	z value (Pr(>|z|))	z value (Pr(>|z|))
Climate zone	-4.453 (8.46e -06)	3.053 (0.002)	-20.443 (<2e-16)
Land use	-5.085 (3.67e -07)	2.333 (0.019)	-11.442 (<2e-16)
Topography	-6.148 (7.87e -10)	1.475 (0.140)	-6.561 (5.342e-11)
Climate zone* land use	4.805 (1.55e-06)	-1.786 (0.074)	7.667 (1.76e-14)
Climate zone*topography	6.277 (3.46e-10)	-1.544 (0.123)	8.597 (<2e-16)
Land use*topography	5.555 (2.77e -08)	-1.883 (0.060)	3.872 (0.0001)

Table 2. Density, biomass of *S. obtusifolia* and herbaceous vegetation richness in climate zones

Climate zone	Sahelian	Soudano-sahelian	soudanian	Pr(>F)
Density (individual/m²)	75.36 ± 70.17	32.95 ± 37.39	7.22 ± 7.36	<2.2e-16
Biomass (kg/m²)	0.70 ± 0.67	1.20 ± 1.23	2.25 ± 1.22	<2.2e-16
Species richness (species/m²)	8 ± 3.01	10.42 ± 3.13	11.56 ± 4.34	<2.2e-16

Effect of duration of full protection on S. obtusifolia performance

In 2017, at the beginning of the experiment, density, aboveground biomass and heigh of *S. obtusifolia* were higher (Table 3) within fenced plots. The performance of *S. obtusifolia* in land invasion declined significantly at least one year after a full protection of invaded lands. While *S. obtusifolia* performance decreased, the companion herbaceaous species increased significantly in biomass, height and density. After 3 years protection, the dominance of *S. obtusifolia* was at least divided in 3 times and that were profitable to companion species.

Table3. Effect of 3 years full protection on *S. obtusifolia* performance. Data were analyzed with anova parametric test. p ≤0.05 was statistically significant

years	**2017**	**2018**	**2019**	**P-value**
Density (individual.m^{-2})	160.87 ± 69.99	77.33 ± 59.79	41.50 ± 31.19	1.272e -10
Heigh (cm)	129 ± 16.03	95.96 ± 18.99	85.46 ± 19.98	2.547e -13
Biomass of Senna (kg)	1.45 ± 0.34	0.68 ± 0.29	0.37 ± 0.17	2.2e -16
Biomass of others species (kg)	0.20 ± 0.11	0.60 ± 0.31	0.83 ± 0.38	1.079e -12

Discussion/Implications

The climate conditions seem to be the first environmental driver that influence more the performance of *Senna obtusifolia*. It for this reason, rangelands in the semi-arid zones (Sahel) are severely invaded by this species while, this species is rarely found in the humid zones. Results of the greenhouse experiment suggest that the invasion of rangelands by *S. obtusifolia* could also be related to biotic environmental factors, particularly to a high grazing pressure that reduces the abundance of competing, high-value fodder species. Hence, unpalatable species become more dominant and negatively affect forage quality and quantity in West African rangelands. After three years of full protection of a grazing land previously invaded by *S. obtusifolia*, we observed the decline of its abundance. Hence its invasiveness in rangelands should be supported by combined effects of grazing disturbances (overgrazing) and drought that weakens the competitivenss of previously dominant plant species, and favor the expansion of undesirable species. The control of *S. obtusifolia* expansion is conditioned by the reformulation of the land management systems and by a promotion of sustainable environmental policies. Results of this experiment open perspectives to explore the probable impact of land use and climate

change on plant productivity in the Sahel and to predict the list of potential plant species that could be more vulnerable (or resilient) in response to climate change.

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