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W. A. Zida,
B. A. Bationo, J.-P. Waaub

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Effects of land-use practices on woody plant cover dynamics in Sahelian agrosystems in Burkina Faso since 1970-1980 droughts

Wendpouiré Arnaud Zida ^a

Babou Andre Bationo ^b

Jean-Philippe Waaub ^c

^a *Institute of Environmental and Agricultural Research, Burkina-Faso*

^b *Institute of Environmental Sciences, University of Quebec in Montreal, Canada*

^c *Department of Geography, & GEIGER, University of Quebec in Montreal, Canada*

^a *GERAD, Canada*

arnaud.zida@yahoo.fr

babou.bationo@gmail.com

waaub.jean-philippe@uqam.ca

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Abstract: The 1970s–1980s droughts in the Sahel caused a significant degradation of land and plant cover. To cope with this situation, populations have developed several biophysical and social adaptation practices. Many of these are agroforestry practices and contribute to the maintenance of agrosystems. Unfortunately, they remain insufficiently documented and their contributions to the resilience of agrosystems insufficiently evaluated. Many authors widely link the greening in the Sahel after droughts to the resumption of rainfall. This study examines the contribution of agroforestry practices to the improvement of woody plant cover in the North of Burkina Faso after 1970s–1980s droughts. The examination of practices is carried out by integrating the rainfall, soil and geomorphology variables. Landsat images are used to detect changes in woody plant cover: increasing, decreasing and no-change in Enhanced Vegetation Index. 230 field observations, coupled with interviews conducted on the different categories of change have allowed to characterize the biophysical environment and identify land-use practices. The results show a variability of vegetation index explained to 9% ($R^2 = 0,09$) by rainfall. However, Chi-Squared independence tests show a strong dependence between changes in woody plant cover and geomorphology ($p = 0,0018 *$), land-use, land-cover ($p = 0,0001 *$) and land-use practices ($p = 0,0001 *$).

Keywords: Sahelian agrosystem, Land degradation, Agroforestry, Land-use practices, Regreening in the Sahel

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1 Introduction

The 1970s–1980s droughts were particularly stressful socio-economically and environmentally in the Sahel region of West Africa (Bonnecase, 2010; Brandt et al., 2014; Doso-Jnr, 2014). The drastic decrease in rainfall over several successive years has led to a fall in primary production and triggered serious food crises (1999; Bonnecase, 2010). The northern region of Burkina Faso was the most affected with a migration of Isohyets from the north to the south (Thiombiano and Kampmann, 2010). The most notable environmental consequences have been land degradation and loss of biodiversity (Brandt et al., 2014; Doso-Jnr, 2014). In response to the negative effects of climatic hazards and the increasing degradation of natural resources, rural communities have developed, from the 1980s, with the support of civil society organizations and state services, several biophysical and/or social adaptation practices (Reij et al., 2005; Botoni and Reij, 2009; Reij et al., 2009). Many of these are indigenous or imported agroforestry practices and contribute to the maintenance of agrosystems (Reij et al., 2005; Botoni and Reij, 2009; Reij et al., 2009). They promote woody plant regeneration and create a favourable environment for their development. Unfortunately, these practices remain insufficiently documented and their contributions to the resilience of agrosystems are insufficiently evaluated.

Since the end of the 1990s, several remote sensing diachronic studies have supported a remarkable improvement of plant cover in the Sahel region of West Africa (Anyamba and Tucker, 2005; Olsson et al., 2005; Epule et al., 2014; Bamba et al., 2015). This improvement would be the result of the recovery of precipitation after the 1970s–1980s droughts (Anyamba and Tucker, 2005; Bamba et al., 2015). However, the non-uniform distribution of vegetation over the entire area and the diversity of anthropogenic adaptation practices developed in the Sahel (Epule et al., 2017), suggest that recovery in rainfall is not the only factor in this improvement. Other biophysical and anthropogenic factors should also be considered (Herrmann and Hutchinson, 2005; Olsson et al., 2005; Reij et al., 2005; Reij et al., 2009).

Although evoked, the role of land-use practices in the greening and the evolution of the floristic diversity of Sahelian agrosystems has not been the subject of deep investigations on a large scale. The purpose of this study is to examine the contribution of agroforestry practices to the improvement of woody plant cover in the Northern Region of Burkina Faso after the 1970s–1980s droughts. The review of practices covers both anthropogenic variables such as land-use, land-cover and land-use practices. It also integrates climatic (rainfall) and environmental (soil and geomorphology) variables that can influence the dynamics of woody plant cover.

2 Methodology

2.1 Location of the study area

The study is carried out in Burkina-Faso, a West African country with predominantly Sahelian climatic conditions. The country is defined according to the average annual rainfall in three main climatic zones: the Sahelian climatic zone in the north (300–600 mm/year), the Sudanian climatic zone in the south (900–1200 mm/year), and the Sudano-Sahelian climatic zone in the centre (600–900 mm/year) (Thiombiano and Kampmann, 2010). The study area is located in the Sudano-Sahelian climatic zone of the Northern Region of the country (Figure 1). It is located between latitudes 12°38' and 14°02'N and longitudes 1°33' and 2°55'W, and covers an area of 13950 Km². It includes the administrative provinces of Loroum, Passoré, Yatenga, and Zondoma.

2.2 Evolution of woody plant cover

The sampling sites for field observation use in this study is based on an analysis of woody plant cover change. For this, the first part of the study was to highlight by remote sensing the different categories of woody plant cover change: increase, decrease and no-change of vegetation index (VI). The vegetation is monitored by using a series of satellite images from 1986, 1999 and 2015 of 30 m spatial resolution

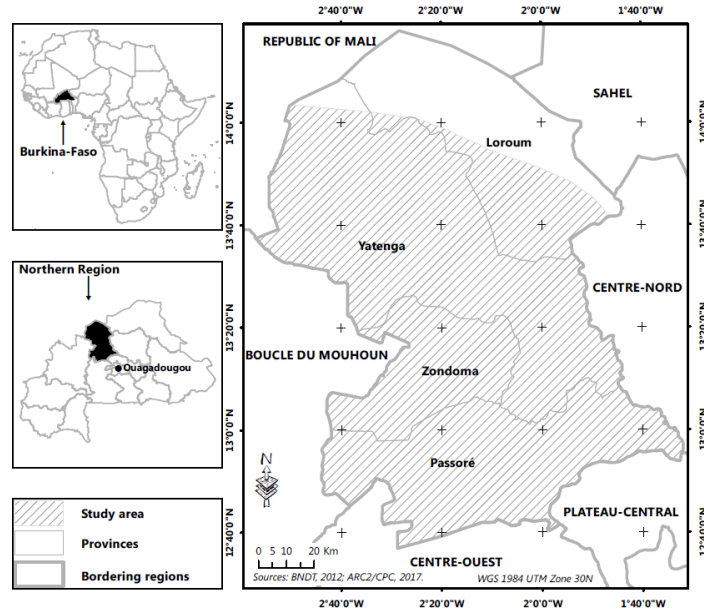


Figure 1: Location of the study area.

from Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI/TIRS sensors (USGS, 2017). The images of the beginning of dry season (October, November) are uploaded to discriminate grasses and crops. This period marks the end of the vegetative stage of herbaceous plants and crops and a persistence of the vegetative stage in almost all Sahelian wood plants (Hiernaux et al., 1994; Brandt et al., 2016). The images were subjected to atmospheric and terrain correction using ATCOR Ground Reflectance algorithms of PCI Geomatica 2017.

The variation of Enhanced Vegetation Index (EVI) is used as proxy for woody plant cover change. It derives from the Normalized Difference Vegetation Index (NDVI) but uses the wavelength in blue, a correction factors for ground reflectance and aerosol diffusions to reduce atmospheric effects and signals emitted by the soil below the vegetation (Huete, 1988; Huete et al., 2002). This improves the accuracy of comparisons of multi-date images taken at different times under different soil and atmosphere conditions (Huete, 1988; Huete et al., 2002).

$$\mathbf{EVI} = \mathbf{G} \times \frac{(\rho_{\text{nir}} - \rho_{\text{r}})}{(\rho_{\text{nir}} + \mathbf{C1} \times \rho_{\text{r}} - \mathbf{C2} \times \rho_{\text{b}} + \mathbf{L})}$$

ρ_{nir} : pixel values of the near-infrared band

ρ_{r} : pixel values of the red band

ρ_{b} : pixel values of the blue band

\mathbf{G} : gain factor, $\mathbf{G} = 2.5$

\mathbf{L} : ground reflectance correction factor, $\mathbf{L} = 0.5$

$\mathbf{C1}$ et $\mathbf{C2}$: correction coefficients of the aerosol diffusions, $\mathbf{C1} = 6$, $\mathbf{C2} = 7.5$

As the purpose of this section of the study is focused on the monitoring of the woody plant cover change, the negative values of the vegetation index coming from potentially non-vegetated pixels (wetlands and water) are excluded by being reduced to zero (approximately like bare soils) (Jamali et al., 2014; Yao et al., 2019). This is important to avoid overestimating of the increase or decrease of plant cover on water surfaces at the time “n” passed in bare soils or other vegetation types at the time “n+1” and vice versa. The method of detecting change by differentiation of vegetation index between two dates by using pixel-over-pixel comparison is used (Gandhi et al., 2015; Jamali et al., 2015). The different categories of change in woody plant cover between two dates: increase, decrease and no-change of the vegetation index; highlighted were subjected to overlay analysis in order to establish the

sequence of change of the woody plant cover. This is necessary to take into account in the sampling, areas where the increase, decrease and no-change of vegetation index are started in 1986 and continued until 2015 (1986–2015) and those for which it started in 1999 (1999–2015). Figure 2 highlights the different categories and sequences of woody plant cover change obtained by image analysis and use for sampling.

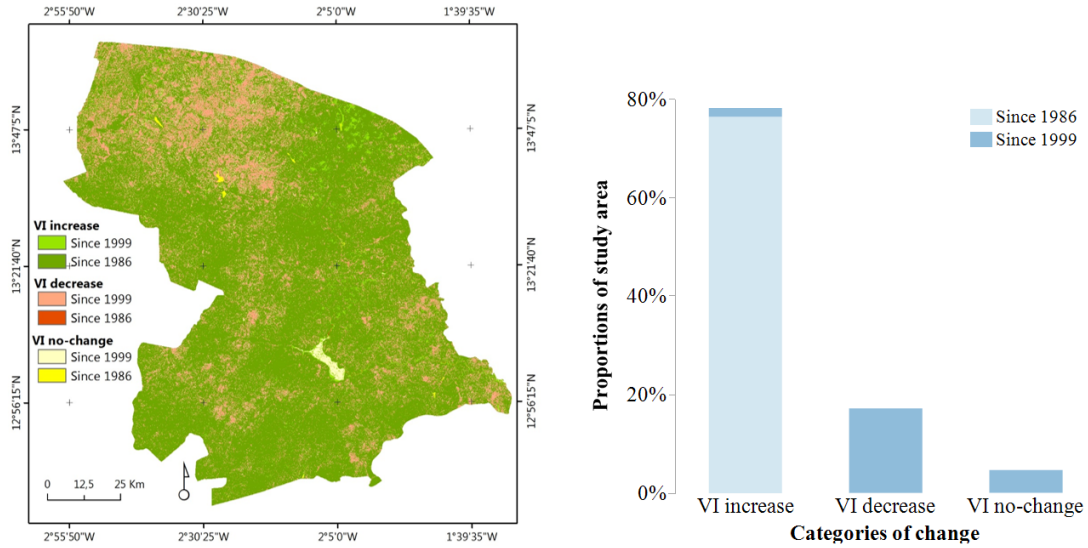


Figure 2: Categories and sequences of woody plant cover change.

2.3 Sampling

The mapping of the categories and sequences of woody plant cover change is used to define the number of field observation sites. For each category and sequence of woody plant cover change, the number of observation sites (Table 1) was calculated using the normal approximation of the binomial distribution using the proportion method (Dagnelie, 1998).

$$n = \frac{U_{1-\alpha/2}^2 \times p(1-p)}{e^2}$$

with:

n = the number of observation sites;

p = the proportion of the considered site;

e = the margin of error resulting from the estimation of any other parameter calculated from the observations, a value of 8% is considered;

$U_{1-\alpha/2}$ = the value defined by the normal law according to the desired confidence level, a 95% confidence level value for a value of $U_{1-\alpha/2}=1,96$ is considered.

The spatial distribution of the observation sites is made by a random selection on a set of systematic grid points (400 m x 400 m) covering the entire study area. A number of sites corresponding to the number defined in Table 1 are assigned to each category and sequence of change.

2.4 Data

The data used in this study come from the databases described below, as well as field observations and semi-directional interviews. They relate to climatic (rainfall), environmental (soil and geomorphology) and anthropogenic (land-use, land-cover and land-use practices) variables.

Table 1: Study sample by category of sequences of tree cover change.

Categories of woody plant cover change	Sequence of change	p	$1-p$	$U_{1-\alpha/2}^2$	e^2	n	n_{final}
VI increase	Since 1999	1,76%	98,24%	3,8416	0,0064	10	118
	Since 1986	76,38%	23,62%	3,8416	0,0064	108	
VI decrease	Since 1999	17,11%	82,89%	3,8416	0,0064	85	85
	Since 1986	0,08%	99,92%	3,8416	0,0064	0	
VI no-change	Since 1999	4,55%	95,45%	3,8416	0,0064	26	27
	Since 1986	0,13%	99,87%	3,8416	0,0064	1	
Total		100%	-	-	-	230	230

2.4.1 Rainfall

Rainfall data for 1950–2015 from five (5) stations of the National Meteorological Agency of Burkina Faso distributed homogeneously over the entire study area are used to monitor the evolution of rainfall (ANAM-BF, 2017). Estimation of the spatial distribution of daily precipitation produced by “Africa Rainfall Climatology” version 2 (ARC2) on a grid of 0.1o x 0.1o (CPC, 2017) are used to analyze the relationship between spatial variation of vegetation index and rainfall on the temporal scale of the study (1986-2015).

2.4.2 Soils

Soil data are obtained from the soil map of Burkina Faso at the scale of 1:500 000 (ORSTOM, 1973). Five classes of soils are represented on the observation sites: Ferruginous soils, Sodic soils, Hydromorphic soils, poorly evolved soils and Lithosols.

2.4.3 Geomorphology

The data on the geomorphology of the area are obtained by direct observation of the local relief configuration. Three forms of relief are described: shallows (deep terrain), plateau (flat terrain), and mound (relatively higher terrain in the immediate environment).

2.4.4 Land-use and land-cover

Land-use and land-cover data are obtained by direct observation and semi-directional interviews with populations in the field. Nine (9) classes of land-use and land-cover are described: agroforestry park, conserved area (classified or protected forest, community forest), riparian forest, shrub savannah, wooded savannah, steppe, bare land, water surface and habitation.

2.4.5 Land-use practices

Land-use practices that are favourable or unfavourable to the regeneration of woody species are identified and described by direct observation and semi-directional interviews with populations in the field. The practices with high potential for woody plant regeneration cover soils and water conservation/soils protection and restoration (SWC/SPR) and agroforestry practices, developed in the Sahel region (Bationo et al., 2012; Mbow et al., 2014; Epule et al., 2017). Land-use practices that may affect the establishment and development of woody plant include: agricultural expansion, bush fire, pasture, urban development, gold panning and wood harvesting.

2.5 Data analysis

The evolution of rainfall in the study area is shown by calculating the standardized precipitation index according to the approach developed by Ali et al. (2008). The relationship between woody plant cover change and rainfall is highlighted by regression analysis between spatial variation in vegetation

index and the average rainfall over the period 1986–2015 (Hair et al., 2014). The vegetation index data is resampled to match the spatial resolution of rainfall data by using the nearest neighbours method (Fensholt et al., 2004). The relationship between the categories of woody plant cover change (increase, decrease and no-change of the vegetation index) and environmental, anthropogenic variables is verified by the Chi-Squared test (χ^2) (Hair et al., 2014). Modalities of soil, land-use and land-cover, and land-use practices variables are grouped to have an expected values of at least 5 in cell of the contingency table. The Ferruginous soils, Sodic soils and Hydromorphic soils of the soil variable, poorly represented, are grouped under the name other soils. The bare land, habitation and water surface of the land-use and land-cover variable are grouped under the name of “no-vegetation” while conserved area, riparian forest, savannah and steppe are grouped under the name of “natural vegetation”. The modalities of land-use practices variable are grouped into three classes: planting/RNA (planting, assisted natural regeneration and fallow), SWC/SPR (animal parking in the farm, earth bund, grass strip, half-moon, mulching, organic amendment, stones dyke barrier, stone row, vegetated earth bund, vegetated stone row, woody strip and zaï), and tree-threatening practices (agricultural expansion, bush fire, pasture, urban development, gold panning and wood harvesting). The first two groups are practices with high potential for woody plant regeneration or agroforestry practices. A correspondence analysis is performed with the dependent variables to bring out the modalities of the environmental and anthropogenic variables characteristic of each category of woody plant cover change.

3 Results

3.1 Evolution of rainfall in the study area

The standardized precipitation index shows that the study area suffered from the droughts of 1970s–1980s (Figure 3). The wet years of 1950s, which continued into the early 1960s, quickly gave way to a long period of dry years (1970–1980) characterized by a succession of negative rainfall anomalies. A slight recovery of rainfall is observed from the 1990s. This recovery, however, does not show a clear trend and is characterized by an alternation of positive and negative rainfall anomalies until 2005 when a regularity of rainy years seems to settle down (Figure 3).

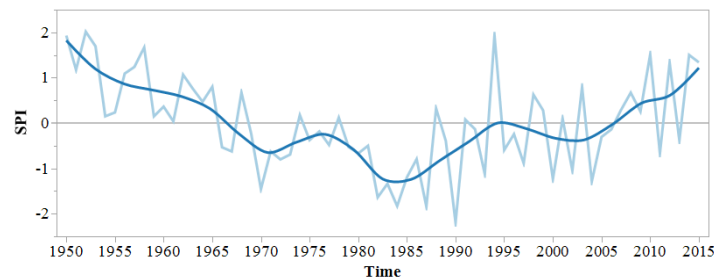


Figure 3: Standardized Precipitation Index (SPI) for the study area, 1950–2015 period.

3.2 Environmental characteristics of observed sites

The observed sites are based on five (5) soil classes dominated by the poorly evolved soils (Table 2). The latter accounts for 55% of sites located where vegetation index increase, 62% of sites where vegetation index decrease, and 56% of sites with a vegetation index remained no-change.

The geomorphological characteristics of the observed sites shows a predominance of the plateaus which shelter 53% of sites where vegetation index increase, 53% of sites where vegetation index decrease and 70% of sites where vegetation index remains no-change. However, a rather remarkable number (45%) of sites where vegetation index decrease is observed on mounds (Table 2).

Table 2: Environmental characteristics of observed sites by category of tree cover change.

Environmental variables	Categories of woody plant cover change						Total	
	VI increase		VI decrease		VI no-change		Number	%
	Number	%	Number	%	Number	%		
Soils								
Ferruginous soils	11	9%	12	14%	2	7%	25	11%
Hydromorphic soils	17	14%	8	9%	5	19%	30	13%
Lithosols	24	20%	10	12%	5	19%	39	17%
Poorly evolved soils	65	55%	53	62%	15	56%	133	58%
Sodic soils	1	1%	2	2%		0%	3	1%
Total	118	100%	85	100%	27	100%	230	100%
Geomorphology								
Mounds	35	30%	38	45%	5	19%	78	34%
Plateaus	62	53%	45	53%	19	70%	126	55%
Shallows	21	18%	2	2%	3	11%	26	11%
Total	118	100%	85	100%	27	100%	230	100%

Ferruginous soils: are characterized by an individualization of the sesquioxides of iron and manganese which gives them a hue in the range of 7.5 YR and 10 YR, a massive structure of horizons A and B, a possible presence of indurated horizon in cuirass or carapace, a rapid decomposition of the organic matter, a poverty in mineral elements; **Sodic soils:** are soils whose evolution is dominated by the presence of soluble salts (chlorides, sulphates, carbonates, bicarbonates of sodium and/or magnesium) or by the presence of exchangeable sodium (and/or magnesium) with appearance of a massive, diffuse structure and a high compactness; **Hydromorphic soils:** are soils whose characters are due to an evolution dominated by the effect of an excess of water because of a temporary or permanent waterlogging of part or all the profile; **Poorly evolved soils:** are soils with AC profile characterized by a low mineral alteration and low organic matter content; **Lithosols:** are soils with (A)C, (A)R, or R profile characterized by a mineral matter that remains in the raw state often mechanically fragmented with a virtual absence of organic matter (CPCS, 1967; Cardarelli, 2008).

3.3 Landscape characteristics of observed sites

On a landscape level, nine land-use and land-cover classes are observed on all sites (Table 3). The distribution of classes by category of woody plant cover change shows that agroforestry park (55%) and shrub savannah (26%) dominate sites with increasing vegetation index. On sites with decreasing vegetation index, the most represented classes are bare land (51%) and agroforestry park (26%), while bare land (44%), water surface (19%) and habitation area (15%) dominate on sites with no-change vegetation index.

Table 3: Landscape characteristics of observed sites by category of woody plant cover change.

Land use, land cover	Categories of woody plant cover change						Total	
	VI increase		VI decrease		VI no-change		Number	%
	Number	%	Number	%	Number	%		
Agroforestry park	65	55%	22	26%	2	7%	89	39%
Bare land	3	3%	43	51%	12	44%	58	25%
Conserved area	8	7%	2	2%		0%	10	4%
Habitation	2	2%	6	7%	4	15%	12	5%
Riparian forest	2	2%		0%	2	7%	4	2%
Shrub savannah	31	26%	6	7%	2	7%	39	17%
Steppe	5	4%	6	7%		0%	11	5%
Tree savannah	1	1%		0%		0%	1	0%
Water surfaces	1	1%		0%	5	19%	6	3%
Total	118	100%	85	100%	28	104%	230	100%

3.4 Land-use practices

Field observations and interviews reveal fifteen (15) practices with high potential for woody plant regeneration and six (6) practices with high risk for woody plant deterioration. The description and role in the regeneration or deterioration of the woody plant cover of all practices has been documented in the literature and from our experience, and is presented in Appendice.

The highest frequencies of practices with high potential for woody plant regeneration are observed in areas with increasing vegetation index (Figure 4). Assisted natural regeneration and zaï are the most commonly observed practices.

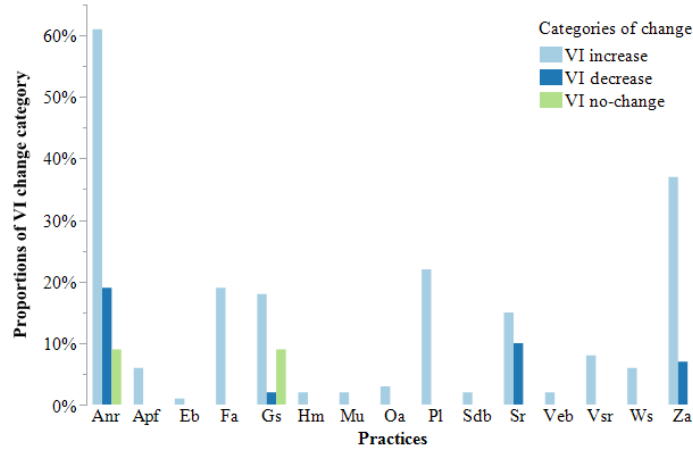


Figure 4: Frequencies of practices with high potential for woody plant regeneration by category of woody plant cover change. Anr: Assisted natural regeneration; Apf: Animal parking in the farm; Eb: Earth bund; Fa: Fallow; Gs: Grass strip; Hm: Half-moon; Mu: Mulching; Oa: Organic amendment; Pl: Planting; Sdb: Stones dyke barrier; Sr: Stones row; Veb: Vegetated earth bund; Vsr: Vegetated stones row; Ws: Woody strip; Za: Zaï.

Practices with high potential for woody plant regeneration are generally combined (Table 4). Thirty-nine (39) combinations of practices were observed, of which thirty-eight (38) were observed on 47% of sites where vegetation index increase.

Plantations and RNA on one side, and zaï, grass strip, and stones row on the other side are the most involved practices in combinations (Figure 5). Practices with high potential for woody plant regeneration are particularly implemented in agroforestry park with frequencies of 95% and 68% respectively for planting/RNA and SWC/SPR practice groups (Figure 6).

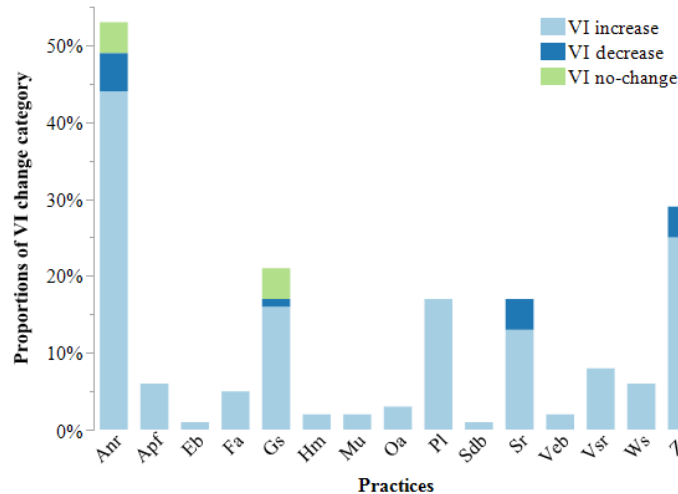


Figure 5: Frequencies of practices participating in combinations based on the sample size of the VI change category.

Practices with high risk for woody plant degradation are best illustrated in areas with decreasing or no-changed vegetation index (Figure 7). Wood harvesting, pasture and urban development are the commonly observed practices. They are most observed in natural vegetation and no-vegetation areas (Figure 6).

Table 4: Description and frequency of combination of high potential practices of tree regeneration observed

N° Combinations	Practices						Number the combination is observed		
							VI increase	VI decrease	VI no-change
1	Anr	Mu	Gs	Sr	Hm	Za	1		
2	Anr	Pl	Gs	Sr	Za		1		
3	Anr	Pl	Gs	Vsr	Za		2		
4	Anr	Pl	Ws	Vsr	Za		1		
5	Anr	Apf	Pl	Sr			1		
6	Anr	Apf	Sr	Za			1		
7	Anr	Apf	Vsr	Za			1		
8	Anr	Fa	Pl	Za			1		
9	Anr	Gs	Ws	Za			1		
10	Anr	Pl	Gs	Sr			1		
11	Anr	Mu	Gs	Za			1		
12	Anr	Pl	Gs	Za			1		
13	Anr	Pl	Sr	Za			2		
14	Anr	Pl	Vsr	Za			1		
15	Anr	Sdb	Eb	Sr			1		
16	Anr	Sr	Hm	Za			1		
17	Anr	Apf	Pl				2		
18	Anr	Apf	Sr				2		
19	Anr	Fa	Ws				1		
20	Anr	Fa	Za				1		
21	Anr	Gs	Sr					1	
22	Anr	Gs	Vsr				1		
23	Anr	Gs	Ws				2		
24	Anr	Gs	Za				3		
25	Anr	Oa	Gs				1		
26	Anr	Oa	Veb				1		
27	Anr	Pl	Gs				1		
28	Anr	Pl	Oa				1		
29	Anr	Pl	Za				3		
30	Anr	Sr	Za				2	2	
31	Anr	Veb	Za				1		
32	Anr	Vsr	Za				3		
33	Anr	Gs					2		1
34	Anr	Oa					1		
35	Anr	Pl					2		
36	Anr	Ws					2		
37	Anr	Za					2	1	
38	Fa	Gs					1		
39	Fa	Sr					2		
Total number of combinations							55	4	1
Frequency on the total number of sample							47%	5%	4%

Anr: Assisted natural regeneration; **Apf:** Animal parking in the farm; **Eb:** Earth bunds; **Fa:** Fallow; **Gs:** Grass strips; **Hm:** Half-moons; **Mu:** Mulching; **Oa:** Organic amendments; **Pl:** Planting; **Sdb:** Stones dyke barrier; **Sr:** Stones row; **Veb:** Vegetated earth bunds; **Vsr:** Vegetated Stones row; **Ws:** Woody strips; **Za:** Zai.

3.5 Relationship between woody plant cover change and rainfall

The linear regression analysis between the change in the vegetation index and the annual rainfall mean recorded between 1986–2015 shows that the percentage of variability in vegetation index explained by rainfall is low (Figure 8). The coefficient of determination of the linear regression model $R^2 = 0.09$ with a degree of overall significance $p < 0, 0001^*$ associated to the model. In other words, 91% of the variability in the vegetation index is explained by other factors. This fully justifies exploring the other factors.

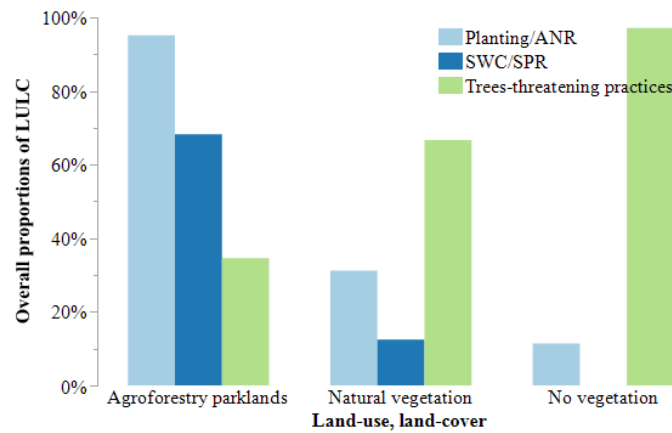


Figure 6: Frequencies of the groups of practices observed in the different land-use, land-cover (LULC) categories. **Planting/ANR:** Assisted natural regeneration, Planting, Fallow; **SWC/SPR :** Animal parking in the field, Earth bunds, Grass strips, Half-moons, Mulching, Organic amendments, Stones dyke barrier, Stones row, Vegetated earth bunds, Vegetated Stones row, Woody strips, Zai; **Trees-threatening practices:** Agricultural expansion, Bush fires, Gold panning, Pasture, Urban development, Wood harvesting; **Natural vegetation:** Savannah, Steppe, Riparian forest, Conserved area; **No-vegetation:** Bare land, Habitation, Water surface.

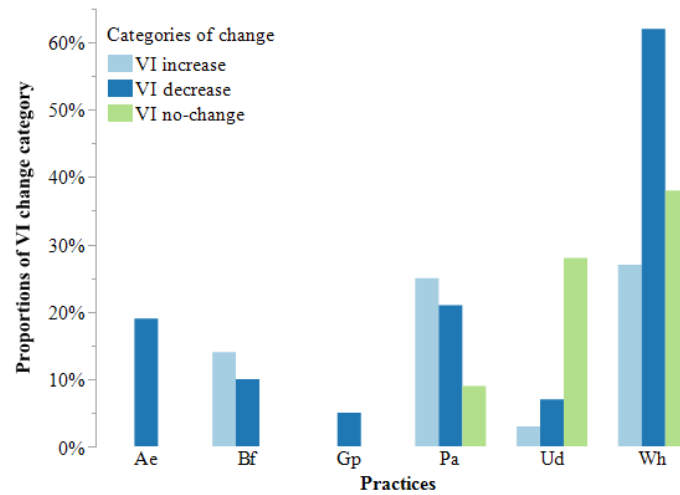


Figure 7: Frequencies of practices with high risk for woody plant deterioration by category of woody plant cover change. **Ae:** Agricultural expansion; **Bf:** Bush fires; **Gp:** Gold panning; **Pa:** Pasture; **Ud:** Urban development; **Wh:** Wood harvesting.

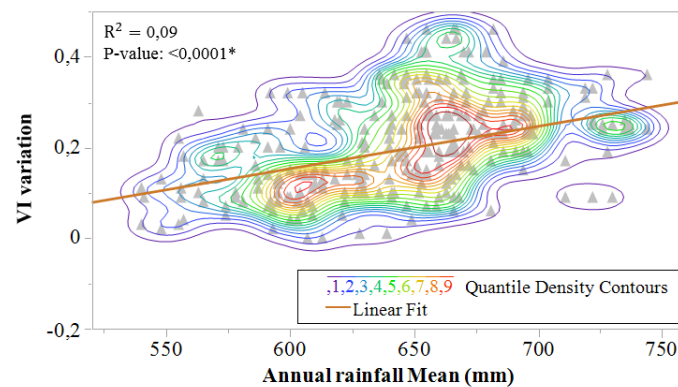


Figure 8: Relationship between spatial variation of vegetation index (VI) and the annual rainfall mean between 1986–2015.

3.6 relationship between woody plant cover change and environmental / anthropogenic variables

The Chi-Squared independence tests between the categories of woody plant cover change and the environmental and anthropogenic variables shows that the evolution of the wood plant cover strongly depends on factors such as the geomorphology of the area ($p = 0.0018^*$), land-use and land-cover ($p < 0,0001^*$) and land-use practices ($p < 0,0001^*$) (Table 5). Anthropogenic variables are best correlated with changes in woody plant cover with the lowest probability values. The dependence between the categories of woody plant cover change and soil classes, on the other hand, is not proven to go well beyond the limit of $p = 0.05$ (Table 5).

Table 5: Independence test between categories of woody plant cover change and environmental and anthropogenic variables

Environmental and anthropogenic variables	Pearson's Chi-Squared test (χ^2) according to the categories of woody plant cover change: VI increase, VI decrease, VI no-change	
	ChiSquare	Prob>ChiSq
Soils	2,704	0,6084
Geomorphology	17,219	0,0018*
Land-use, land-cover	93,837	<0,0001*
Land-use practices	160,818	<0,0001*

3.6.1 Woody plant cover change and geomorphology

The difference in the independence of the correspondence analysis is explained at 83% by the dimension 1 of the graph which contrasts the sites in decrease of vegetation index with those in increase and no-change of vegetation index (Figure 9). Dimension 2, which explains 17% of the difference in the independence, contrasts sites with an increase of vegetation index with those with vegetation index no-change. The distribution of the modalities of the two variables shows that the decrease in the vegetation index is observed preferentially on the mounds while the shallows are the places of preference for vegetation index increase (Figure 9).

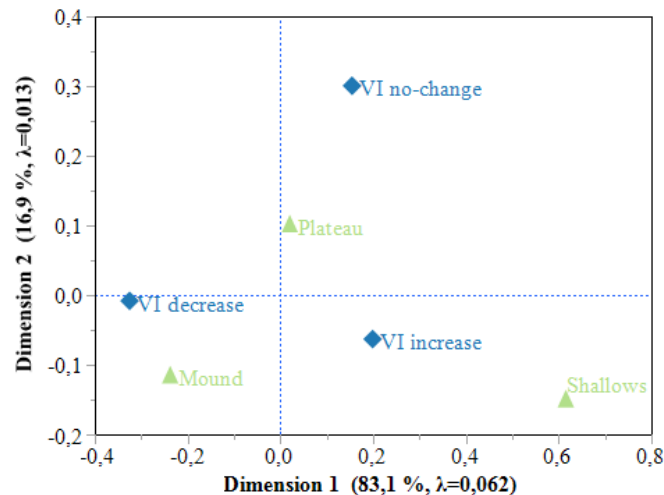


Figure 9: Correspondence Analysis between woody plant cover change and geomorphology.

3.6.2 Woody plant cover change and land-use, land-cover

The Correspondence analysis shows that the sites with increasing vegetation index are opposed to those with decreasing and no-changed vegetation index by the dimension 1 which explains 99% of total inertia (Figure 10). The distribution of the modalities of the two variables shows that the

increase in the vegetation index is more attached to agroforestry park but also to natural vegetation (steppes, savannah, riparian forest, or conserved area) (Figure 10). The decrease and no-change of the vegetation index, on the other hand, is preferably observed on no-vegetation area (habitation area, bare land and water surface) (Figure 10).

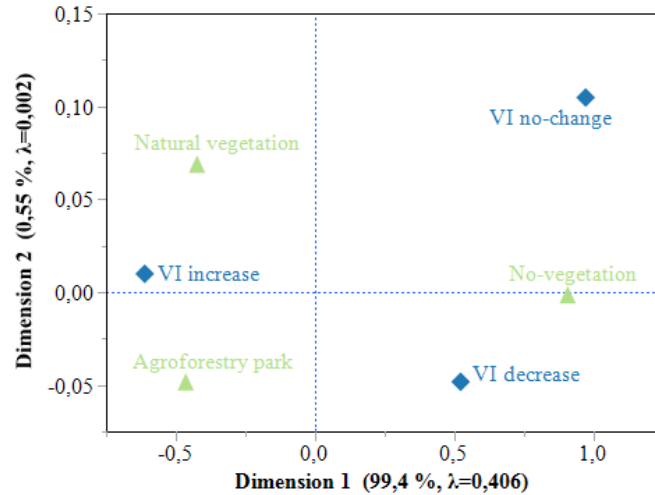


Figure 10: Correspondence Analysis between categories of woody plant cover change and land-use, land-cover. Natural vegetation: Savannah, Steppe, Riparian forest, Conserved area; No-vegetation: Bare land, Habitation, Water surface.

3.6.3 Woody plant cover change and land-use practices

The sites in increase of vegetation index are opposed to those in decrease and no-change of the vegetation index by the dimension 1 of the graph of correspondence analysis which explains the quasi-totality of the total inertia observed (Figure 11). The sites in increase of vegetation index are characterized by the CES/DRS and Plantation/RNA practice groups (Figure 11), dominated by the practices of zai, Stones row, Grass strips on one side, and planting and assisted natural regeneration on the other (Figure 4). Rather, practices with high potential for wood degradation characterize sites with decreasing and no-changed vegetation index (Figure 11).

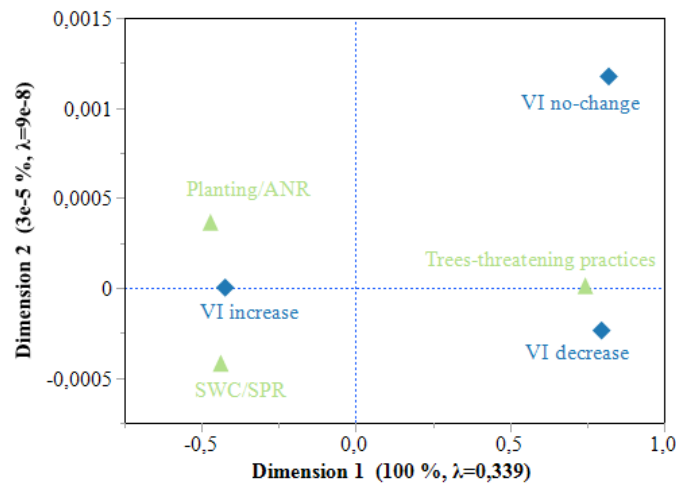


Figure 11: Correspondence Analysis between woody plant cover change and land-use practices. Planting/ANR: Assisted natural regeneration, Planting, Fallow; SWC/SPR : Animal parking in the field, Earth bunds, Grass strips, Half-moons, Mulching, Organic amendments, Stones dyke barrier, Stones row, Vegetated earth bunds, Vegetated Stones row, Woody strips, Zai; Practices threatening trees: Agricultural expansion, Bush fires, Gold panning, Pasture, Urban development, Wood harvesting.

4 Discussion

The results of this study show a strong dependence between changes in woody plant cover and variables such as the geomorphology of the area, land-use and land-cover, and land-use practices, in order of increasing importance.

The decrease of woody plant cover is observed preferentially on the mounds, while the shallows are the preferred areas of improvement of woody plant cover. This emergence of vegetation at the bottom of the slope at the expense of heights is widely observed in many landscapes (Sherratt, 2015; Baartman et al., 2018). Lateral drainage and accumulation of sediment, nutrients and water at the bottom of slopes are favourable to plant germination, survival and development (Gerardin and Ducruc, 1990; Xu et al., 2017).

The improvement of woody plant cover in agroforestry parks is facilitated by the forestry potential of agricultural practices (SWC/SPR) largely developed in the Sahel after the 1970s–1980s droughts to cope with climatic and environmental constraints (Reij et al. 2005; Botoni and Reij 2009; Reij et al. 2009). The improvement of woody plant cover can also be explained by the growing awareness of the socio-economic and ecological roles of ligneous plants in adaptation to climate change (diversification of income sources, food, energy, crafts, soil fertility, spirituality, climate regulation, etc.) (Brandt et al., 2016; Sanou et al., 2019). In addition, the scarcity of forest reserves with forest products (woody and not) (FAO, 2010), has led people to plant and/or maintain woody trees on their farms. Trees on farm are therefore increasingly included in the family patrimony on which the farmer exercises a right of ownership. Woody species such as *Piliostigma reticulatum* and *Guiera senegalensis* once marginalized are valued and help to protect and restore soil fertility on farms (Bationo, et al., 2012).

Land-use and land-cover, and land-use practices are anthropogenic variables that fall under land management forms and are interrelated (Breu et al., 2011). They reflect the human will and reveal the important role of man in the evolution of the ecological trajectory of ecosystems (Carter et al., 2014; Hull et al., 2015). In many situations, man is perceived as a factor of degradation because of the pressures he exerts on natural resources (Ghazoul, 2013; Shoko et al., 2015). However, despite an increase in the population of the study area (INSD, 2016), the area is experiencing an improvement in woody plant cover since the end of 1970s–1980s droughts. This trend observed in this part of the Sahelian area, composed mainly of agropastoralists, testifies to the strong resilience and adaptability of the populations (Epule et al., 2017). The human, socio-economic and environmental damage of the 1970s–1980s droughts (Bonnecase, 2010; Brandt et al., 2014; Doso-Jnr, 2014) have quickly forced people to improve their production and natural resources management of systems (Reij et al., 2005; Olsson et al., 2005; Reij and Garrity, 2016). The agricultural practices described above, which have a high potential for woody plant regeneration, have been developed and characterize the areas in improvement of woody plant cover. Although practices that compromise the establishment and development of trees are also observed in these areas (improving woody plant cover), they are not important enough to lead to degradation. Conversely, in areas with decreasing woody plant cover, practices with high potential for woody plant regeneration are sometimes observed but are not important enough to prevent degradation. As in any socio-ecological system, the dynamics of the area operates according to the state of the system in the direction of the dominant variables (uncontrolled natural phenomena and management decisions) (Petrosillo et al., 2015; Elsayah et al., 2017).

The lack of correlation between changes in woody plant cover and rainfall observed in this study is also observed elsewhere (Bégué et al., 2011; Huber et al., 2011). Similar results were observed in the Sudano-Sahelian area in Mali by Bégué et al. (2011), which show a lack of a clear trend of recovery of rainfall with, however, a strong increase in the vegetation index between 1982–2006. The same observation is made for a large part of Senegal which records between 1982–2007, a significant greening with however a non-significant increase in rainfall (Huber et al., 2011). These results suggest that above a minimum rainfall threshold, agrosylvopastoral and socio-ecological practices further determine woody plant regeneration. Water availability remains one of the determining factors in the development of plants in the Sahel (Doso-Jnr, 2014; Epule et al., 2014). A deterioration in floristic diversity was ob-

served in the Sahel after 1970s–1980s drought compared to the pre-drought situation (Gonzalez et al., 2012; Epule et al., 2014). Plants are therefore not insensitive to the resumption of rainfall, but once a minimum threshold is reached, its effect is eclipsed by that of land-use and management practices. The improvement of plant cover on natural vegetation more prone to degradation actions is moreover to be attributed to the pedoclimatic conditions mainly. This confirms the results and observations of other authors (Borja, 2014; Bose et al., 2016; Brandt et al., 2018).

Although the dependence between changes in woody plant cover in agrosystems and the pedoclimatic factors is not statistically significant, they are crucial in the dynamics of flora and vegetation (Borja, 2014; Bose et al., 2016). The soil serves as a support, a reservoir of water and provides the mineral elements necessary for plant growth (Rovero, 2017). Kusserow (2017) has concluded in his work that soil types are mainly responsible for the recovery of vegetation in the African Sahel. The dominance of a single soil class (Poorly evolved soils) in the study area could justify the independence between soils and change in woody plant cover observed.

5 Conclusion

In agrosystems, rainfall alone is not sufficient to explain the dynamics of woody plant cover. Agricultural and social practices related to the dynamics of farmer perceptions play a key role. These practices can be more decisive than rainfall in the establishment and development of woody plants. This highlights the central role of man in the fight against desertification and land degradation. Practices with high potential for woody plant regeneration are commonly observed throughout the study area even in areas of decreased woody plant cover. But on the latter, harmful practices to tree development are more important and lead to degradation. Containing these harmful practices could stimulate the woody plant regeneration of these areas on which the practices with high potential of woody plant regeneration are already implemented. It is therefore important, in order to optimise actions to combat deforestation and land degradation, that the factors likely to influence the adoption of the land-use practices highlighted in this study be explored for a better understanding of the underlying causes of their adoptions. One hypothesis would be socio-economic conditions. The cost of practices, the land status of farms (inheritance, donation, lending and purchase of land), the level of poverty and education of farmers, seem to us to be rather important factors to take into account.

Appendice A

Table 6: Description of land-use practices observed that affect on tree dynamics.

Practices	Descriptions	Role in trees regeneration and development / regression
High potential practices for woody plant regeneration		
Assisted natural regeneration	Assisted natural regeneration is to protect and maintain forest species growing naturally in farms or natural areas	<ul style="list-style-type: none"> · Increases water infiltration, retains soil moisture through to pockets often made around trees · Improves tree nutrition through to the organic matter brought to the associated crops · Increases strength and survival of seedlings through mentoring, protection and monitoring
Animal parking in the farm	Animal parking in the farm consists of nightly stocking of cattle, sheep and goats on farm to improve the manure stock in dry season and fallow land intended for cultivation the following year in the rainy season	<ul style="list-style-type: none"> · Manure brought is generally rich in forest seeds · Increases water infiltration, retains soil moisture through improved soil structure · Improves soil fertility and tree nutrition

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Table 6 – continued from previous page

Practices	Descriptions	Role in trees regeneration and development / regression
Earth bunds	Earth bunds are compacted earth structures in the form of low walls aligned along the contour lines generally	<ul style="list-style-type: none"> · Slow water runoff and facilitate the trapping and germination of forest seed · Increase water infiltration and retain soil moisture · Facilitate accumulation of organic debris, and thus improve soil fertility and tree nutrition
Fallow	Fallow-land consists of leaving land under agricultural holding for a longer or shorter period of time	<ul style="list-style-type: none"> · Slows water runoff and facilitates trapping and germination of forest seed due to the high density of plants that constitute a biological barriers · Increases water infiltration, and retains soil moisture due to the high density of plants that create a screen effect reducing evaporation and improving soil structure through their root systems · Improves soil fertility due to decomposition of growing plant biomass and tree nutrition
Grass strips	Grass strips are biological barriers made up of herbaceous plants (<i>Andropogon gayanus</i> , <i>Andropogon ascinodis</i> , and <i>Pennisetum pedicellatum</i> generally), installed in farms following the contour lines generally	<ul style="list-style-type: none"> · Slow water runoff and facilitate the trapping and germination of forest seed · Increase water infiltration and retain soil moisture · Facilitate accumulation of organic debris, and thus improve soil fertility and tree nutrition
Half-moons	Half-moons are structures of compacted earth or stones in the shape of a semi-circular with openings perpendicular to the direction of water flow and arranged in quinconxes; the earth inside the half-moons is enriched in organic manure	<ul style="list-style-type: none"> · Manure brought is generally rich in forest seeds · Half-moons facilitate the trapping and germination of forest seeds carried by run-off water · Increase water infiltration, and retain soil moisture · Improve soil fertility and tree nutrition
Zai	Zai consists of digging pits of 0.7 to 1.2 m distant during the dry season, introducing organic manure and then waiting for the rains to disseminate the agricultural seeds in the middle of these pits	<ul style="list-style-type: none"> · Manure brought is generally rich in forest seeds · Pits facilitate the trapping and germination of forest seeds carried by run-off water · Increases water infiltration, and retain soil moisture · Improves soil fertility and tree nutrition
Mulching	Mulching consists of covering the soil with a layer of grass (<i>Loudebia togoensis</i> generally) or with branches or crop residues (millet or sorghum) to ensure soil cover	<ul style="list-style-type: none"> · Facilitates the trapping and germination of forest seeds carried by run-off water · Increases water infiltration, and retain soil moisture · Improves soil fertility due to the decomposition of plant debris and tree nutrition
Organic amendments	Organic amendments consist of the application of organic manure coming from cowsheds, composting, and household waste	<ul style="list-style-type: none"> · Manure brought is generally rich in forest seeds · Increases water infiltration, retains soil moisture through improved soil structure · Improves soil fertility and tree nutrition
Planting	Tree planting consists of planting seedlings on farms or sylvo-pastoral areas	<ul style="list-style-type: none"> · Increases the number of standing trees available
Stone dyke barriers	Stone dyke barriers are mechanical structures composed of stones placed upstream of a gully head to stop the gully erosion and allow a lowland farming	<ul style="list-style-type: none"> · Slow water runoff and facilitate the trapping and germination of forest seed · Increase water infiltration and retain soil moisture · Facilitate accumulation of organic debris, and thus improve soil fertility and tree nutrition
Stones row	Stones rows are mechanical structures composed of stones aligned along contour lines generally	<ul style="list-style-type: none"> · Slow water runoff and facilitate the trapping and germination of forest seed · Increase water infiltration and retain soil moisture · Facilitate accumulation of organic debris, and thus improve soil fertility and tree nutrition

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Table 6 – continued from previous page

Practices	Descriptions	Role in trees regeneration and development / regression
Vegetated earth bunds	Vegetated earth bunds are compacted earth structures in the form of low walls aligned along the contour lines generally and associated with woody or grassy strips	<ul style="list-style-type: none"> · Slow water runoff and facilitate the trapping and germination of forest seed · Increase water infiltration and retain soil moisture · Facilitate accumulation of organic debris, and thus improve soil fertility and tree nutrition
Vegetated Stones row	Vegetated stones rows are mechanical structures composed of stones aligned along contour lines generally and associated with woody or grassy strips	<ul style="list-style-type: none"> · Slow water runoff and facilitate the trapping and germination of forest seed · Increase water infiltration and retain soil moisture · Facilitate accumulation of organic debris, and thus improve soil fertility and tree nutrition
Woody strips	Woody strips are biological barriers consisting of trees and shrubs, installed in farms following the contours lines	<ul style="list-style-type: none"> · Slow water runoff and facilitate the trapping and germination of forest seed · Increase water infiltration and retain soil moisture · Facilitate accumulation of organic debris, and thus improve soil fertility and tree nutrition
High risk practices for woody plant decrease		
Agricultural expansion	Agricultural expansion consists of clearing a wooded area of trees to increase the cultivated area of an existing farm or to develop a new farm	<ul style="list-style-type: none"> · Destroys plants (fires, cutting and uprooting of standing trees) · Destroys soils: reduced soil fertility due to loss of soil organic matter, exposure to runoff, erosion and leaching · Reduces soil water infiltration and water availability due to degradation of soil structure, loss of soil biomass and intense evaporation favoured by soil exposure
Bush fires	Bush fires are fires of natural (lightning) or human (intentional or unintentional) origin that spread over forested areas	<ul style="list-style-type: none"> · Destroy plants · Destroy soils: reduced soil fertility due to loss of soil organic matter, exposure to runoff, erosion and leaching · Reduce soil water infiltration and availability due to degradation of soil structure, loss of soil biomass and intense evaporation favoured by soil exposure
Gold panning	Gold panning refers to the artisanal gold mining and research activities that sometimes occurs in wooded areas	<ul style="list-style-type: none"> · Destroys plants (fires, cutting and uprooting of standing trees) · Pollutes soils and intoxicates plants · Destroys soils: reduced soil fertility due to loss of soil organic matter, exposure to runoff, erosion and leaching · Reduce soil water infiltration and availability due to degradation of soil structure, loss of soil biomass and intense evaporation favoured by soil exposure
Pasture	Pasture refers to the extensive breeding of sheep, goats and cattle in silvo-pastoral areas	<ul style="list-style-type: none"> · Destroys plants · Could, when the carrying capacity of pastures is not exceeded, contribute to woody regeneration through the dissemination of seeds and the fertilization of rangelands
Urban development	Urban development here refers to the expansion of cities at the expense of wooded areas	<ul style="list-style-type: none"> · Destroys plants (cutting and uprooting of standing trees) ·
Wood harvesting	Wood harvesting refers to the exploitation of firewood for household consumption needs mainly	<ul style="list-style-type: none"> · Destroys plants · Destroys soils: reduced soil fertility due to loss of soil organic matter, exposure to runoff, erosion and leaching · Reduces soil water infiltration and water availability due to degradation of soil structure, loss of soil biomass and intense evaporation favoured by soil exposure
(Reij et al., 2005; Botoni and Reij, 2009; Bationo et al., 2012; Mbow et al., 2014; Reij and Garrity, 2016; Epule et al., 2017)		

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