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Scientific documentation of crop land changes in the Sahel: A half empty box of knowledge to support policy?

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ABSTRACT

The Sahel has been subject of considerable environmental research and development efforts, specifically since the droughts of the 1970s and 1980s. This article uses a meta-study approach to summarize knowledge of crop land change, the documented driving forces, and the perceived impacts. The analysis of case studies shows that crop land has increased in the majority of cases mainly due to population increase. However, despite population increase, crop land has been stable in some areas, particularly where land availability is a limiting factor or where farmers are able to intensify their farmers from expanding their plots or because households have diversified their activities. The study shows the huge gap in the scientific literature concerning actual measurements of crop land change in the Sahel, which is in contrast to the attention given to crop land changes in theoretical and policy discourses. On the basis of the poor documentation available on crop land change and the contrasting results observed, we point out the need to exercise caution with regard to simple narratives about crop land change.

1. Introduction

Land use and land cover changes are closely interconnected in multiple and bidirectional ways to changes in local livelihoods and the provision of ecosystem services (carbon, biodiversity, water, etc.). As such, they have become recognized over the last 15 years as important global environmental changes in their own right (Turner II, 2002). Since the Rio summit in 1992, the conceptual perspectives of land use and land cover transitions have been increasingly dealt with by land change science (DeFries et al., 2004; Foley et al., 2005; Turner et al., 2007), and the notion of proximate and underlying driving forces has been broadly accepted as a useful way of framing the analysis of land use and land cover change processes (Geist and Lambin, 2002; Lambin and Geist, 2006). In the course of the last three to four decades a range of environmental policies has been concerned with sustainable land use and natural resource management systems, e.g. in the Sahel. Significant, internationally initiated policy documents, such as the National Environmental Action Plans (from the 1980s), National Adaptation Plan of Action (from the 2000s) or the Great Green Wall Initiative (signed in 2010), are prominent examples. The most recent efforts have accentuated the action needed in response to expected climatic changes, the emerging global food shortage, and the accelerated competition for global land resources. They consider, among other issues, land use changes and their relation to multiple driving forces (Reenberg, 2012). With the increased awareness of the accelerating exposures of changes in climate, population pressure, and globalization processes affecting local livelihoods in the Sahel, research on land use and land cover change has become more prominent, not least in regard to regions characterized by economic poverty and low agricultural productivity.

The Sahel region, a salient dryland region, has been the subject of considerable policy efforts. Especially, the severe droughts in the 1970s and 1980s drew much attention to this specific region and gave impetus to policy action. Sahelian and Sudano/Sahelian countries created the Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS) to improve food security and reduce the impacts of desertification through a range of activities, such as development and harmonization of national strategies and policies to reduce desertification, scientific and technical cooperation, collection and distribution of information, capacity enhancement, and guidance for policy formulation.

The urgent need to provide recommendations for policy makers also boosted research projects aimed at identifying the possible causes and consequences of land use change and desertification. It has, however, been noted that scientific knowledge was produced and communicated to the policy domain in such a way that the

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salience of knowledge (i.e. the relevance to the stakeholders) was given priority over legitimacy (i.e. unbiased with respect to values) and credibility (i.e. based on adequate scientific evidence) (Grainger, 2009). A closer look at the environmental policy initiatives is rather disappointing with regard to how the most recent scientific knowledge has, in general, been communicated to the policy domain (Reenberg, 2012). More specifically, the environmental policy discourse at the regional level is fuelled by well-established field expansion and land degradation narratives. These include, for example, the image of vicious circles of crop land encroachment and land degradation, prompted by population pressure and low rainfall, leading to excessive expansion of fields onto marginal land, which in turn leads to irreversible degradation of the natural resource base, lower productivity, and the need for larger areas to sustain the population. Such narratives about field expansion and land degradation have become established truths beyond need for further documentation (Reenberg, 2012). Scattered empirical evidence from recent rapid assessments (Bolwig et al., 2008; Rasmussen and Reenberg, 2012; Reenberg, 2009) suggests that land use and land cover change in the drier part of the Sahel may not correspond well to the simplistic notion of more people/less rain indisputably leading to vicious circles of field expansion and soil degradation. Our theoretical understanding of land use changes in the Sahel seems thus to be based on fragmented and poorly coordinated empirical knowledge. Several authors have suggested that the prevailing droughts during the second half of the twentieth century were at least partly caused by land use and land cover changes in tropical and subtropical Africa (Pielke, 2005; Zeng et al., 2001); hence the question, 'Do humans cause deserts?' (Reynolds et al., 2007). Recent literature, however, also urges caution and advises critical examination of received wisdom in order to avoid misinterpretations of the processes of change and the likely future directions (Mortimore and Turner, 2005; Rasmussen et al., 2012).

Empirical evidence of the significance of various factors of change seems to be sparse and not synthesized in any systematic manner. Thorough insight into trends and dynamics of land use and land cover trajectories is an important knowledge basis for the formulation of future sustainable land use strategies and policies (Pare et al., 2008). Yet there may be a need to highlight the possible "black boxes" in our understanding of land use and land cover changes. On the same token, environmental policies should be informed by accurate knowledge of the different drivers of change and their impacts on environment, agriculture and food security. This article uses a meta-analysis approach to scrutinize the total pool of peer-reviewed articles on crop land dynamics in the Sahel. The cumulative knowledge that emerges from the scientific literature is explored through the following guiding questions: 1. What do empirical case studies document about crop land expansion and contraction in the Sahel since the 1950s?; 2. What seminal variables do scientific papers propose as drivers of crop land changes?; and 3. What are the impacts associated with crop land change? The paper is organized as follows: First, we provide a brief overview of the dynamic patterns that characterize livelihoods in the Sahel. This is followed by a description of the methods employed for the collection of published data and of the statistical analysis used to synthesize the causal explanations. The results section provides an overview of the accumulated insight into crop land change in the Sahel, the suggested important drivers, as well as observed impacts that can be drawn from the case studies.

2. Background: changing patterns in the Sahel region

The Sahelian regions span a large territory, 500 km deep and 300 km wide (Raynaut, 1997), and any generalizations will not suffice to adequately describe environmental, economic, socio-cultural, and political conditions that enable and constrain the contemporary land use practices. As a background, this section will, nevertheless, briefly mention some of the most prominent traits of the development of change, which have had a bearing on the Sahelian land use strategies in the past decades. We do not aim to provide a full elaboration, but rather to give some examples of the complex causal relations that need to be considered in order to fully explore the changes in the land system. Issues related to the exposures of population pressure, climate change and economic integration as well as land rights and conflicts are briefly described.

2.1. Population increase

The Sahel region experienced one of the world's highest demographic growths from about 1.5% yr^{-1} in the 1950s to about 3% yr^{-1} in the 1990s, which has resulted in a three-fold increase in the population in the second part of the 20th century (Raynaut, 2001). In Burkina Faso alone, the total population increased from 5.6 million inhabitants in 1975 to 13.7 million inhabitants in 2006 (INSD, 2007); it is estimated that 90% of the population practice rain-fed subsistence agriculture. Population pressure has often been suggested as the root cause of land degradation (e.g. Geist and Lambin, 2004) although more nuanced explanations have also been put forward (e.g. Mazzucato and Niemeijer, 2002). The strong demographic growth has been supported by an increase in the surface area of rain-fed cultivated lands at the expense of the natural woody savannah (Raynaut, 2001; Ringrose and Matheson, 1994). The sometimes rapid increases in the size of local human populations are often linked to the in-migration of cultivators into rangelands or regions with large-scale irrigation schemes, or of herders into marginal sites, and not only to the intrinsic population growth (Geist and Lambin, 2004). Repeated droughts and low soil productivity have often been cited as major factors pushing people to leave their villages (Cordell et al., 1994; Marchal, 1977). A link between environmental conditions and migration was indeed documented in several settings in rural Africa (Ethiopia (Ezra, 2001); Mali (Findley, 1990)).

2.2. Climate variability

There is increasing evidence that climate change is strongly affecting the African continent and will be a challenging issue in future development, particularly in the drier regions (Adger et al., 2007; Haile, 2005; Huq et al., 2004). The likely impacts of climate change on ecosystem services, agricultural production, and livelihoods will represent a challenge to the adaptation strategies in a region dominated by economic poverty, subsistence food production, and a low and highly variable natural production potential. Climate variability in the Sahel was characterized by negative anomalies from 1910 to 1916, positive anomalies from 1950 to 1967, negative from 1970 to 1974, and finally, another period of negative anomalies lasting from 1976 to 1993, the longest and most intense of the century (L'Hôte et al., 2002). Although Sahelian populations are accustomed to drought, as historical accounts and oral histories reveal (Rains, 1983; Watts, 1983), the droughts of the 1970s and 1980s were significant because of their severity, but also because they prompted profound economic and political reforms and extensive international assistance. Recent "rainy years" such as 1994, 1999, 2003, and 2005 could be seen as a comeback of good rainfall years, but models projecting future rainfall trends have provided unclear answers as to whether the climate will become more arid or more humid (Christensen et al., 2007). What characterizes the region is moreover not an average total annual rainfall but a high degree of spatial and temporal variability in precipitation. Rainfall trends and variability affect – directly or indirectly – various other variables, such as rain-fed crop productivity, vegetation and soil degradation processes, reduction in the quality and quantity of ecosystem services, human livelihoods etc. (Boko et al., 2007).

2.3. Market orientation

During the colonial period, a shift from subsistence to cash crop production was observed in many Sahelian countries. For example, the decision by the colonial government in Senegal to introduce groundnut in the 1840s was a significant landmark for environmental change. The expansion of agriculture, dominated by groundnuts, resulted in the reduction of fallow land and savanna vegetation in this part of Senegal. Another example is the "new cotton basin" in Mali, an area where the government pushed for expanded production related in part to declining yields in the old cotton basin (Koutiala and Sikassou Districts). Since the creation of the CMDT (Compagnie Malienne pour le Dévelopement du Textile) in 1974, cotton production has increased markedly with policies that guaranteed purchase, a fixed floor price, and credit for agricultural inputs. Despite the often mentioned "cash crop revolution", the so-called "Peanut Basin" of Senegal and the "New cotton basin" in Mali provide telling illustrations of partial intensification paths and farmers' possible soil mining. Indeed, Sahelian farmers' use of improved inputs and equipment (such as fertilizers, fungicides, improved seeds, and animal traction) stagnated or declined during the 1980s and 1990s, when the process of structural adjustment triggered a thrust towards liberalization and privatization of the agricultural sector, including the removal of price controls, the lifting of restrictions on input markets, the disengagement of the state from providing services, and the devaluation of the West African franc. However, locally prominent examples in West Africa provide evidence of environmental improvement and agricultural intensification with traditional inputs (shorter fallows, increasing levels of labour, organic fertilizer and manure use, soil conservation measures, crop residue management practices). Studies in the Kano Close-Settled Zone and nearby areas of Nigeria and Niger suggest that farmer investments in the land have led to agricultural intensification with positive consequences for the environment and economy (Adams and Mortimore, 1997). Reij et al. (2005) also found that faced with drought and declining yields in the 1980s, farmers from the Central Plateau in Burkina Faso began to experiment with various soil and water management practices (SWM). Their major objective was rehabilitation of the productive capacity of the land through better control of rainfall and runoff, as well as through improved soil fertility management and reforestation. By 2000, thousands of hectares of farmland had been treated with SWM, leading to reclamation of barren land, a crop yield increase of 50–60%, better water availability, and larger tree cover in the fields.

2.4. Diversification of local economies

The role of agriculture for people's livelihoods in the Sahel is changing due to increased livelihood diversification, particularly outside of agriculture (Ashley, 2000). Rural livelihood diversification can imply a change from agricultural to non-agricultural activities or it can be defined as "…the process by which rural households construct an increasingly diverse portfolio of activities and assets in order to survive and to improve their standard of living" (Ellis, 2000). In recent years, a number of studies on livelihood diversification have been published (Ellis, 2000; Ellis and Mdoe, 2003). Non-agricultural income forms a significant part of diversification and it has been reported by some to have increased in importance in many parts of sub-Saharan Africa (Bryceson, 1996; Savadogo et al., 1998). In the Sahel, most non-agricultural livelihood diversification is restricted to the dry season. According to Mortimore (1998), on-farm diversification strategies are often sparse, unlike off-farm strategies, such as working in major cities or on agricultural schemes, and self-employment in small enterprises. In central Sudan, non-agricultural diversification and off-farm activities have increased over the last 30 years through labour migration, development projects, horticulture, small-scale commerce – especially by the women – and livestock sales (Elmquist and Olsson, 2005). In northern Burkina Faso, temporary migration is also one of the diversification strategies observed (Nielsen and Reenberg, 2010).

2.5. Land use conflicts

During the last few years, violent land use conflicts in the Sahel have become the most popular example of the alleged link between global climate change and conflict. It is often argued that the idea that climate change leads to violent conflict in general can be regarded as a continuation or revised version of the Malthusian concept of resource scarcity as a cause of environmental degradation, poverty, and an escalating struggle for resources (Homer-Dixon, 1994). The juxtaposition of communities with different lifestyles and economic activities and the ongoing agrarian changes (modernization) in Sahelian societies are mentioned as possible sources of conflict (Benjaminsen and Ba, 2009). There is a body of case study literature that focuses on the relationship between farmers and herders in Africa (e.g. Bassett, 1988; Benjaminsen and Ba, 2009; Moritz, 2008; Turner, 2004). Strategies of agrarian modernization and of converting mobile people into 'productive' sedentary farmers have been criticized by these scholars pointing out that the causes of conflicts often have a political origin. Policies that underestimate the pastoral productivity and pastoral contribution to the national economy (Hesse and Cotula, 2006) and overestimate the negative impacts of grazing on the ecology (Behnke and Scoones, 1993; Ellis, 1988; Turner, 1999) contribute to the ongoing process of pastoral marginalization.

3. Cropping decisions: theoretical perspectives

Land use practices are known to be closely linked to especially the population (Turner et al., 2007), and the use of land has been dealt with in length in the literature about agrarian change (e.g. Bilsborrow and Ogendo, 1992; Boserup, 1965; Netting, 1993). The theoretical scholarship on the population–agricultural change nexus has notably been anchored in two seminal works. One is Thomas Malthus's (1798) essay on the intrinsic imbalance between population growth rates and food production. The other is the book by Esther Boserup (1965) that suggests that farmers in 'primitive' agricultural systems tend to produce below the maximum because this allows for the optimal input–output efficiency. The conceptual frameworks suggested by Malthus and Boserup have had a huge impact on various scholars who have addressed the issue of how and why agricultural change and land use intensification occur. Although the models are contestable simplifications of real world situations, they have nevertheless provided a constructive starting point from which to discuss the complexity of agricultural change and land use trajectories. A number of classic studies (e.g. Adams and Mortimore, 1997; Netting, 1993; Turner et al., 1977, 1993; Wiggins, 1995) have provided empirical documentation, which supports the perception that Boserup's model fits fairly well for land use systems that rely on land and labour extensive methods when land is abundant. More recent research emphasizes a number of economic, social or political factors that shape land use change beyond what is implicitly assumed in Boserup's simple model

(Stone, 2001). The possible effect of population factors may be overshadowed by other factors; market access may, for example, play a significant role in the change trajectories when the land use system becomes part of a larger, spatial setting (Netting, 1993). Political ecologists, like Blaikie and Brookfield (1987), specifically note that even under seemingly similar ecological and socio-economic conditions, population pressure may prompt very different patterns of agricultural change because of differences in farmers' ability to invest, withstand risk and attract subsidies. Hence, there is substantive support for the view that population pressure does not work in an unmediated fashion (Keys and McConnell, 2005). The internal demographic growth becomes part of a larger picture that encompasses seasonal, generational and permanent flows of labour and consumers, as well as of knowledge, skills and priorities of immigrants. This can give the occasion of change in cropping choice in space and time (Reenberg, 1999). Intensification policies, conflicts, and diversification opportunities may also influence crop land changes regardless of the population changes.

4. Methods

Our methodology is based on a meta-analysis of case studies used to collect data on land cover changes (particularly crop land), drivers of change, and impacts on livelihoods and the environment. The data was used to compute a cluster analysis to group case studies according the main drivers of crop land change and a canonical variate analysis to determine the drivers that best explain the increase, decrease, or stability of crop land change. Finally, we used a qualitative comparative analysis to determine the combination of impacts observed when crop land increases, decreases, or remains stable.

4.1. The meta-analysis

Our meta-analysis follows what Lambin and Geist (2006) call *a posteriori* comparison of already published case studies. In accordance with Rudel (2008) we use the term 'meta-analysis' loosely to refer to any systematic attempt to investigate patterns across a set of studies (as opposed to others that see meta-analysis as involving a direct pooling of data). Using a meta-analytical approach implies a set of important decisions. First, an operational definition of which studies (cases) should be included in the analysis must be decided upon; second, coding procedures must be selected; and finally, which variables to include must be determined.

As the **operational definition** of the phenomenon under study we selected 'peer-reviewed journal papers from the Sahel region, specifically utilizing a longitudinal approach to study *trends* in crop land change, but also describing *drivers* and *impacts* of these changes on the environment, agricultural practices and local livelihoods'. All case studies considered were published from 1990 to 2010, representing changes occurring between 1950 and 2010. In order to identify publications relevant for this specific study we used the ISI Web of Knowledge database searching for 'Sahel' with the word 'land use'. We then searched for additional papers using the combinations 'Sahel' + 'crop land' or 'Sahel' + 'land cover'. Subsequently, we used the same words in combination with the names of each of the Sahelian countries and added any paper that was not already included in the list obtained using 'Sahel'. A detailed screening of the texts allowed us to remove papers that were not associated with crop land change processes in the Sahel. This selection process allowed us to focus on the identification of the causality links between drivers of change and crop land change. To avoid the potential draw back of leaving aside important information on specific themes (e.g. methodological aspects of remote sensing techniques, hydrological or carbon related themes, changes in woodland extent, and land degradation) we used the content of these papers for the background section and for the interpretation and discussion of results. In this fashion, we have tried to adopt an iterative routine in which we cycle back and forth between the rigorous material and the more qualitative material in the case studies (as advised by Rudel, 2008). In addition, and to acknowledge the contribution of francophone authors, we searched for scientific journal articles using two main French databases: "Agritrop" (developed by CIRAD) and "Horizons Pleins Textes" (with publications from IRD). The same geographical key words were used in combination with "utilisation des sols" or "utilisation des terres".

The **coding procedure** was based on the case study, defined as a geographical site where the changes in the extent of crop land were described. In all the cases presented, changes in crop land proved to be studied by combining information from aerial photographs and satellite imagery, often complemented with information obtained through group discussions or interviews with farmers. Most of the articles presented only one case study, but when a publication described more than one site, each site was entered as an individual case study in our database and treated as such in the subsequent analyses. Case studies were geo-referenced and results were mapped using ARCGIS10 for a better geographic visualization of results.

The **variable selection procedure** for the case studies was developed in an iterative process. After an initial pre-screening, a set of reasonable common denominators of variables to describe our three main themes was decided upon. Changes in the extent of crop land were qualified as: "increase", "decrease", or "stable or fluctuates". Changes in woodland,[1] shrubland, grassland, and bare soil were also qualified in the same way when the information was available. The list of drivers was based on the typology used by van Vliet et al. (2012) and adapted on the basis of information described in the case studies. *Drivers of change* in crop land included demographic, economic, agro-technical, institutional, and climatic drivers (Table 1).

Some of the drivers initially identified were never mentioned in the case studies and were therefore removed from the analysis. Other drivers were mentioned in less than three case studies and were only retained for the descriptive analysis. *Impacts of crop land change* included impacts on livelihoods, on agricultural practices and on the environment (Table 2).

Because the causality links are often reciprocal, the initial list of impacts included the variables used as drivers. The list was then adapted according to the impacts mentioned in the case studies.

4.2. Analysis of data

The analysis of data is based on three main approaches: 1) a simple description of changes in crop land; 2) a cluster analysis to identify the combination of drivers that best explain changes in crop land, complemented by a canonical variate analysis to identify the best predictors of crop land change, and 3) a qualitative comparative analysis to understand which combinations of impacts resulted from the increase, decrease, or stability of crop land.

4.2.1. Description of crop land change

Changes in crop land were mapped to show the geographic location of case studies and the respective trends in crop land change. Changes in crop land were also described in relation to changes in other land cover types.

[1] Definitions of woodland, shrubland and bare soil were not necessarily exactly the same in all case studies. Here we use woodland and shrubland as defined by the authors of the papers.

Table 1
Variables used to describe drivers of crop land change in our case studies.

Abbreviation of variable name	Variable name
Demographic	
Popden	Population density
Mig	In-migration
outMig	Permanent out-migration[a]
Economic	
Road	Road access[a]
Preecon	Presence of economic structures (credit, inputs, projects)
Natmark	Access to national markets
Intmark	Access to international markets
Price	Price changes[a]
Divers	Increased opportunities for diversification in off-farm jobs
Agro-technical	
Newvar	New varieties[a]
Graz	Overgrazing[a]
Soildeg	Soil degradation[a]
Plough	Introduction of plough
Fert	Increased use of fertilizers
SWMP	Presence of soil and water management practices
Irrig	Irrigation systems[a]
Labor	Lack of labour force[a]
Land	Land scarcity[a]
Institutional	
Preenv	Presence of environmental policies[a]
Agripol	Presence of land tenure or agricultural policies
Absagripol	Absence of land tenure or agricultural policies
Climatic	
Rain	Rain availability and distribution
Fire	Fires[a]

[a] Variables that were mentioned in less than three case studies and therefore not included in the multivariate analysis.

4.2.2. *Cluster analysis and canonical variate analysis of drivers of crop land change*

In order to identify the combinations of drivers that best explain the changes observed in crop land extent, we computed a hierarchical cluster analysis (Euclidean distance) of case studies ($N = 40$), with 'drivers of crop land change' as the explanatory variable, using Xlstat 2010®. Cluster analysis is the task of assigning a set of cases to clusters. In our analysis, the cases are grouped according to the main drivers of change in crop land extent, and the distance between groups (assessed using Ward's method) represents the likelihood that a similar combination of drivers applies to the cases. The different clusters are represented using a dendrogram, a tree diagram frequently used to illustrate the arrangement of the clusters produced by the hierarchical clustering. In addition to the cluster analysis and in order to investigate which drivers were the best predictors of crop land change, a canonical variate analyses (CVA), also known as discriminant factor analysis, was computed using Xlstat 2010®. CVA can accommodate any metric variable without the strict assumption of normality and is a widely used method for analysing group structure in multivariate data (Hair et al., 1999). CVA makes it possible to identify the variables that differentiate the most between the groups of individuals (based on crop land change, in this case) previously constituted on the basis of an exogenous variable (in this case, drivers of crop land change), thereby minimizing intra-group variance and maximizing the between class variance ratio. Wilks' lambda test is used to test whether there are significant differences between the increase, decrease, or stability in crop land extent based on the drivers of change.

Table 2
Variables used to describe the impacts of crop land changes as described in the case studies.

Variables
Impacts on livelihoods
Permanent out-migration
Increased conflicts
Increased yields
Decreased yields[a]
Increased labour force
Decreased labour force[a]
Increased involvement of women
Impacts on agricultural practices
Introduction of the plough[a]
Increased use of fertilizer
Decrease in fallow period[b]
Increase soil and water management practices[b]
Impacts on the environment
Decreased number of trees in farming plots[b]
No sign of land degradation[a]
Land degradation[b]
Decreased biodiversity[a]
Increased biodiversity
Decreased water availability
Decreased carbon stocks[a]

[a] Impacts never mentioned in our case studies.
[b] Impacts mentioned in more than one case and included in the QCA.

4.2.3. *Qualitative comparative analysis of the impacts of crop land change*

Because of the low number of case studies describing the impacts of crop land change, it was not possible to compute any multivariate analysis to test whether the impacts were significantly different between cases that showed an increase, decrease, or stability of crop land. Qualitative comparative analysis (QCA), computed using FsQCA2008®, was used as a way to understand which combinations of impacts resulted from the increase, decrease, or stability of crop land. Only those impacts that were mentioned in more than one case study were retained for the analysis (e.g. land degradation, increased soil and water management practices, decreased numbers of trees in farming plots, decreased fallows). QCA is normally suited to case-oriented work to analyse complex causations, involving different combinations of causal conditions capable of generating the same outcome. However, the same approach may apply to understand the different combinations of outcomes that are generated by the different causal conditions (crop land increase, decrease, or stability). QCA is particularly useful for research designs involving small and intermediate-size *N*s (e.g., 5–50). It uses Boolean algebra to implement principles of comparison used by scholars engaged in the qualitative study of macro social phenomena. These combinations can be compared with each other and then logically simplified through a bottom-up process of paired comparison (Ragin, 2000).

5. Results

5.1. *Data availability and information gaps*

Despite the high number of pre-selected papers found as described above, only 25 papers were finally selected for the analysis (Table 3). Indeed, many papers from the original pool were irrelevant to the present meta-study either because their focus was on methodological aspects of remote sensing techniques, hydrological or carbon related themes, changes in woodland extent, and land degradation or because they lacked the longitudinal analysis of crop land change that we were looking for.

Table 3
Combination of key words that yielded publications with information on crop land change in specific case studies.

Keywords used for the search		Total number of papers found on the Isi Web	Number of papers finally selected for the study
Land use	Sahel	62	20
Land cover	Sahel	27	1[a]
Land use	Burkina Faso	38	4[a]

[a] Only publications that were not already listed from the search using 'sahel' + 'land use' were added here.

In total, the 25 publications provided crop land change information for 50 case studies in eight Sahelian countries, particularly in Senegal and Burkina Faso (Table 4 and Fig. 1). Only 40 out the 50 case studies reported drivers of crop land change and 17 reported impacts of crop land change.

The fact that 22 (out of the 25 publications) were published after 2000 suggests that there has been an increased attention to land cover change over the last 10 years as compared to the 1990–2000 period. Of the case studies, 40% look at changes happening at the village scale, 40% look at the provincial scale, and 10% look at the landscape level. The majority of our case studies describe slow processes of change over several decades, particularly from 1965 to 2000 (Table 4). Only one study in Mali (Ruelland et al., 2010) and one study in Burkina Faso (Ouedraogo et al., 2009) describe changes until 2005 and 2010 respectively. As a result, changes in land use/cover that have occurred in the last ten years are very poorly documented.

5.2. *Intimate links between crop land change and population trends*

Since the 1960s, crop land has slowly increased in 73% of the case studies, decreased in 6%, and remained stable in 21% of the

Table 4
List of case studies in different countries, type of data provided in the publication and time span of the study. Each line represents a case study. Some publications describe several case studies when crop land trends are described in different geographic locations.

Country	First author and publication year	Publication provides information on:			Time span
		Crop land change	Drivers of change	Impacts of change	
Burkina Faso	Ouedraogo et al., 2009	Yes	Yes	Yes	1975–2010
	Pare et al., 2008	Yes	Yes	No	1985–2000
	Pare et al., 2008	Yes	Yes	No	1985–2000
	Pare et al., 2008	Yes	No	No	1985–2000
	Wardell et al., 2003	Yes	Yes	No	1985–2000
	Reij et al., 2005	Yes	Yes	No	1970–2000
	Reij et al., 2005	Yes	Yes	No	1970–2000
	Reij et al., 2005	Yes	Yes	No	1970–2000
	Wittig et al., 2007	Yes	No	No	1960–2000
	Mazzucato and Niemeijer, 2002	Yes	Yes	Yes	1960–2000
	Reenberg et al., 1998	Yes	Yes	Yes	1960–1990
	Gray, 1999	Yes	Yes	No	1980–1990
	Gray, 1999	Yes	Yes	No	1980–1990
	Barbier et al., 2009	Yes	Yes	Yes	1975–2000
Ghana	Wardell et al., 2003	Yes	Yes	No	1985–2000
Mali	Tappan and McGahuey, 2007	Yes	Yes	Yes	1965–2000
	Tappan and McGahuey, 2007	Yes	Yes	No	1965–2000
	Ruelland et al., 2010	Yes	Yes	Yes	1965–2005
	Ruelland et al., 2010	Yes	Yes	Yes	1965–2005
	Ruelland et al., 2010	Yes	Yes	No	1965–2005
	Ruelland et al., 2011	Yes	Yes	No	1980–2005
	Bégué et al., 2011	Yes	No	No	1960–2000
Niger	Mortimore and Turner, 2005	Yes	No	No	1975–1995
	Wezel and Haigis, 2002	Yes	Yes	Yes	1980–2000
	Leblanc et al., 2008	Yes	Yes	Yes	1960–1990
	Séguis et al., 2004	Yes	No	Yes	1960–2000
	Moussa et al., 2011	Yes	No	Yes	1980–1990
Nigeria	Mortimore and Turner, 2005	Yes	Yes	No	1975–1995
	Mortimore and Turner, 2005	Yes	Yes	No	1975–1995
	Mortimore and Turner, 2005	Yes	No	No	1975–1995
	Mortimore and Turner, 2005	Yes	Yes	No	1975–1995
	Mortimore et al., 1999	Yes	No	No	1960–1990
	Mortimore et al., 1999	Yes	No	No	1960–1990
Senegal	Mbow et al., 2008	Yes	Yes	Yes	1960–2000
	Woomer et al., 2004	Yes	Yes	No	1965–2000
	Wood et al., 2004	Yes	Yes	No	1975–2000
	Tappan et al., 2004	Yes	Yes	No	1985–2000
	Tappan et al., 2004	Yes	Yes	Yes	1985–2000
	Tappan et al., 2004	Yes	Yes	No	1985–2000
	Tappan et al., 2004	Yes	Yes	Yes	1985–2000
	Tappan et al., 2004	Yes	No	No	1985–2000
	Tappan et al., 2004	Yes	Yes	No	1985–2000
	Tappan et al., 2004	Yes	Yes	No	1985–2000
	Tappan et al., 2004	Yes	Yes	Yes	1985–2000
	Tappan et al., 2004	Yes	Yes	Yes	1985–2000
	Tappan et al., 2004	Yes	Yes	Yes	1985–2000
	Tappan et al., 2004	Yes	Yes	Yes	1985–2000
	Mortimore and Turner, 2005	Yes	Yes	Yes	1975–1995
Sudan	Elmqvist and Khatir, 2007	Yes	Yes	No	1960–2000
Ivory Coast	Goetze et al., 2006	Yes	Yes	No	1960–1995

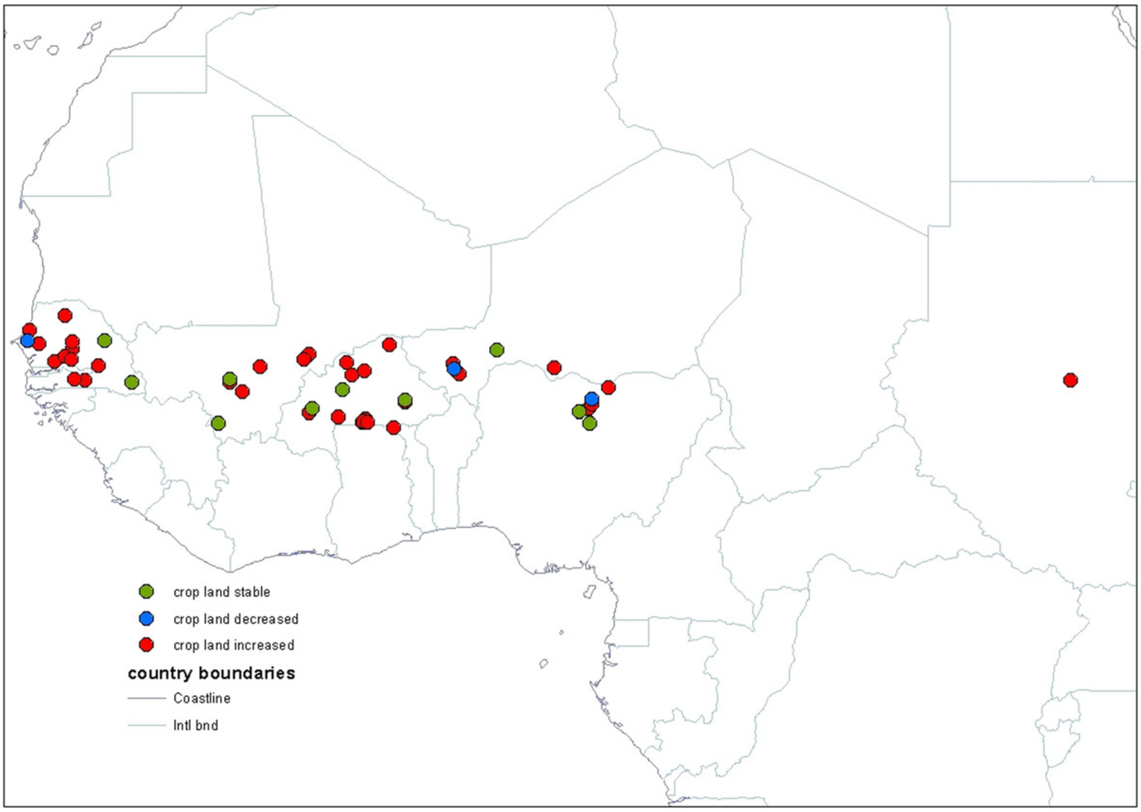


Fig. 1. Geographic location of the 50 case studies used in our analysis and changes in crop land observed.

cases (Fig. 2). Although net changes of each land use type can't be assessed through the available studies, it is possible to assess the relative changes between land use types as fallows: crop land has increased at the expense of shrubland and woodland whereas shrubland has increased at the expense of woodland through forest degradation (Leblanc et al., 2008; Ouedraogo et al., 2009; Ruelland et al., 2010; Tappan et al., 2004; Wardell et al., 2003; Wood et al., 2004).

Crop land increase is observed at sites with a population density increase (Gray, 1999; Leblanc et al., 2008; Mbow et al., 2008; Mortimore and Turner, 2005; Ouedraogo et al., 2009; Pare et al., 2008; Reenberg et al., 1998; Ruelland et al., 2010; Tappan et al., 2004) or where in-migration is observed (Gray, 1999; Mortimore and Turner, 2005; Ouedraogo et al., 2009; Pare et al., 2008; Tappan et al., 2004; Wardell et al., 2003; Wood et al., 2004) (Fig. 3). In southern Burkina Faso, migration started in the 1980s when the severe drought affected the northern and central regions of the country, inflicting significant losses in terms of crops and livestock to farmers (Gray, 1999; Ouedraogo et al., 2009; Pare et al., 2008; Reenberg and Lund, 1998). From that period onwards, migrating to

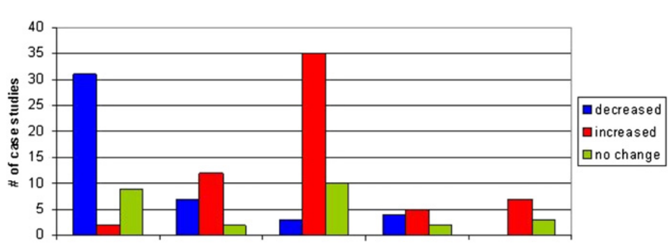


Fig. 2. Changes in crop land and other land cover types.

less drought affected areas (in the south, east, and west of the country) has become an important livelihood diversification strategy. In southern Burkina Faso, the size of crop land increased at an annualized rate higher than 1% during 1986–2002, driven, presumably, by migrant population size and distribution (Ouedraogo et al., 2009; Pare et al., 2008). In Eastern Saloum, Sénégal, rural population grew considerably in many villages between 1958 and 1988, partly due to in-migration for groundnut production launched by the Société Terres Neuves (Mbow et al., 2008). In Maradi, Niger, rapid in-migration and population growth have been identified among the main drivers of land use/cover change, linked to a boom in the production of groundnuts for an export market (Mortimore and Adams, 2001). In southwest Niger, the need to cultivate more millet for the growing population between 1950 and 1992 led to land clearance, firstly on the most favourable terrains on sandy slopes and in clayey valley bottoms, and secondly on more peripheral lands at the expense of the natural vegetation cover (Leblanc et al., 2008). On the land of Sararya Makawi, Sudan, the population density increased from 3 to 20 persons per km^2 between 1969 and 2002, and while cultivated area increased, the cultivated area per capita declined from 7.4 to 1.9 ha capita^{-1} during this period of time. In Kouonbaka, Mali, the growth of the area's population has increased the pressure on arable land (population density rose linearly from 18 to 34 persons per km^2 between 1967 and 2003), mainly related to the increased demand for millet and sorghum production (Ruelland et al., 2010).

Stable crop land despite increased population density is mainly observed in cases where farmers were able to intensify production for international markets (particularly where the plough was successfully introduced) and farmers were able to diversify, or else where arable land had already been saturated. In Southern Mali, a number of agricultural communities have shown a clear indication

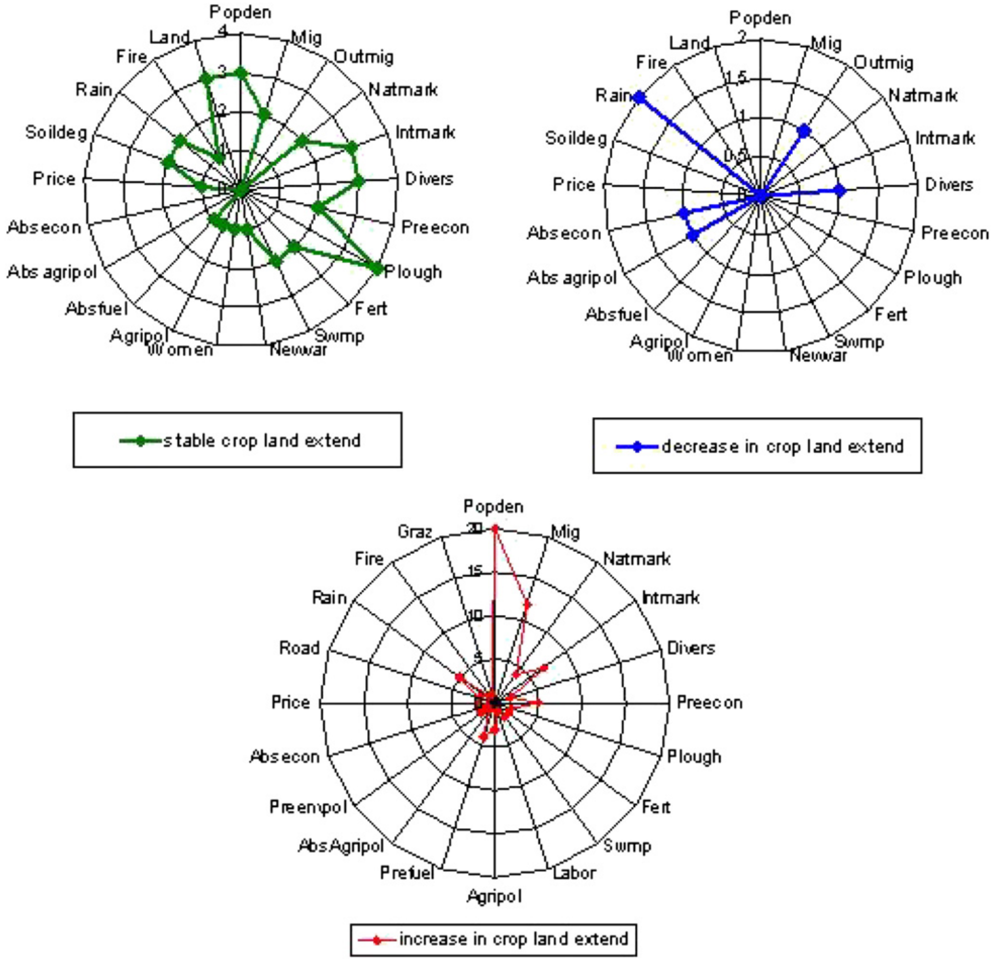


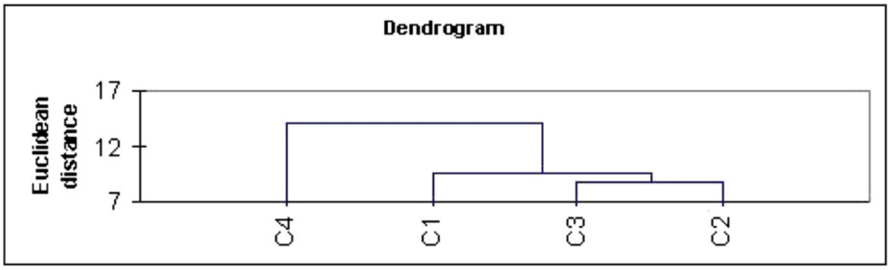
Fig. 3. Drivers of change in crop land.

of agricultural intensification and diversification since the late 1980s and the cultivated area has stabilized since 1988, despite a growing rural population and a decline in rainfall since the 1960s (Tappan and McGahuey, 2007). In Burkina Faso, Mazzucato and Niemeijer (2002) found that crop land did not change significantly despite population growth, because changes in the local informal institutions, such as land tenure systems, but also customs, norms, and networks, allowed farmers to intensify production (fertilizers, plough, soil and water management practices) and diversify sources of income. In south-western Burkina Faso, land under cultivation in the village of Sara did not change from 1981 to 1993, reflecting a saturation of arable land (Gray, 1999).

A decrease in crop land was mainly observed in cases where rain variability is a limiting factor, but also in the absence of government support and the presence of diversification activities and out-migration. The village of Kaska, in Nigeria, is a locally notorious case of 'desertification' (Mortimore and Turner, 2005), where crop land area declined while remobilized sand dunes increased under conditions of declining rainfall. In the Peanut Basin (West Central eco-region) in Senegal, cultivated area peaked to 80% of the land in the mid-1980s, when farmers still benefited from agricultural subsidies, but this trend then reversed itself, declining to about 67% of the land under cultivation in 2000. The reasons for the decline described by the authors are droughts and declining rainfall in the past 30 years, bringing about such risks in rain-fed cultivation that farmers abandoned their crops in favour of other economic activities. The withdrawal of government support since the mid-1980s, resulting in the breakdown of the agricultural economy, including a lack of seeds, agricultural credits, and agricultural equipment, has also resulted in great reductions in the cultivated area.

5.3. Main combination of drivers that explain crop land change, besides and/or in addition to population change

The results of the cluster analysis of case studies based on the main drivers of crop land change show that the case studies can be grouped in four classes (Fig. 4). Cluster 1 ($n = 10$) groups case studies that are characterized by crop land increase and where the main drivers of crop land change are demographic variables (population density and in-migration). Cluster 2 ($n = 21$) groups those case studies where the main driver of change is population density but where the crop land increases (76% of the cases), decreases (10%), or is stable (14%). Cluster 2 actually shows that the increase in population density is usually associated with an increase in crop land, but population density alone does not by itself predict trends in crop land cover (24% of the cases did not show an increase in crop land despite increased population density) and other factors might explain the decrease or stability of crop land change as demonstrated by the results of the canonical variate analysis below. Cluster 3 ($n = 5$) groups cases with market access (national or international), presence of economic structures, and intensification practices (use of the plough and soil/water management practices). In this class, the majority of cases show an increase in crop land (60%) and the rest show stability in the crop



Clusters	Combination of drivers that describe each group (based on the value of centroïds of each cluster)	crop land decreased	crop land increased	no change in crop land
C1	population density	0% (n=0)	100% (n=10)	0% (n=0)
	in migration			
C2	population density	10% (n=2)	76% (n=16)	14% (n=3)
C3	access to national markets	0% (n=0)	60% (n=3)	40% (n=2)
	access to international markets			
	presence of economic structures			
	plough			
	soil and water management practices			
C4	population density	0% (n=0)	25% (n=1)	75% (n=3)
	in-migration			
	presence of economic structures			
	diversification			
	access to international markets			
	plough			
	fertilizers			
	agricultural policies			
	land scarcity			

Fig. 4. Results of the hierarchical cluster analysis of case studies based on the drivers that influence crop land change.

land extent (40%). This cluster shows that intensification and access to markets are not necessarily associated with land sparing. Cluster 4 ($n = 4$) groups cases with multiple driving forces such as demographic drivers (population density and in migration), together with economic drivers (presence of economic structures, diversification, access to international markets, agricultural policies), intensification practices (plough and fertilizers), and a natural limit to the expansion of crop land, which translates into land scarcity. Three of the cases in Cluster 4 are characterized by stability in crop land and one by an increase in crop land.

The results of the canonical variate analysis show that there are significant differences in the drivers that mostly affect crop land increase, decrease, or stability (Lambda de Wilks Test, $p = 0.04$) (Fig. 5). The main drivers that best explain crop land increase are population density and in-migration. A decrease in crop land is associated with cases where households have diversified their sources of income or where rain has been unpredictable enough to discourage farmers from expanding their crop land despite population density. Crop land extent has been stabilized in contexts where farmers have intensified their production practices (plough, fertilizers, soil/water management practices) and where they have had access to international or national markets.

5.4. Impacts of crop land change on livelihoods, agricultural practices and the environment

The impacts of crop land change were dealt with in 16 case studies in total. Impacts were described for 11 cases where crop land increased and for five cases where crop land was stable (Fig. 6). None of the three case studies where crop land decreased described the impacts.

The qualitative comparative analysis suggests that among the case studies where crop land increased, the main impact was land degradation (mentioned in 53% of the cases) (Table 5). In Saloum Senegal, with the increase of cultivated land and shortening of fallow cycles, soils have become less fertile close to the villages, although fallow land away from the settlement gained in size, mainly due to out-migration (Mbow et al., 2008). In Kano, northern

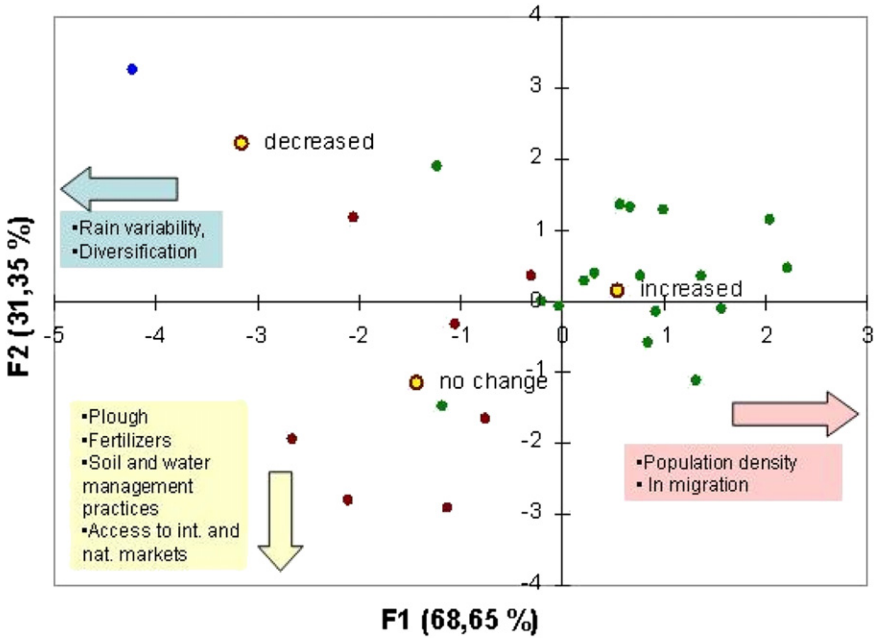


Fig. 5. Results of the canonical variate analysis.

Nigeria, where traditional agriculture had already been eliminated by the 1980s, the highly intensive agricultural system led to an increase in degraded land (Mortimore and Turner, 2005). In southern Mali, Tappan and McGahuey (2007) showed that there were very few signs of severe erosion in cultivated fields, but small patches of severely eroded soils had begun to appear throughout the study area. In a small Sahelian catchment in Niger, the increase in cultivated land from 1950 to 1998 was associated with an increase in the extent of eroded land (from 7 to 16%) at the expense of the savanna (Séguis et al., 2004). In Kouonbaka village, Mali, a 40-year trend indicates a steady increase in crop land and eroded bare soils and a correspondingly drastic reduction in woody covers (Ruelland et al., 2010).

The stability of crop land has translated into an increase in soil and water management practices and a decrease in fallow periods. In southern and central Niger, where crop lands have remained stable and the cropping area left fallow has decreased, farmers have started to employ different fertilization techniques aimed at maintaining or restoring the soil nutrient pool of the fields while providing physical protection against wind and water erosion (e.g. animal manure, mulch, mineral fertilizer, or planting pits) (Wezel and Haigis, 2002). In south-western Burkina Faso, where crop land extension has stabilized, agricultural practices illustrate how some farmers have responded to the lack of fallow land by intensifying their production system (e.g. trees on agricultural fields, use of more inputs, and construction of anti-erosion barriers on sloped fields to prevent erosion) (Gray, 1999).

6. Discussion and conclusions

This study, based on a meta-analysis of local case studies, has been useful in making qualitative assessments of published documentation of crop land changes in the Sahel. However, given the biases inherent in meta-analysis used for generating regional

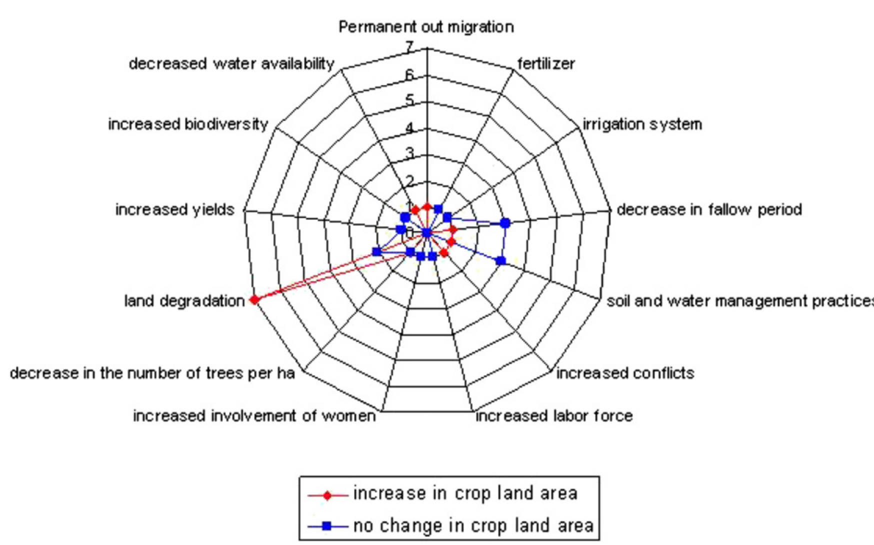


Fig. 6. Impacts of crop land increase and stable crop land.

Table 5
Results of the qualitative comparative analysis. The sign * means "AND"; the sign ~ means that the variable named just after is absent from the combination. As such, the impact of crop land increase is land degradation; the impact of the stability of crop land is the development of soil and water management practices AND reduced fallow length.

Intermediate solution of the QCA	Solution coverage = 0.77	Consistency cut off = 0.85	Solution cut off
Impacts of crop land increase			
landdeg*~trees*~fallow*~swmp	0.77	0.85	1
Impacts of crop land stability			
~trees*swmp*fallow	0.4	1	1

knowledge from local case studies, the results should be considered with caution (Messerli et al., 2009; Rudel, 2008). We recognize several caveats to generating regional knowledge from local case studies (Messerli et al., 2009). Most importantly, the case studies themselves may very likely be biased towards the following: (a) interesting issues or hot spots; (b) publications in English leaving out insights from French research institutions that could possibly represent additional insight with a longer time-depth; (c) outcomes that lend themselves to publication; or (d) a particular discipline (Rudel, 2008). Obviously, studies that have been planned and implemented as individual endeavours in their own right do not necessarily share a common conceptual framework or data collection practices that allow for easy common treatment and interpretation of the individual findings. Besides, conclusions based on this approach for a region constrained by the limited availability of case studies, are necessarily tentative. Nevertheless, this approach is the only expedient way to extract a tentative sketch of regional patterns of trends, drivers, and potential impacts of crop land change.

Available knowledge in the recent scientific literature shows that crop land has increased in the majority of cases explored (mostly at the expense of woodland), and population increase and in-migration have been found to provide the most prominent explanation. The main impact of crop land expansion identified and described in the literature is land degradation (through soil erosion and loss of soil fertility), or increased weed pressure. This causal relationship corresponds well to the conventional notion of more people indisputably leading to vicious circles of field expansion and soil degradation. However, increased population density has not necessarily systematically led to crop land increase in all cases. Indeed, some case studies document situations where, despite population increase, crop land has remained remarkably stable. Such trends seem to be found where land has become a limiting factor to expansion of agricultural production and where farmers have been able to intensify their agricultural practices (through the use of plough, fertilizers, soil and water management practices). This trend occurs particularly in places where farmers have had access to national or international markets and to supportive agricultural policies. However, it should be noted that intensification is often described in the studies as both a driver and an impact of crop land stability. If we explore the land use change trends through the classic theoretical lenses of Ester Boserup (1965), we can expect intensification measures to stabilize field expansion despite a population increase. This trend is seen in some of the case sites where the necessary conditions were present (i.e. supportive policies, markets, available resources (e.g. water)). Other areas have experienced a decrease in crop land despite a population increase. This is mainly explained by rainfall variability, which has discouraged farmers from expanding their plots or by situations where households have diversified their income through non-farm income generating activities, thereby reducing livelihoods vulnerability.

Perhaps most importantly, the meta-analysis exposes the surprisingly huge gap in the scientific literature when it comes to actual measurements of crop land change in the Sahel, which are in sharp contrast to the number of scientific papers and policy discourses that refer to important past and ongoing changes in land use/cover and desertification. Promoters of the development of NEAPs, for example, anticipated them to be a holistic process, focussing on the underlying causes of degradation and environmental problems, which include a range of social, cultural and economic factors. In reality, many of the plans boiled down to conservative shopping lists of projects to be presented to the donor community (Speirs and Marcussen, 1999: 87). They did not recognize new theories about natural resource management issues emerging during the 1990s. Marcussen (1999) mentions, as examples, that project documents often postulate that many hectares have been degraded over the past few decades and that population pressure more or less automatically leads to the extension of land under cultivation, without having a valid set of data on which to base such assessments. As regard the more recent generation of policy documents, Kalame et al. (2011) conclude from their survey of the NAPA for Burkina Faso that "the proposed priority projects were limited to the institutional and specialized fields of the experts who conducted the NAPA process", and insight into change processes is lacking.

Lately, the GGW plan (GEF, 2011) was launched with the explicit ambition to promote sustainable management of land, water and vegetation on up to 2 million hectares of crop lands, rangelands, and dryland forest ecosystems per country. Although this initiative is still in the planning stage, and hence difficult to assess, it seems that the concerns discussed above are relevant to mention again in this context. Assessed from the prioritized project proposals (Reenberg, 2012), the mindset which frames the intervention has not changed much since the 1980s.

This leads us to caution against replications of poorly supported characterizations of land use changes in theoretical conceptualizations or important policy documents. Wise use of scarce land resources, globally as well as more specifically in the Sahel, is becoming a prominent challenge for sustainable development and food provision for growing populations. It seems, however, that reliable knowledge to understand the contexts in which crop land increases, decreases, or remains stable, is in shorter supply than what is normally perceived by important policy agents.

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