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Agricultural Water Management Technology Expansion and Impact on Crop Yields in Northern Burkina Faso (1980–2010): A Review

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SEI Stockholm Environment Institute

Preface

This work is based on the presentation *Cases of successful adoption of agricultural water management interventions: What can we learn?* by Barron et al., at the Third International Forum on Water and Food, held from November 14 to 17, 2011, in Tshwane, South Africa, and the review by Douxchamps et al. (2014) *Taking stock of forty years of agricultural water management interventions in smallholder systems of Burkina Faso*. Ultimately, we seek to address a knowledge gap on what technologies are in use, and what large-scale impacts on yields can be explained by this technology uptake.

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Abbreviations

AEZ	Agro-Ecological Zone
AGRISTAT	Statistiques Agricoles, Burkina Faso
AWM	Agricultural Water Management
BFPVolta	Basin Focal Project Volta
CILSS	Comité permanent Inter-États de Lutte contre la Sécheresse dans le Sahel – Permanent Interstate Committee for Drought Control in the Sahel
CPWF	Challenge Program on Water and Food
CSIR	Council for Scientific and Industrial Research
DGPER	Direction Générale de la Promotion de l'Economie Rurale
DGPSA	Direction Générale des Prévisions et des Statistiques Agricoles
DGRE	Direction Générale des Ressources en Eau
DPSAA	Direction de la Prospective des Statistique Agricoles et Alimentaires
EA-QUIBB	Enquête Annuelle sur les Conditions de Vie des Ménages au Burkina Faso en 2005, Enquête Annuelle avec le Questionnaire Unifié des Indicateurs de Base du Bien Être en 2005
ENSA	Enquête Nationale de Statistiques Agricoles
EPA	Enquête Permanente Agricole
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	Statistics Division of the Food and Agricultural Organization of the United Nations
GERES	Groupement Européen de Restauration des Sols
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
INERA	l'Institut de l'Environnement et de Recherches Agricoles / Institute for Environment and Agricultural Research
INSD	Institut National de la Statistique et de la Démographie
KNUST	Kwame Nkruma University for Science and Technology
MARA	Ministère de l'Agriculture et des Ressources Animales
MAHRH	Ministère de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques
MEF	Ministry of Economy and Finance
NDVI	Normalized Difference Vegetation Index
NGO	Nongovernmental organization
OXFAM-PAF	Oxfam Projet Agro-Forestier
PATECORE	Projet Aménagement des Terroirs et Conservation des Ressources dans le Plateau Central
PS CES/AGF	Le Programme Spécial de Conservation des Eaux et des Sols et d'Agroforesterie
SWC	Soil and Water Conservation
UO	University of Ouagadougou

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Summary

Agricultural water management (AWM) interventions, such as soil and water conservation or small-scale irrigation around small-scale water reservoirs, have repeatedly shown benefits to yields, soil fertility and water availability – at the field and experimental farm scale. It is assumed that these benefits will result in better and more sustainable livelihoods. However, there has been little published evidence of such wide-scale beneficial impacts. This study synthesizes evidence, at the sub-national scale of region, across northern Burkina Faso, of adoption rates of AWM interventions compared with indicators of impact on livelihoods in the form of yield changes, poverty indices and food security. Using several independent sources (national statistics and independent reports and peer papers), the study has found multiple pieces of evidence that since the 1990s provincial adoption rates have been a minimum of 10-20% in provinces with >700 mm of rainfall and up to 40% in several other provinces. Over the same time period, regional cereal yields have had similar rates of increase (ca 3%) as the adoption of soil water conservation and small reservoir expansion. The link to poverty and food security is less clear, highlighting that at the provincial and regional scale much more data is needed to establish the causality between AWM adoption, crop yields and poverty/food security impacts. Multiple methods exist for developing knowledge on provincial and regional level AWM technology adoption and livelihood impacts, but such information is not readily available in the public domain for decision making, research or policy. The methods for measuring indicators of development impact should be explored further. It is particularly critical to capture indicators linking field-scale improvements to the broader socioeconomic and institutional pro-poor development agenda of rural livelihood systems in semi-arid West Africa.

1. Introduction

Since the 1970s, significant investments have been made in the Volta basin to develop and promote a range of agricultural water management (AWM) technologies in order to improve food productivity, food security and farmers' income in the face of extreme rainfall variability and severe droughts (Douxchamps et al. 2012, 2014). Substantial experimental evidence is available at the field scale showing high potential to increase crop production and productivity (e.g., Zougmoré et al. 2000a, b, 2003, 2004, 2005, 2010; Kaboré and Reij 2004; Barry et al. 2008; Sawadogo 2011). At the same time, a growing body of regional research on the "greening of the Sahel" suggests widespread improvement in biomass production, and that this improvement is possibly linked to the uptake and adoption of AWM technologies (e.g., Haglund et al. 2011; Bégué et al. 2011; Olsson et al. 2005; Herrmann et al. 2005). Yet, fundamental data gaps persist, e.g., have smallholder farmers adopted agricultural water management technologies to scale?[1] Whereas it is fairly easy to access information on the amount and locations of land degradation (e.g., the GLASOD project, ISRIC 2013), it is less straightforward to find evidence of where farmers already practice specific AWM technologies to scale. The location and rate of specific AWM technology adoption to scale is neither well understood nor systematically documented. This knowledge gap can lead to various misunderstandings on needs for research and investments in technology out scaling, both by researchers and development agents. The objective of this study is to determine whether evidence can be found at an intermediate scale between the field and the sub-continent for the past and current expansion and impact of AWM technologies. This study is targeted to one level below national, which in Burkina Faso is the administrative unit of regions.

The two questions addressed in this study are;

i) What is the evidence of the adoption and spread of various AWM technologies among smallholder farmers (in areal extent) over the past 30 years? Can adoption be located in space and quantified over time?

ii) Can any impacts on crop production (yield) and/or secondary impacts on rural poverty be discerned in relation to the expansion of AWM technologies?

In Section 1, a review approach is applied to address the above mentioned questions, focusing on northern and central Burkina Faso. Section 2 describes the data processing carried out and assumptions made. Sections 3 and 4 present the results of the expansion of AWM technologies and the temporal development of key cereal yields, poverty rates and food security indices in the study area. A discussion follows in Section 5, and a summary and recommendations are presented in Section 6.

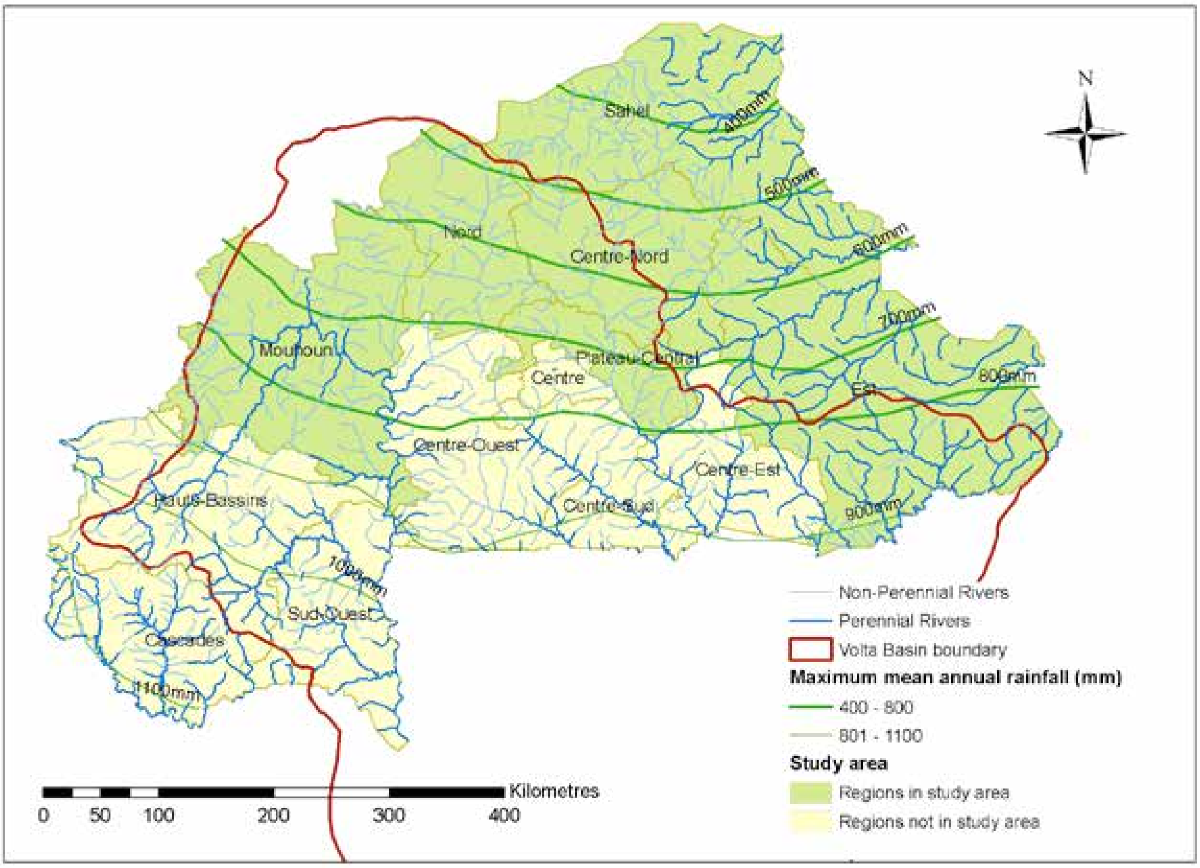
[1] 'to scale' refers to an out scaling of technology both in time and space , beyond a specific intervention, and to an aggregated area which could potentially have impacts on various ecosystem services and functions, either intended as in erosion control, or unintentionally as biodiversity loss or changes in water flows. Typical spatial scale could be of 100 hectares to hundreds of thousands of km^2.

2. Methods

This study used a comparative approach to establish preliminary relationships based on the available evidence and to assess the state of the data to determine what is required for a more rigorous analysis. The scope of the study was guided by the convergence of greening studies on the northwestern part of Burkina Faso, and a typology of AWM interventions used in the Volta Basin. Data on AWM use, crop yields and poverty indicators was collated or derived from secondary sources and then analyzed for relationships between AWM adoption and impact on the well-being of farmers.

2.1 Study Area

The study area was informed by the convergence of results from greening studies highlighting a 'hotspot' of greening in northwestern Burkina Faso, an area covering parts of the Nord, Plateau-Central, Centre-Nord and Mouhoun regions. The practice of *zai* and stone rows as soil and water conservation (SWC) interventions is said to have been particularly successful in this area too (Kaboré and Reij 2004; Atampugre 1993). The final study area was expanded to cover the semi-arid area of Burkina Faso, where agricultural water management is an important strategy for enhancing smallholder farmers' income generation and food security (D'haen 2012). The spread of AWM adoption has also been suggested as substantial in this area (Douxchamps et al. 2014). The study area was defined as the regions with more than half their surface area receiving between 400 and 800 mm rainfall per year, according to the mean rainfall isohyets described in Ouedraogo et al. (2006) for the period 1971-2000. The regions, therefore, included in this analysis are Sahel, Nord, Centre-Nord, Mouhoun, Est and the Plateau-Central (see Figure 1). The total surface area studied is 161 865 km^2.



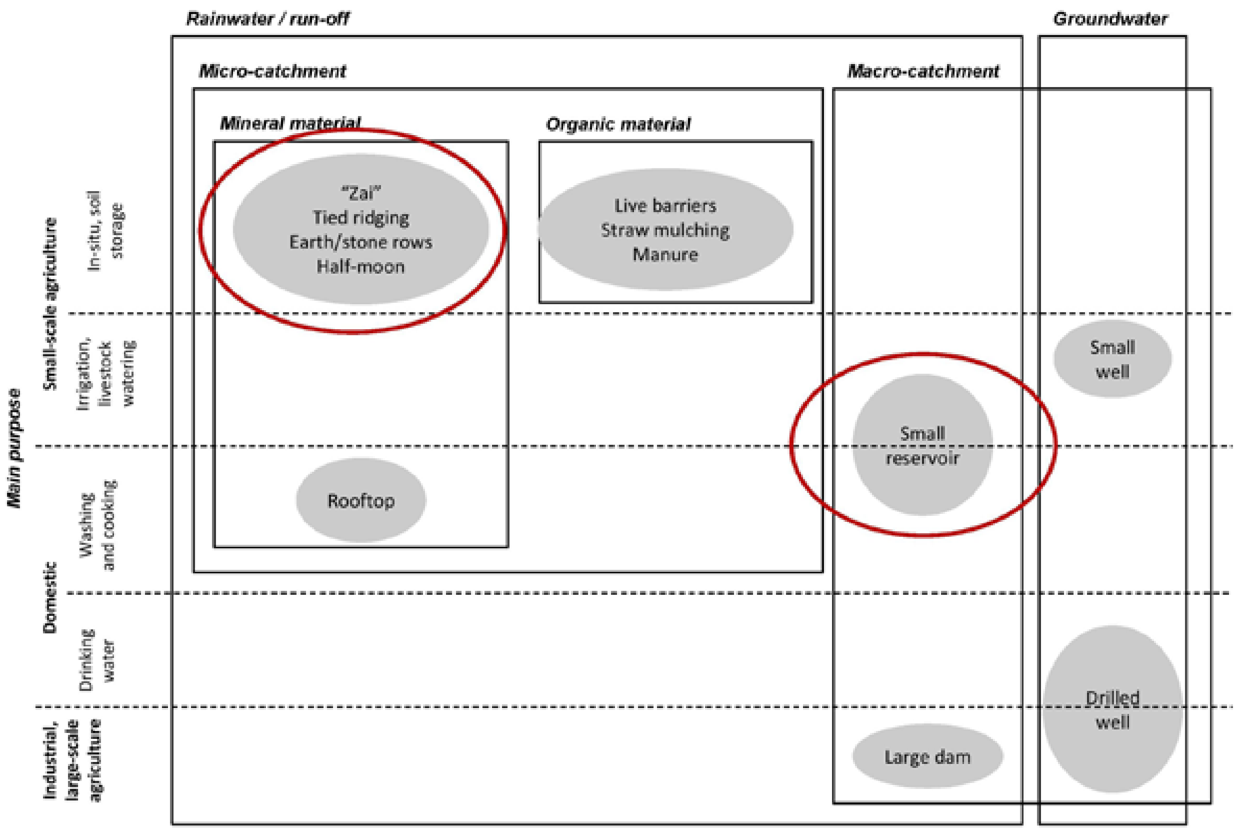
Source: Compiled by author from De Condappa et al. (2008b). Outline of mean long-term isohyets for 1971-2000 redrawn from Ouedraogo et al. (2006).

2.1.1 Typology of Agricultural Water Management Interventions

The scope of agricultural water management (AWM) interventions included in this review was guided by the typology of AWM interventions adapted by Douxchamps et al. (2012; after Johnston and McCartney 2010) (see Figure 2) and other previous work that identified high potential for adoption and adaptation of three main streams (listed below) of AWM technology, covering the water use spectrum from rainfed to irrigated (Barron et al. 2011; Evans et al. 2012):

i) small reservoirs
ii) small electric/diesel pumps for smallholder irrigation
iii) soil and water conservation (SWC)

Figure 2: Classification of agricultural water management (AWM) technologies used in the Volta basin.



Source: Douxchamps et al. (2012)

Small reservoirs

Small reservoirs were defined as dammed reservoirs with a capacity of <1 million m^3 (Cecchi et al. 2009; De Condappa et al. 2008a). Small reservoirs are used for multiple purposes, including irrigation, fishing and livestock watering (Sally et al. 2011). Smaller, ephemeral ponds, which are elusive to record, are particularly important for complementary irrigation during the post-rainy season period. In 2001, there were a total of 881 geo-referenced small reservoirs with a known volume in Burkina Faso. An additional 440 reservoirs are recorded in the database with no known volume. It was suggested by De Condappa et al. (2008a) that these reservoirs are most likely small reservoirs. Thus, results of this study are based on the minimum amount of stored water and therefore likely to underestimate the impact of small reservoirs on livelihoods. Note that Venot et al. (2012) suggested serious discrepancies in the locations of small reservoirs captured in different data sets, so these records can be considered a "best estimate".

Soil and water conservation (SWC)

Soil and water conservation (SWC) interventions incorporate a range of technologies for reducing soil erosion and improving soil moisture infiltration for crop and plant growth, including the *zai* (half-moons), various reduced-tillage practices and tied ridging, earth/stone rows and vegetation strips (live hedges), which are commonly used in the Volta basin (see Figure 2). Two SWC interventions, i) stone bunds (Atampugre 1993) and ii) the revived traditional practice of planting pits known as *zai* (Reij et al. 2009) in particular, have been substantially promoted in externally-funded projects. AWM interventions using mineral (soil) material and live hedges at the micro-catchment (in-field) level were also included in this study.

2.2 Data Sources

The three principal sources of data that were used in the study to synthesize information of AMW interventions in use and the potential benefits (impacts) to scale are;

i) Small Reservoir Toolkit (Andreini et al. 2009);
ii) National and sub-national statistics available online from the National Institute of Statistics and Demographics (INSD, www.insd.bf/fr/), CountrySTAT Burkina Faso (http://countrystat.org/bfa) and AGRISTAT (www.sisa.bf/agristat) databases; and
iii) Published peer-reviewed and 'grey' literature in the form of journal articles, project documents, working papers and national reports.

Available datasets

The analysis of small reservoir development used a database of reservoirs in Burkina Faso, compiled by Cecchi (2008) as part of the Small Reservoir Project and based on data supplied by Direction Générale des Ressources en Eau (DGRE) and Ministère de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques (MAHRH). This database holds records of dates of construction, total capacity and other characteristics of 1,453 dammed reservoirs (in total), across Burkina Faso that were built up until 2001 and that vary in size from 9.7 million m^3 to 15 m^3. The database is available on the BFP Volta Data Disc (De Condappa et al. 2008b). A valuable analysis of the database and the small reservoir context was obtained from Cecchi et al. (2009) and Venot et al. (2012).

Consistent quantitative data about soil and water conservation (SWC) adoption by farmers across the country is available from the annual national agricultural survey (Enquête Permanente Agricole, EPA), which records, for each agricultural household sampled, the number of fields on which farmers utilize any form of anti-erosive measures, including stone barriers, earth dams, *zai* (half-moons) and hedging (live or dead). The proportion of fields utilizing SWC measures provides an indicator for estimating regional adoption of SWC. Statistics for the provincial level (% of fields) are published for 1993 (INSD 1994).

The yield (kg ha^{-1}) produced and the area planted for major cereal crops were reproduced from the AgriSTAT database series for 1984-2004 (DGPER 2008) and the INSD regional series for 1995-2008 (INSD 2013a, 2012c). Millet, sorghum, maize and rice were selected as being the main staple crops produced in the region for food and income.

Poverty indices have been published for 1994, 1998 and 2003, based on national household surveys (MEF 2000; INSD 2012b). To complement each poverty index, ownership of agricultural equipment and animal draft power was collated from household and agricultural surveys for 1993, 2003 and 2007 (INSD 1994, 2003, 2007), following Moll's (2005) analysis of livestock as insurance, financing, a savings mechanism and a status symbol.

A second complementary index of poverty is food security. In addition to D'haen's research (2012), Botoni and Reij (2009) found that villagers' perceptions of their own poverty level were often defined by characteristics of food security. Regional food security data, estimated by the Institut National de la Statistique et de la Démographie (INSD) as the proportion of cereal demand (in %) met by production and published in regional periodic reports (INSD 2012a), is analyzed for the period 1992-2006.

Data analysis

Soil and water conservation (SWC) adoption for 2006 (% of fields using SWC measures) was calculated from raw EPA survey data (MAHRH and DGPSA 2007). Provincial level adoption was calculated as the number of fields using any form of anti-erosive measure as a proportion of the total number of fields surveyed in 2006/7. Regional level statistics for both 1993 and 2006 were calculated as the area-weighted average of the provincial statistics, using available provincial level cropland area from the Ministère de l'Agriculture et des Ressources Animales (MARA) agricultural survey reports for the closest year (1993: INSD 1994; 2004/5: MAHRH et al. 2006).

Academic journal databases (Scopus, Science Direct, ISI Web of Science) were searched for supplementary studies reporting independently surveyed areas of agricultural land (in hectares) on which SWC technologies have been or are still being implemented to complement the national overview of SWC adoption. We used the keywords "zai", "stone bunds", "soil and water conservation", "anti-erosion" and "Burkina Faso". Of the 75 articles found, most report the results of field trials (see Appendix A2) and do not have a record of the adoption of agricultural water management (AWM) technologies by farmers. Excluded articles were related to work in countries other than Burkina Faso or were not explicitly related to SWC. The project reports published by international organizations responsible for promoting SWC measures since the 1970s (PATECORE 2004; Atampugre 1993; IFAD 2004) provided the number of hectares of agricultural land treated by the projects, although the overall areal extent encompassed by a particular project was not always clearly defined. Using the information available, we derived an estimated percentage of coverage by calculating the hectares treated as a percentage of the total area cultivated with cereals and using available regional level data from the agricultural survey reports for the season closest to the publication of the reports (MAHRH et al. 2006). In project-treated areas covering several regions, the percentage apportioned to each region was area-weighted by the cultivated area. It should be noted that these estimates do not account for any adoption beyond the project's direct intervention and therefore could be underestimates. Nonetheless, the statistics provide a counterpoint to the national statistics presented.

The yield (kg ha^{-1}) was calculated at the regional level from the average total production (t) and average total crop area (ha) of the provinces within each region. Cereal production per person was calculated using regional population statistics for 1996-2006 (INSD 2013b). For all agricultural statistics, a 5-year moving average was calculated, and then the time series was normalized to the first year of the series,before comparing it to the small reservoir and SWC development trends.

3. Expansion of AWM Technologies Since 1950

3.1 Small Reservoirs

Of the 1,453 reservoirs recorded in the Cecchi (2008) database, 881 are small reservoirs with a storage capacity of less than 1 million m^3; 74% of those have less than 300 000 m^3. Although accounting for the majority of reservoirs by number (61% of the 1,453), small reservoirs only hold 3.5% of Burkina Faso's total storage volume (Table 1a) and only 3% of the total storage volume in the study area (Table 1b). Overall the dataset is still incomplete, with 30% of reservoir entries not having information on volume. Moreover, cross-referencing between remote-sensing, field surveys and national reports revealed the difficulties in collecting a comprehensive inventory of reservoirs, with the location of reservoirs being at most 30% consistent between the sources of data (Venot et al. 2012). Nonetheless, the dataset provides a general guideline and the best current estimate of small reservoir development over the past 50 years.

Table 1: Characteristics of recorded reservoirs in Burkina Faso

a) Storage capacity and date of construction for all reservoirs recorded in the database

Type	Number	Known volume (m^3)	% total known volume
All	1 453	4 962 870 175	100.0
Large (>10 million m^3)	14	4 452 435 000	89.7
Large/med (>1 million m^3)	118	337 262 000	6.8
Small (<1 million m^3)	**881**	**173 173 175**	**3.5**
Small reservoirs built at an unknown date	136 (9% of total)	23 857 415	13.8% of the small reservoirs
Unknown volume	440 (30% of total)		

b) Amount and volume of small reservoirs for the six study areas (Centre-Nord, Est, Mouhoun, Nord, Plateau-Central and Sahel)

Type	Number	Known volume (m^3)	% total known volume
All	717	2 953 251 565	100.0
Large (>10 million m^3)	10	2 652 700 000	89.8
Large/med (>1 million m^3)	77	212 386 000	7.2
Small (<1 million m^3)	**452**	**88 165 565**	**3.0**
Small reservoirs built at an unknown date	81 (11% of total)	14 019 415	15.9% of the small reservoirs
Unknown volume	188 (26% of total)		

Source: Cecchi (2008)

In the study area, the rate of development of small reservoirs increased rapidly after the droughts of the 1970s (Table 2, Figure 3). On average, over 85% of small reservoirs were built after 1970, with intense development occurring on the central plateau during the 1980s in particular when 50% of small reservoirs in Nord, Centre-Nord and Plateau-Central were built. The Est region had an early period of higher development (1950s-1960s) in addition to the 1980s boom, which continued into the 1990s. In Sahel, small reservoir expansion started later and continued until more recently, into the 1990s.

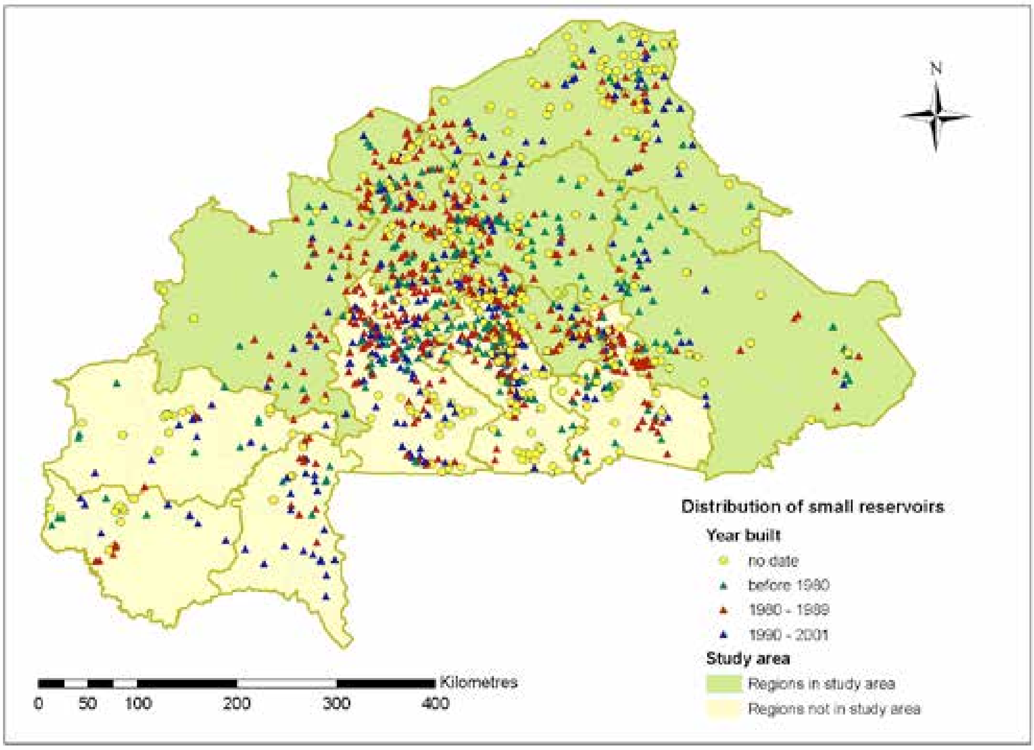
Table 2: Growth of storage volume in small reservoirs (% of current volume added each decade)

Region	Pre-1950s	1950s	1960s	1970s	1980s	1990s	Date unknown
Sahel	0	2	0	1	26	43	27
Nord	1	1	5	13	54	9	17
Centre-Nord	2	8	13	12	50	9	6
Plateau-Central	0	0	2	3	50	27	18
Mouhoun	0	11	5	3	34	36	11
Est	0	14	24	6	20	18	17

Data source: Cecchi (2008)

Mapping the locations of the small reservoirs reveals that they are concentrated mainly on the central plateau of Burkina Faso, matching the areas of higher population density (>25 people per km^2, CIESIN et al. 2011; see Figure 13 in Appendix A1). A higher density of reservoirs is also evident in the arid, northern Sahel region (Figure 3). Figure 3 differentiates the distribution of small reservoirs over time, according to the decades of intense reservoir building: up to 1979 (green); 1980-1989 (red); and 1990-2001 (blue).

Figure 3: Distribution of small reservoirs according to date of construction.



Source: Drawn from data in Cecchi (2008).
Note: Includes 381 reservoirs with no recorded construction date.

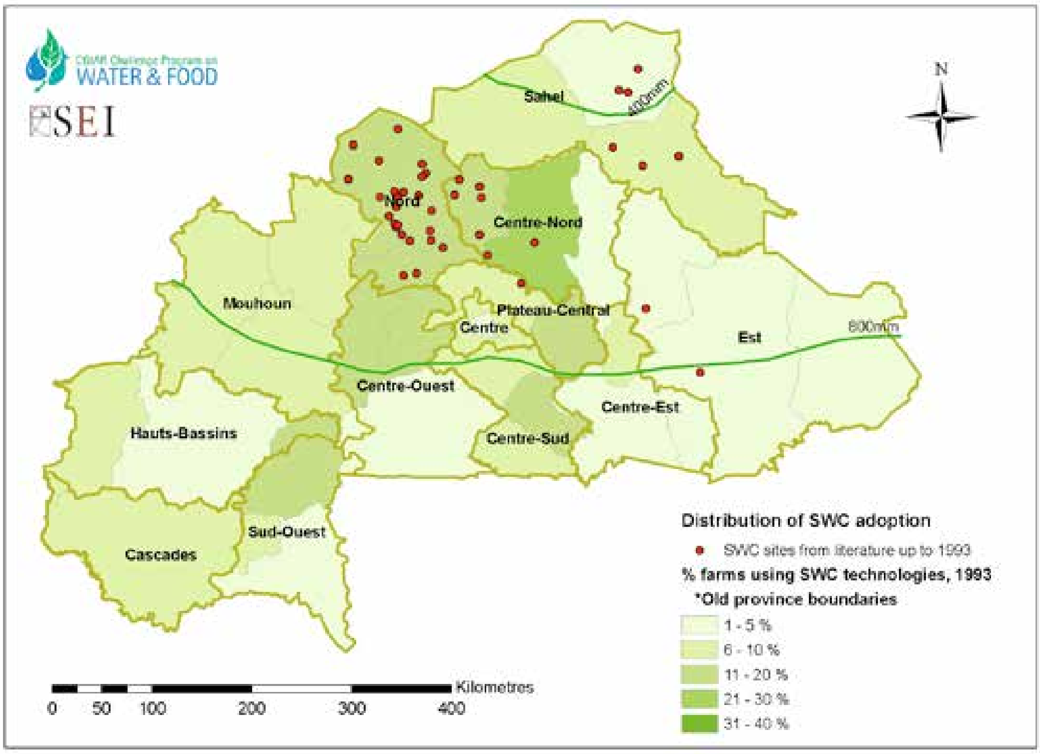
The increase in reservoir development on the central plateau in the 1980s mirrors the promotion of soil and water conservation measures on the plateau, which will be discussed in the following section.

3.2 Soil and Water Conservation (SWC)

Results from the national agricultural surveys show a marked increase from 1993 to 2006 in the proportion of surveyed farmers' fields having at least one SWC measure in place (Figures 4a and 4b; Table 4), particularly in Sahel - the driest region in the study area. It is important to note that often farmers use a combination of measures, which has a greater impact than using one in isolation (Magombeyi et al. 2014; Zougmoré et al. 2003, 2005). However, this initial study did not disaggregate the data by practice, but instead it categorized fields simply by presence or absence of any SWC intervention. The relatively high 1993 levels of SWC in Nord, Centre-Nord and Plateau-Central reflect the intensive investment in projects focused on that central region since the 1980s, and their continued improvement up to 2006 suggests that the projects and other promotional efforts were successful in increasing SWC adoption. The tripling of SWC presence in Sahel suggests spreading and diffusion of SWC from the central region. Mouhoun and Est, the two regions with large areas in the 800-900 mm rainfall zone, show a lesser increase in the adoption of SWC. The lower proportion of arid and semi-arid areas in these two regions may contribute to explaining the reason for minimal SWC adoption in the locality.

Analyzing the adoption rates at the provincial level reveals some interesting trends (Figure 4a and 4b). For example, in the provinces that lie within the 600-700 mm rainfall zone in Mouhoun and Est, the share of cultivated land where SWC practices were used increased to 16-18% and 11-15%, respectively, in 2006 while there was no increase (7%), or even a decline (down to 0%), in the provinces receiving more than 700 mm of rainfall per annum. In general, SWC coverage increases across the 400-800 mm rainfall zones. Provinces in the southern parts of Mouhoun and Est, as well as many other southern provinces, show a decrease in SWC coverage from 1993 to 2006. At the provincial level, the highest rates of SWC coverage in 2006 were 35% and 36% in Bam and Sanmatenga, respectively (both Centre-Nord, see Appendix A3 for provincial statistics).

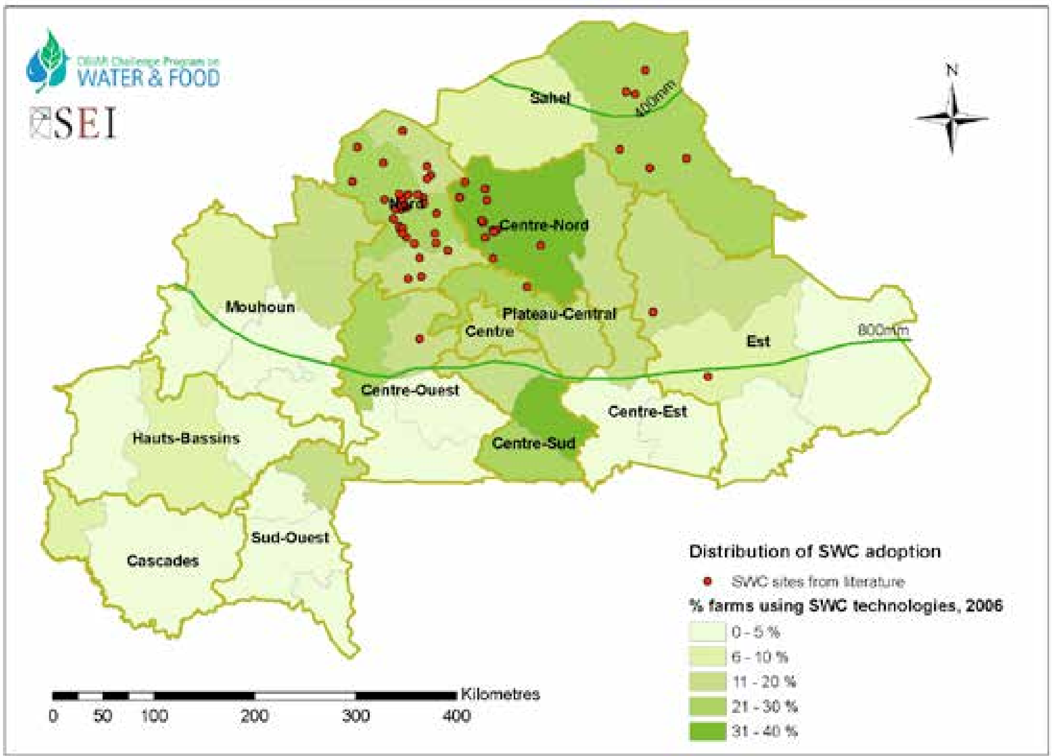
Figure 4a: Proportion of fields using SWC in 1993, as a percentage of total fields sampled and villages where SWC measures have been recorded.



Data sources: Percentage of farms using SWC technologies mapped from data in INSD (1994), Tableau 29; villages sourced from various publications (see Appendix A4 for references); mean annual rainfall isohyets for 1971-2000 redrawn from Ouedraogo et al. (2006).

*Note: the boundary lines are mismatched because the 1993 data was collected for the old boundaries (30 provinces) and is mapped accordingly.

Figure 4b: Proportion of fields using SWC in 2006, as a percentage of total fields sampled and villages where SWC measures have been recorded.



Data sources: Percentage of farms using SWC technologies mapped from data in DGPER (2008); villages sourced from various publications (see Appendix A4 for references); mean annual rainfall isohyets for 1971-2000 redrawn from Ouedraogo et al. (2006).

An examination of peer-reviewed publications and grey literature for estimates to supplement the national surveys showed few quantitative evaluations of adoption. Most peer-reviewed literature relates to experimental field studies observing the impacts of SWC measures in particular fields. All reported locations of *zai* or stone bunds having been adopted, from both peer-reviewed and grey literature, are depicted in Figures 4a and 4b (reference details in Appendix A4), highlighting tthat international projects have focussed on the Nord and Centre-Nord regions. Most references to SWC adoption, either in general or specifically *zai* and stone bunds, are qualitative rather than quantitative and suggest that the technology is "widespread" (Batterbury 1996, p15) and that "every household" uses it (Sawadogo 2011, p123).

Some attempts to quantify the total area treated with SWC measures suggest that zais are used on 30,000-60,000 ha in northwestern Burkina Faso (Sawadogo 2011) and on more than 200,000 ha of agricultural land in central Burkina Faso (Reij et al. 2009). Local adoption rates of 49-60% have been recorded within the Yateng Province (Barbier et al. 2009). However, quantifying adoption at the regional level, for each region, proved challenging. Often project evaluation reports provide the total area treated, for example with stone bunds, but the publications refer to differing and ill-defined areal extents (e.g., Yatenga versus northwestern Burkina Faso), making it difficult to consistently contextualize the reported coverage, and hence it is challenging to compare statistics across years and publications. Therefore, data on documented area of SWC use was extracted only from publications with precise location references (e.g., Yatenga) for which total areas are available. As summarized in Table 3, the area with documented SWC use roughly relates to the total area of cultivated agricultural land in the relevant region, as reported for the agricultural season closest to the publication year of the reference source.

Table 3: Summary of the area of SWC measures in use, extracted from peer-reviewed and grey literature.

Time period	Area of SWC reported, total (ha)	Provinces covered in project/ report	Area of SWC reported, weighted per region (ha)	Area cultivated with cereals, per region (ha)	SWC reported as % of cultivated area, per region	Literature source - SWC	Literature source – cultivated area
1983 – 1989	8 000 Stone bunds	Yatenga	8 000	176 093	4.54	Critchley and Graham (1991); Atampugre (1993)	Agricultural Survey 1993 (INSD 1994)
1988 – 2003	89 600 Stone bunds	Bam; Namentenga; Sanmatenga; Passore; Yatenga; Zondoma; Boulkiemde; Sanguie	Centre-Nord: 32 990 Nord: 36 308 Centre-Ouest: 20 302	Centre-Nord: 284 708 Nord: 325 052 Centre-Ouest: 392 951	Centre-Nord: 11.6% Nord 11.2% Centre-Ouest: 5.2%	IFAD (2004), Intermediate report of PS-CES/AGF project	Agricultural Survey 2004-2005 (MAHRH et al. 2006)
1988 – 2004	60 000 Stone bunds, *zai*, earth dams	Bam, Kourwéogo, Oubritenga	Centre-Nord: 28 840 Plat.-Central: 31 160	Centre-Nord: 284 708 Plat.-Central: 163 648	Centre-Nord: 10.1% Plat.-Central: 19.0%	PATECORE (2004), Final report	Agricultural Survey 2004-2005 (MAHRH et al. 2006)

Assuming the documented areas per project are complementary, and not overlapping with figures reported for other projects, the combined quantified proportion of cropland using SWC measures adds up to roughly 150,000 ha and 5-20% of the cropland per region by 2004, compared to 8,000 ha and 4.5% of cropland in 1990. These data refer to only the area where projects implemented SWC measures and do not include future spread (or abandonment) of those SWC measures. The literature results are therefore expected to be an estimated minimum, assuming that the literature has not documented all instances of adoption. These literature results are comparable to the adoption rates derived from the national statistics, although lower, especially for Nord province (Table 4).

Table 4: Adoption of SWC by region (1993-2006).

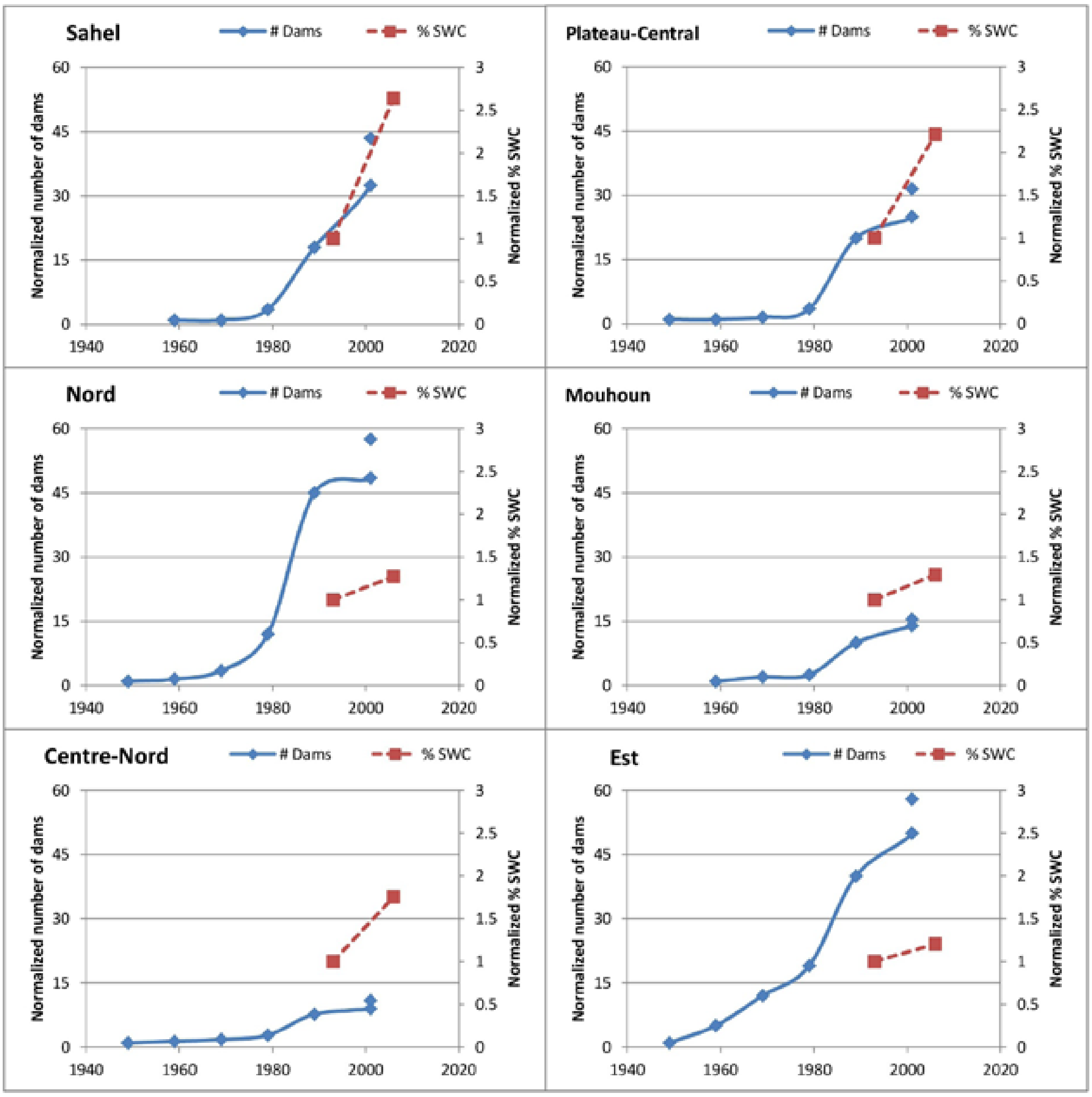
	1993 (ENSA, INSD 1994)		1990 (Literature in Table 3)	2006 (EPA, MAHRH et al. 2006)		2004 (Literature in Table 3)
Region	% farms *	Approx. area (ha)‡	% farms **	% farms *	Approx. area (ha)‡	% farms **
Sahel	6.9	23 000		18.2	62 000	
Nord	17.1	56 000		21.8	72 000	11.2
Centre-Nord	15.9	43 000	4.5	27.9	76 000	21.7
Plateau-Central	9.9	17 000		21.9	38 000	19
Mouhoun	6.4	35 000		8.3	45 000	
Est	2.4	8 672		8.3	26 000	

Sources: National agricultural surveys (INSD 1994; MAHRH/DGPSA 2007) and estimates calculated from literature
Notes:
*Proportion (%) of farms surveyed on which some form of SWC was being practiced (taken from source)
** Proportion (%) of cultivated land on which SWC has been implemented (calculated, see Table 3)
‡ Approximate area of cereal cultivation using SWC, assuming the % farms to represent the approximate area of adoption (calculated)
ENSA: L'Enquête Nationale de Statistiques Agricoles
EPA: L'Enquête Permanente Agricole

In summary, the use of SWC management technologies has increased significantly over the past 50 years and particularly since the 1980s. The evidence in the national statistics of an increase of SWC in Sahel and drier provinces of the Est region suggests outscaling of the technologies beyond the areas that were originally part of the large-scale projects such as PATECORE or IFAD's PS-CES/AGF (mainly Nord and Centre-Nord regions). Although not quantified, Reij et al.'s (2009) estimate of 200,000-300,000 ha preliminarily corroborates this suggestion.

To summarize the expansion of AWM technologies in the study area, the increase in small reservoirs has been complemented by a similar trend in the adoption of SWC (Figure 5).

Figure 5: Small reservoirs and SWC: Development of small reservoirs (number) and proportion of farms using SWC (%) over time (both series normalized to first data year).



Data sources: Small reservoirs from Cecchi (2008); SWC from INSD (1994), DGPER (2008). Note: The disconnected point on the reservoir curve represents the total number of small reservoirs recorded including those with no date of construction.

4. Yield Benefits and Poverty Impact of AWM Outscaling

Field studies and a few village-level case studies have shown that agricultural water management (AWM) technologies can increase yields by more than 100% (Sawadogo 2011; Botoni and Reij 2009); improve soil quality by reducing runoff, sediment loss and nutrient loss (Zougmoré et al. 2010, 2009); and possibly improve groundwater levels (Reij et al. 2005). The following section analyzes socioeconomic indicators at the regional level for evidence of AWM impact.

4.1 Yield Changes

Description of yield and cropland expansion

Both yield (kg ha^{-1}) and crop area planted, viz. with main cereals, have been highly variable over the 25-year time series available (1984-2009), but a trend of increase is more or less evident depending on the crop and the region (Figures 6a and 6b, respectively). In general, a normalized time series of the major cereal crops smoothed with a 5-year moving average produce trendlines with a gradient of around 0.03 (3% increase per year) (Table 5). The r^2 values indicate that millet and sorghum yield has had less inter-annual variation than maize and rice, suggesting that this trend is more reliable and that millet and sorghum yields are more stable. Although very erratic, rice yields have increased dramatically since the 1980s, a result of strong increases in both area cultivated and total production. For the rain-fed cereals (i.e., not including rice), Nord and Centre-Nord show high rates of increase most consistently in their trendlines, i.e., 3-4% per year. These are two regions where SWC promotion also has been concentrated.

In terms of evaluating the impact of AWM technologies on improving the yield, it is important to know how much of the perceived increase is due to expansion into new cropland. In central Burkina Faso, the potential for expansion is limited due to its historically high population pressure (Barbier et al. 2009; Marchal 1977). In Plateau-Central and Centre-Nord, cropland expansion has not exceeded 150% of cropland in 1984, except for rice (Figure 6b). However, in the other regions, such as Nord and Sahel rain-fed crops (millet and sorghum) have expanded dramatically, i.e., 200-350%. In general, Mouhoun, Est and Sahel, being the regions with lower population density and more land availability, have the highest expansion results. The expansion of the area cultivated for rice, although still small in absolute terms, is an order of magnitude higher than the other crops, suggestive of an initial expansion after introduction, particularly in Sahel. It is interesting to note that the area cultivated has inter-annual fluctuations of up to 100,000 hectares or more. In Centre-Nord in particular, the area planted with sorghum has risen and fallen by 60,000–100,000 hectares several times over the 20-year study period. However, it appears that the fluctuation is to some extent due to the alternation of crops, i.e., sorghum with millet, which is more evident in Centre-Nord than in other regions.

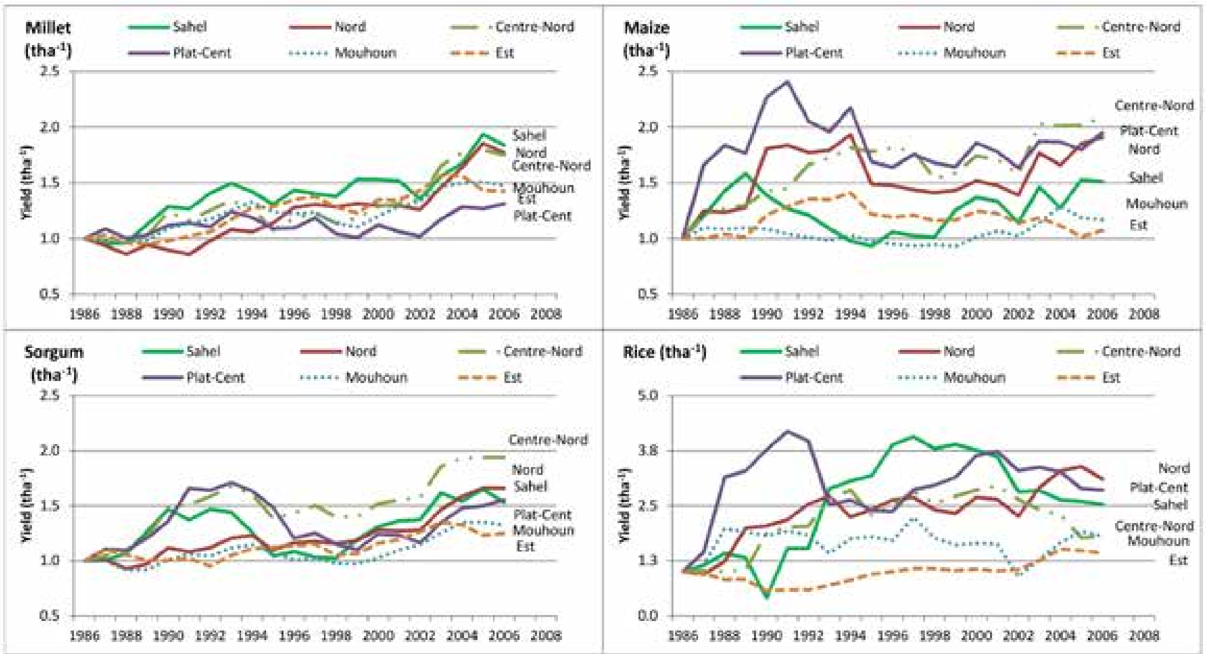
Table 5: Trends in major cereal yields (tha^{-1}, normalized values, with 5-year moving average).

Millet	Gradient	r^2	Sorghum	Gradient	r^2
Sahel	0.0367	*0.7929*	Sahel	0.0193	*0.3099*
Nord	0.0425	*0.8432*	Nord	0.0307	*0.8066*
Centre-Nord	0.0349	*0.7074*	Centre-Nord	0.0365	*0.6807*
Plateau-Central	0.0081	*0.2756*	Plateau-Central	0.0067	*0.037*
Mouhoun	0.024	*0.7636*	Mouhoun	0.0161	*0.5659*
Est	0.0296	*0.8472*	Est	0.0149	*0.6865*

Maize	Gradient	r^2	Rice	Gradient	r^2
Sahel	0.008	*0.0616*	Sahel	0.1143	*0.4047*
Nord	0.018	*0.1872*	Nord	0.0905	*0.7199*
Centre-Nord	0.0398	*0.7188*	Centre-Nord	0.0615	*0.3303*
Plateau-Central	0.0028	*0.0037*	Plateau-Central	0.0386	*0.0962*
Mouhoun	0.005	*0.1143*	Mouhoun	0.0016	*0.0009*
Est	0.0005	*0.0006*	Est	0.034	*0.5964*

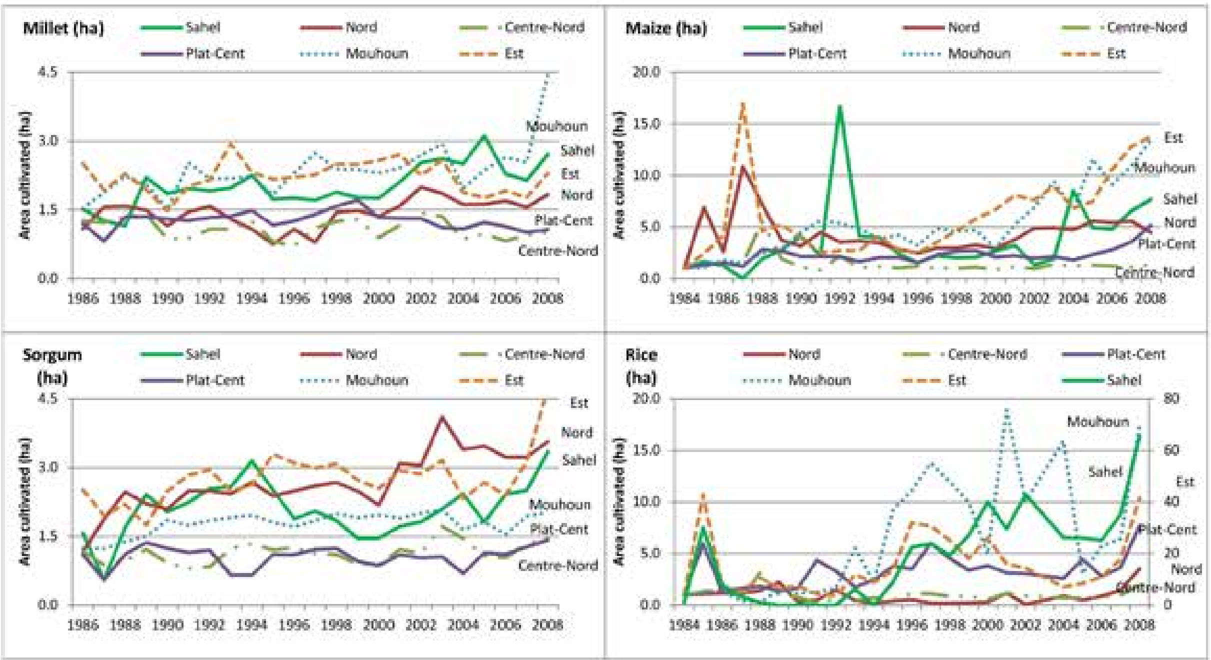
Data sources: DGPER (2008) and INSD (2012c).

Figure 6a: Yield (kg/ha) by region, for major cereal crops, calculated from production (tonnes) and agricultural area (ha) for time period 1984-2008 (5-year moving average, normalized values).



Data sources: DGPER (2008) and INSD (2012c).

Figure 6b: Cultivated area (ha) by region, for major cereal crops, for time period 1984-2008. (All series normalized to first year of data, no smoothing. Note: For rice, Sahel is plotted on a second axis).



Data sources: DGPER (2008) and INSD (2012c).

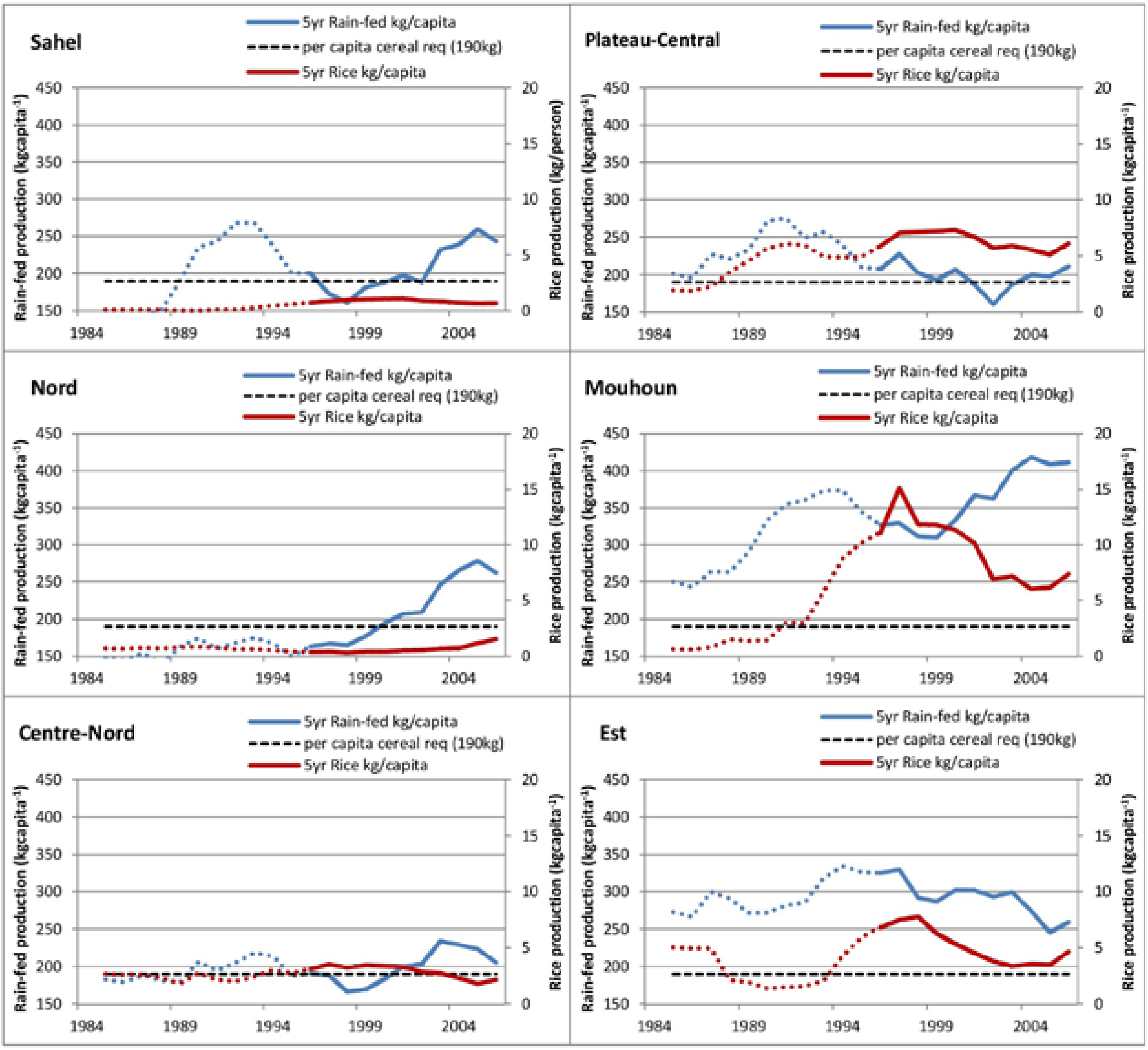
While absolute yield improvement is necessary, the improvement must keep up with population growth and surpass it in order to realize a noticeable improvement in local food security and possibly in farming-dependant livelihoods. Analysis of total cereal production per capita (Figure 7, Table 6) shows that there has only been a consistent rise in production per person for rain-fed cereals (millet, sorghum and maize) in Nord and Mouhoun. In Sahel and Centre-Nord, the series varies periodically, with a first peak around the early 1990s and a second rise toward 2006 (end of the dataset). Nord, Centre-Nord and Sahel also have the highest AWM adoption rates, along with Plateau-Central. Rice production rises slowly and consistently only in Sahel and Plateau-Central; in Mouhoun and Est, per capita production is more periodic and declines toward the end of the time series. Production has not kept up with population and has even declined in Plateau-Central and Est for rain-fed cereals, and in Nord and Centre-Nord for rice. However, all regions were producing more than the minimum cereal requirement per capita by 2008. In summary, these results suggest that food security will improve in Nord; will be relatively stable in Centre-Nord; will be potentially rising but variable in Sahel and Mouhoun; and will be potentially decreasing in Plateau-Central and Est. Systematically higher per capita production in both Mouhoun and Est reflects their lower population density.

Table 6: Trends in major cereal production per capita (kgcapita-1, with 5-year moving average).

Rain-fed	Gradient	r^2	Sorghum	Gradient	r^2
Sahel	3.0553	*0.2071*	Sahel	0.0499	*0.6877*
Nord	**5.4893**	***0.7319***	Nord	0.006	*0.0193*
Centre-Nord	1.3404	*0.2179*	Centre-Nord	0.0124	*0.0238*
Plateau-Central	-2.2124	*0.2488*	Plateau-Central	0.1707	*0.4771*
Mouhoun	**6.4978**	***0.6519***	Mouhoun	0.4372	*0.4111*
Est	-0.1951	*0.0028*	Est	0.0695	*0.0546*

Data sources: DGPER (2008) and INSD (2013b).

Figure 7: Total cereal production per capita (kgcapita-1, 1984-2008, 5-year moving average).



Data sources: DGPER (2008) and INSD (2013b).
Note: For the dashed portions of the graphs, population data was not available and was instead calculated backwards from the available data series (1996-2006) using closest-fit polynomial trendline equations. Dashed horizontal line marks 190 kg per capita, the cereal food requirement value used by INSD.

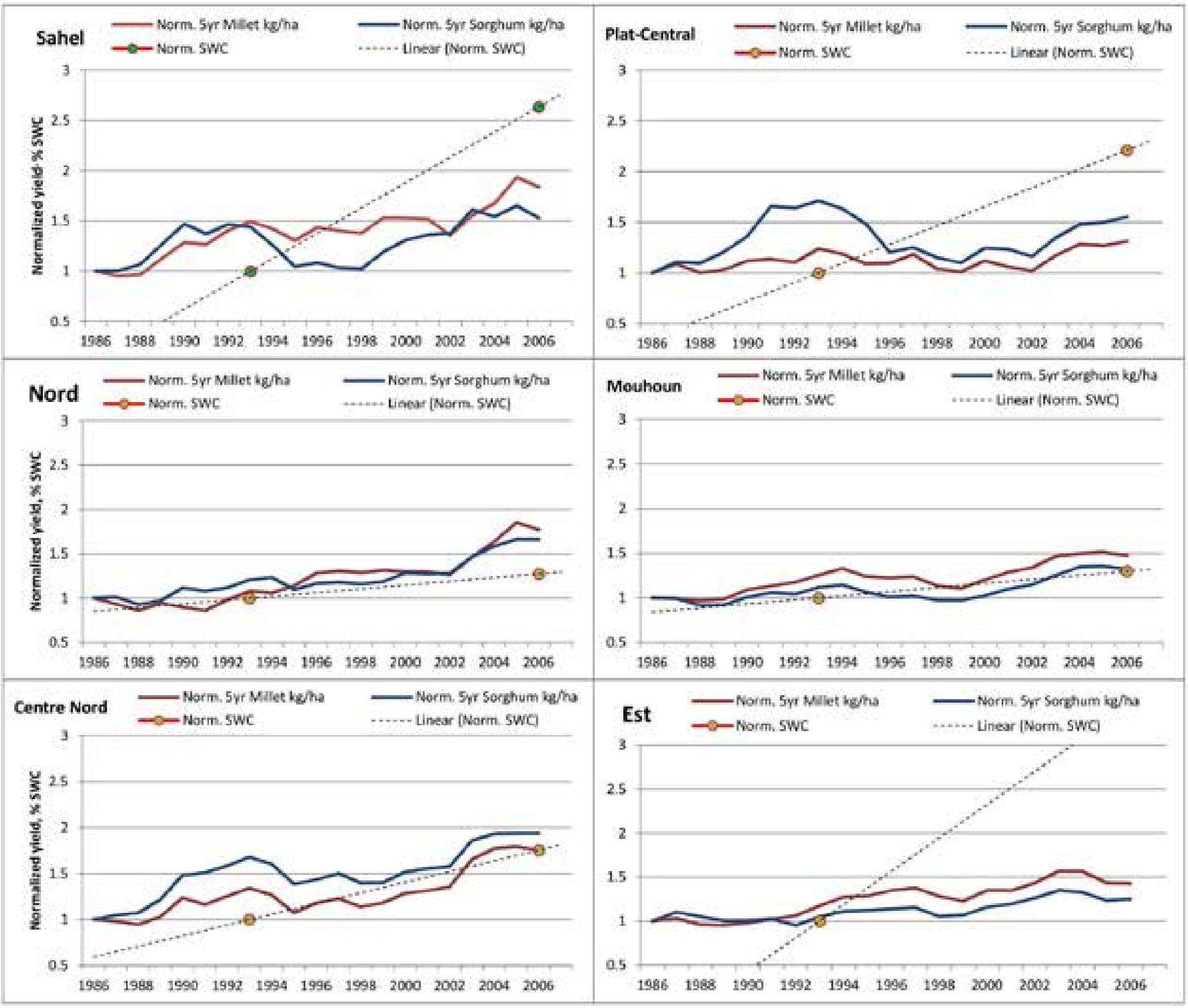
Millet and sorghum are typically rain-fed crops and therefore more likely to be affected by SWC adoption than by the building of small reservoirs due to direct in-field improvements in soil moisture availability. Comparing millet and sorghum yield with the national survey statistics for SWC shows similar gradients for yield and SWC trendlines (Table 7, Figure 8). All series were smoothed using a 5-year moving average to allow any trends to be seen more clearly and normalized by setting the first data point as 1. Thus, similar gradients imply that the changes in the variable are of a similar magnitude, suggesting a possible relationship that could be further tested when more data is available. With r^2 values mostly greater than 0.5, all regions except Plateau-Central show concurrent increases in yield and SWC over the period of development (though this is not the case for sorghum in Sahel). As highlighted in Table 7, Nord, Centre-Nord and Mouhoun all have very similar gradients of between 1% and 6% increase per year. For the remaining regions, SWC adoption has increased far more (10%-20%) relative to yields (1%-4%). While this simple analysis is not able to differentiate the impacts on yield of SWC versus land expansion, Figure 6b showed that land expansion is least significant for millet, which also has the most consistent improvement in yield and therefore the millet results may be more strongly related to SWC adoption. However, land expansion is an important confounder and should be included in further analyses, particularly in relation to sorghum and in general for Mouhoun, Est and Sahel, which have greater possibility for expansion.

Table 7: Characteristics of the trends in cereal yield and SWC adoption (1984–2008).

Trendline	Gradient	r^2	Gradient	r^2	Gradient	r^2
	SAHEL		NORD		CENTRE-NORD	
SWC	0.126	*1*	0.0211	*1*	0.0581	*1*
Millet	0.0367	*0.7929*	0.0425	*0.8432*	0.0349	*0.7074*
Sorghum	0.0193	*0.3099*	0.0307	*0.8066*	0.0365	*0.6807*
	PLATEAU-CENTRAL		MOUHOUN		EST	
SWC	0.0932	*1*	0.0228	*1*	0.1891	*1*
Millet	0.0081	*0.2756*	0.024	*0.7636*	0.0296	*0.8472*
Sorghum	0.0067	*0.037*	0.0161	*0.5659*	0.0149	*0.6865*

Data sources: DGPER (2008) and INSD (2012c); INSD (1994), MAHRH and DGPSA (2007).

Figure 8: Comparison of rain-fed cereal yields with SWC adoption (millet and sorghum, 5-year moving averages, all series normalized).



Data sources: DGPER (2008) and INSD (2012c); INSD (1994), MAHRH and DGPSA (2007).
* Norm. is an abbreviation of 'Normalized'.

Rice benefits more from small reservoirs expansion than SWC adoption, due to the increased irrigation potential. Nonetheless, there are instances of initial experiments using half-moons to cultivate rain-fed rice (Zougmoré, pers. comm.). Small reservoir development was, therefore, compared with normalized, 5-year moving averages of rice yields (Figure 9). As in Figure 8, positive trends of increasing yield can be seen, ranging from around 0.2% per year in Mouhoun to 3% in Plateau-Central and Est and up to 11% in Sahel (Table 8). The most closely comparable rates of increase in reservoirs and rice yields, confirmed by a quick regression, are found in Nord, Centre-Nord and Sahel.

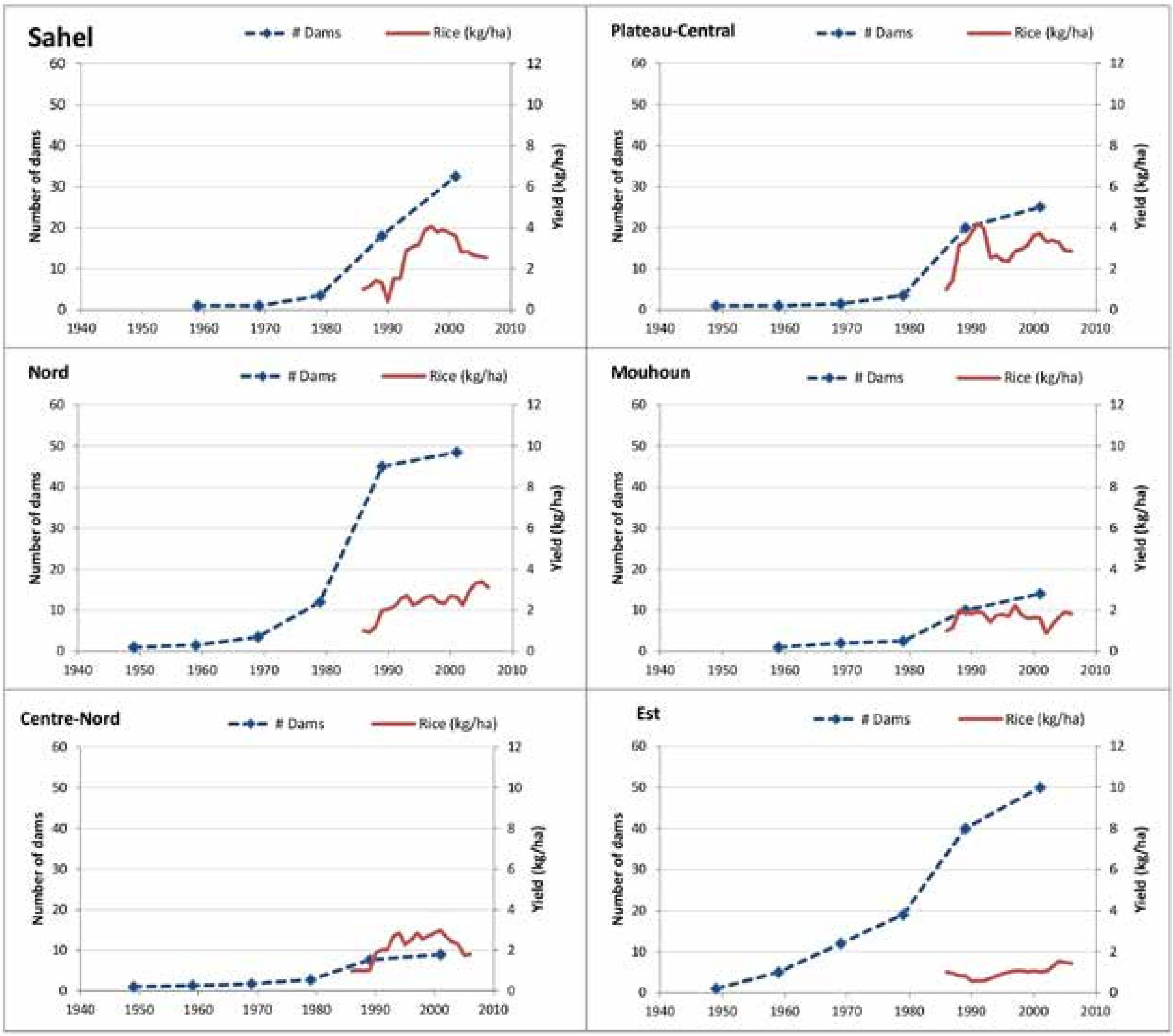
Table 8: Characteristics of the trends in rice yield and reservoir construction (1984 – 2008).

Trendline	SAHEL		NORD		CENTRE-NORD	
	Gradient	r^2	Gradient	r^2	Gradient	r^2
Small reservoirs	0.7779	*0.8542*	0.1048	*0.8259*	0.1673	*0.8515*
Rice	0.1143	*0.4047*	0.0905	*0.7199*	0.0615	*0.3303*
Regression*	1.7904	*0.8193*	3.9849	*0.7881*	5.7231	*0.821*
	PLATEAU-CENTRAL		MOUHOUN		EST	
Small reservoirs	0.5005	*0.7859*	0.3288	*0.8794*	0.9942	*0.943*
Rice	0.0386	*0.0962*	0.0016	*0.0009*	0.034	*0.5964*
Regression*	1.1684	*0.0892*	0.8073	*0.229*	0.4289	*0.2096*

Note: * A simple regression of the rice yields (3-year moving average, not normalized) against the cumulative number of small reservoirs for 1984-2001.

Data sources: DGPER (2008) and INSD (2012c); Cecchi (2008).

Figure 9: Comparison of rice yield with number of small reservoirs for period 1949-2008 (5-year moving average, both series normalized).



Data sources: DGPER (2008) and INSD (2012c); Cecchi (2008).

4.2 Poverty Level

Burkina Faso has a total population of just over 15.2 million (INSD 2013a), of which the rural population is 11 million (72%). 80% of the working population is employed in the agricultural sector (MEF 2000). Poverty analyses of the 1994 and 1998 household surveys show regional poverty levels for the study area remaining the same (40-60%), except for Plateau-Central, where poverty increased from 50 to 55% (Table 9), reflecting the influence of Ouagadougou's higher urban poverty. The official statistics for 2003 and 2006 suggest dramatic fluctuations in poverty, with all regions both better and worse off in either 2003 or 2006 than in 1993 (Figure 10). For example, poverty in Sahel apparently decreased to 37% in 2003, but then rose to 79% in 2006. Discussion in the literature (e.g. Grimm and Günther 2007; Lachaud 2004) suggests that the 2003 results are not comparable to the earlier analyses, because the 2003 analysis (INSD 2003) was based on different expenditure aggregates. The 2006 results may be similarly affected, as they are based on the population census rather than the household surveys. Recalculations for the national level show that poverty, in fact, declined (Grimm and Günther 2007; World Bank 2014) or at least stabilized (Lachaud 2004) over the study period.

Table 9: Poverty level and AWM expansion over a short period (1993-2007).

Region	% Incidence of poverty				% Owning ploughs			% Owning draft power		
	1994	1998	2003*	2006	1993	2003	2007	1993	2003	2007
Sahel	50.1	42.3	37.2	78.9	2.5	26.1	29.5	2.3	30.4	38.6
Nord	61.2	61.2	68.6	43.2	34.2	27.3	43.1	6.05	40.2	33.8
Centre-Nord	61.2	61.2	34	49.4	16.7	27.4	31.7	5.8	34.6	27.1
Plateau-Central	51.4	55.5	58.6	36.5	37.1	51.3	53.3	13.8	58.5	53
Mouhoun	40.1	40.8	60.4	52.7	39	56.3	53.7	35.4	63.2	57.7
Est	54.4	47.8	40.9	67.7	17	43.4	49.1	6.7	47.2	49.9

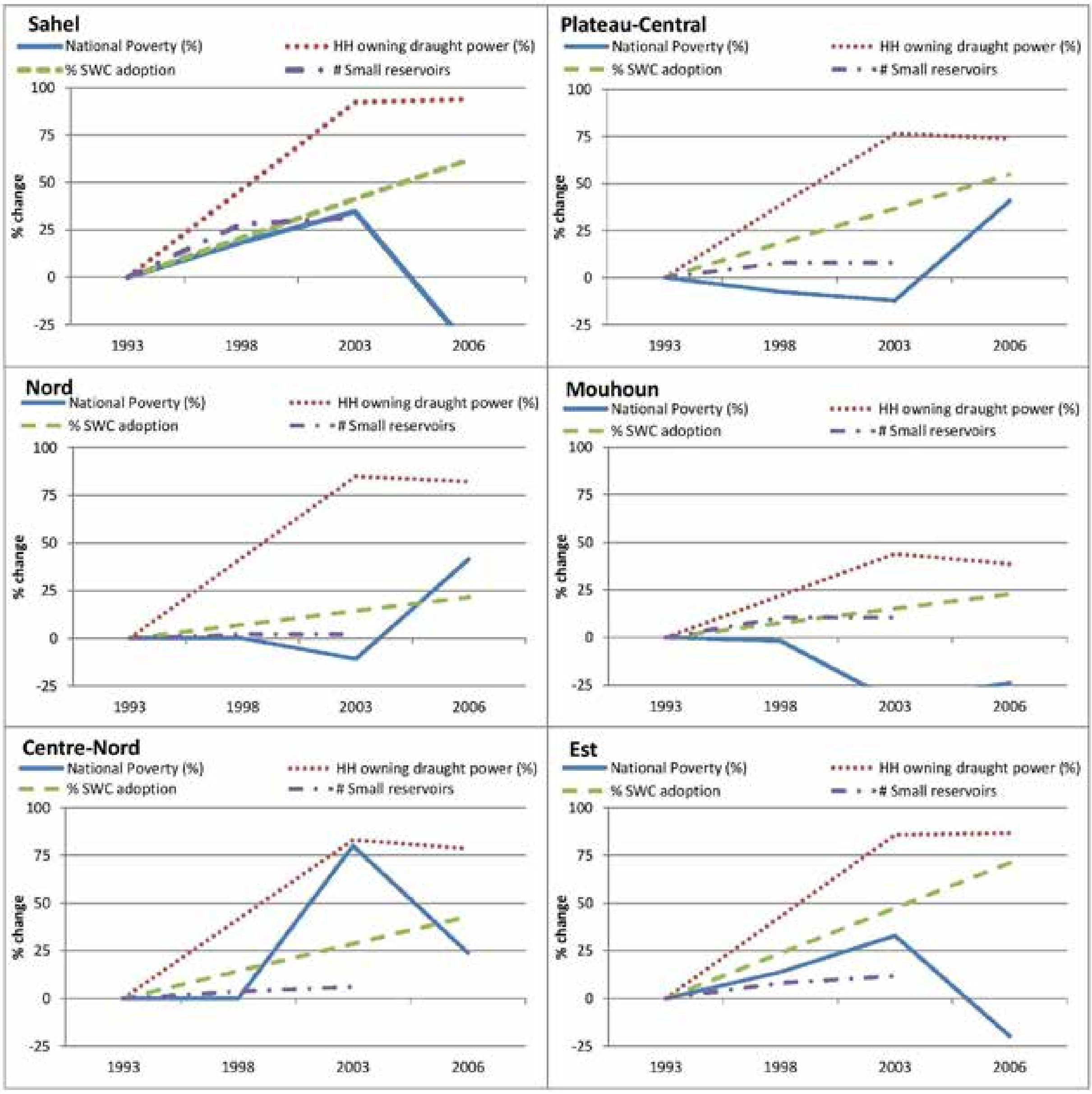
Region	% Plots using SWC measures			No. of small reservoirs		
	1993	2006		1993	1998	2003
Sahel	6.9	18.2		46	64	67
Nord	17.1	21.8		96	98	98
Centre-Nord	15.9	27.9		78	81	83
Plateau-Central	9.9	21.9		47	51	51
Mouhoun	6.4	8.3		26	29	29
Est	2.4	8.3		45	49	51

Data sources:
i) National poverty incidence (%) by region (MEF 2000 for 1994 and 1998; INSD 2012b for 2003; MEF 2009 for 2006).
ii) An indicator of rural poverty - Proportion (%) of households possessing agricultural equipment (INSD 1994, 2003, 2007).
iii) Estimated adoption of SWC measures (National agricultural surveys: INSD 1994; MAHRH and DGPSA 2007)
iv) Total number of small reservoirs recorded (Small Reservoirs Database: Cecchi 2008).
Note:* There has been discussion over the calculations used to produce these numbers (see Grimm and Günther 2007; Lachaud 2004), saying they should be lower.

However, the econometric methodologies used to produce the national poverty statistics are based on household assets and access to services that are mostly relevant to urban areas - electricity, piped water, electrical appliances, concrete, etc. Testing an alternative, i.e., a non-econometric analysis of poverty that is based on food sufficiency and a food poverty line, D'haen (2012) found that in urban areas nation wide, poverty decreased from 2003 to 2007, but rose slightly in 2005 due to higher food prices brought about by very poor harvests across the country. D'haen (2012) shows that incorporating food sufficiency as a central indicator of household well-being reflects poverty levels more comprehensively across rural and urban areas than is the case of econometric analyses. Food security is therefore explored in more depth below in Section 4.3.

An additional indicator of rural wealth can be cattle or livestock ownership, representing investment of excess income (Moll 2005; Sidibé 2005). An analysis of ownership of ploughs and livestock for draft power suggest that all regions were much better off in 2007 than in 1993 (Table 9), as there has been a marked increase in agricultural assets, which may be reflecting improved income due to AWM adoption. More data points, particularly between 1993 and 2003, would confirm whether the increase is a result of a consistent linear trend, or whether, for example, 2003 and 2007 are representing considerably higher than average values, due to experiencing an exceptionally good harvest in year 2003 (D'haen 2012).

Figure 10: Proportional (%) change in poverty and AWM, over a short period (1993-2007), drawn by the author from the data in Table 9.



Note: National poverty incidence data was inverted so that a positive change in national poverty refers to a reduction in poverty incidence (i.e., an improvement).

Poverty and agricultural water management (AWM)

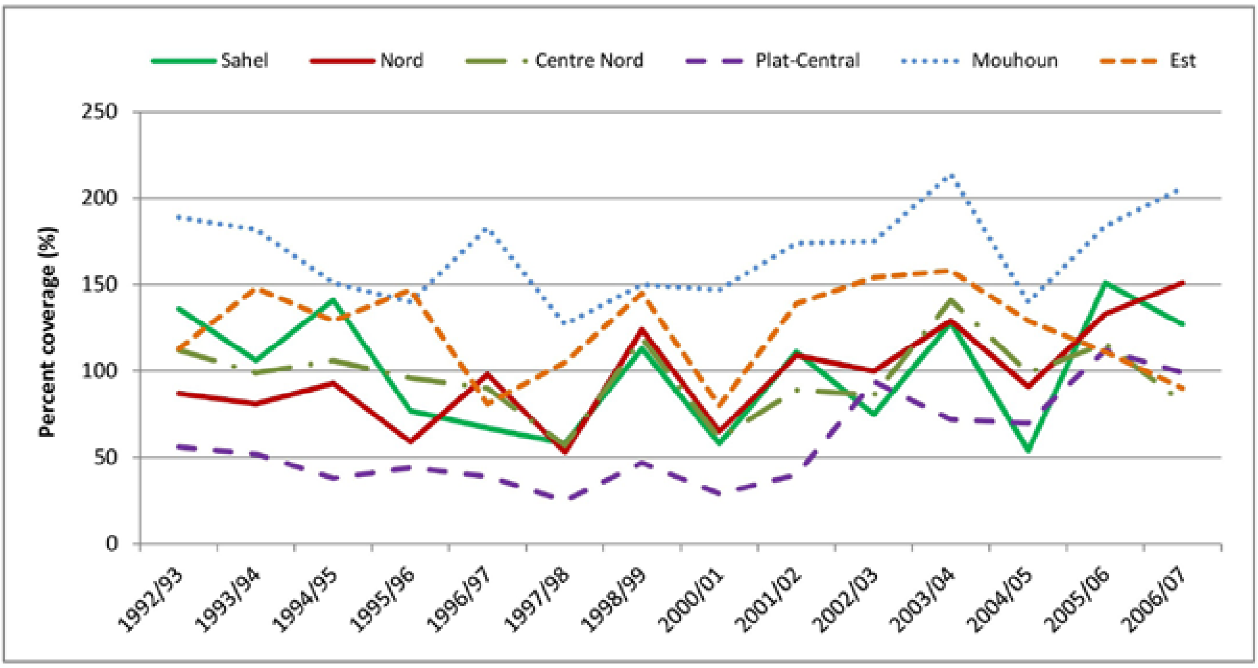
A rigorous analysis of poverty impact resulting from AWM expansion has not been possible with the limited data available, considering also the number of other influences on poverty/wealth, including non-agricultural income sources, improved infrastructure and access to markets, varying demands on income and external shocks. Attributing impact is discussed further in Section 5. However, it is still useful to place the AWM expansion in the context of available indicators of poverty. Rural wealth as indicated by draft ownership has consistently improved alongside AWM expansion (Figure 10) for the period with overlapping data (1993-2007). However, the relative degree of improvement in wealth compared to AWM expansion varies across the regions. For all regions except Mouhoun, wealth has increased by more than 75% of 1993 values, while the proportional change in SWC ranges from 20 to 70% increase from

1993 values. Only in Sahel, Plateau-Central and Est do SWC adoption show similar, though lower, rates of change to rural wealth (50-70%). The change in small reservoirs is generally low over the comparison time period (<15%), as most reservoir expansion had already occurred in the 1980s, except for Sahel where 32% more reservoirs were still to be built after 1993. As the comparison time period captures only the tail end of small reservoir expansion (for the current dataset), it is difficult to make comparisons to wealth, because the impact may have occurred before 1993. Although the national statistics for poverty incidence should be viewed with caution, pending more information on the underlying calculations used, the data suggest at least a 25% improvement in all regions except Mouhoun between 1993 and 2003 or 2006. From the small, current dataset, there is no clear correlation between AWM expansion and wealth; longer and more detailed, overlapping time series are required.

4.3 Food Security

Monitoring food security (INSD 2012a) shows that the northern provinces are mostly able to meet their food requirements (190 kg of cereals per capita) through domestic production, although it fluctuates dramatically from year to year (Figure 11). Overlying the year-to-year variation, larger fluctuations can be seen as minimum and maximum figures decrease from 1993/4 to about 1997/8. Since 1998/9, the minimum rates of coverage appear to have been increasing. This general upward trend is particularly noticeable in the Nord region, which also appears to have a smaller range of fluctuation than the other regions. Centre-Nord has somewhat less inter-annual fluctuation as well, apart from the period 1997-2000. Potentially, this is a crude indicator that the higher intensity of SWC promotion carried out in Nord and Centre-Nord, compared to other regions, has resulted in a slight buffer against seasonal variations in these regions. It should be noted that until 2001, Plateau-Central included Kadiogo, the district containing the capital, Ouagadougou. Therefore, its food coverage for that time is depressed compared to the period after 2001, when Kadiogo was no longer included in the Plateau-Central region. Similarly, it is clear from the data that Mouhoun is one of the "granaries" of Burkina Faso, producing on average 170% of the country's cereal requirements each year.

Figure 11: Rate of coverage of food needs (%) per region, 1992-2006.



Data Source: Tableau de Bord Social (INSD 2012a).

5. Discussion

Despite a wealth of research on the potential benefits of various agricultural production technologies for smallholder farming systems in sub-Saharan Africa, there is limited data available on the actual adoption rates and extent of use of these technologies. Hence, there is limited knowledge on their actual impact on smallholder livelihoods. In this report, we focus on two key agricultural water management (AWM) technologies that have generated substantial research and development investments over the past 40 years (Douxchamps et al. 2014) in northern and central Burkina Faso, as identified in an initial study made to address the knowledge gap.

Small reservoirs expansion

From the Small Reservoir Database (Cecchi 2008), which holds records of most reservoirs built up until 2001, it is clear that small reservoir development accelerated in the 1980s, with over 60% of the current stock being built in the 1980s in most regions, and progressed into the 1990s in Sahel and Est. The highest density of small reservoirs occurs mainly on the central plateau (the most densely populated region) and in the northeast of the Sahel region (the driest part of the country). The summary of statistics from the database highlights that despite accounting for at least 60%, and up to 90%, of all reservoirs recorded in Burkina Faso, small reservoirs only carry around 3% of the total volume of stored water. This has important implications for potential upscaling and restoration of small reservoirs as some studies suggest small reservoirs have marginal impact on the overall basin water balance (e.g. De Condappa et al. 2008a), but enable significant benefits to livelihoods and human wellbeing (Venot et al. 2012).

In terms of the impact of small reservoir expansion on livelihoods, productivity changes in irrigated cereals (rice) for the same available time period (1984-2001) suggests a strong increase in rice productivity. Reservoir development is suggesting expansion of rice in the region, particularly in Sahel, Plateau-Central and Centre-Nord. This result is to be expected as the reservoirs are often built for the purpose of initiating or servicing rice irrigation schemes. The closest correlations in rice are found in the highly populated Nord and Centre-Nord and in the arid Sahel, which realized a 6-11% per year productivity increase, albeit still producing small overall quantities. A case study of such a rice irrigation scheme (de Fraiture et al. 2014) documents the development of additional small-scale, informal market gardening that is occurring concurrently, which highlights the importance of the reservoirs for supplemental irrigation. Their multiple-use function is especially important for livelihood diversification as a coping strategy in highly populated areas where land availability is limited as well as in dry areas where water is scarce. A detailed multiple regression analysis of the additional benefits of supplemental irrigation in comparison to other crops was not possible in this study. Nevertheless, it is essential for evaluating and establishing the best management strategies to ensure sustained benefits from small reservoirs.

Only a brief comparison between small reservoirs and poverty-related indicators (poverty levels, ownership of agricultural assets and food security) was possible in this review, because the overlap in time between the respective datasets was insignificant (less than 10 years and only two data points for poverty). The most significant reservoir development occurred in the 1980s, which is before the time period covered by the poverty indicators (1993-2007). Hence, any immediate impacts on poverty would not have not been captured. However, in Sahel, the one region which had significant reservoir expansion after 1990 (about 25% between 1993 and 2001), both national statistics and ownership of agricultural capital (draft animals and equipment) suggest similar or greater improvements in wealth from 1993 to 1998. Nonetheless, this comparison is based on only two data points for poverty, i.e., in 1993 and 1998. Currently it is assumed that there will be large potential benefits from the expansion of small reservoirs in improving water accessibility to smallholder farmers, without having any significant impact on the overall water balance (Venot et al. 2012). However, the benefits must be balanced against reservoirs' hydrological (in)efficiency and the negative impacts of mismanagement and siltation (Venot et al. 2012). It is therefore critical to access better time series that allow a more accurate assessment linking small reservoir development to more sustainable livelihoods.

Adoption of soil and water conservation (SWC)

The wide-scale dissemination of soil and water conservation (SWC) technologies began on the central plateau in the 1980s. By 2006, SWC practices had successfully expanded, with evidence of adoption rates (the percentage of cultivated land where SWC is in use) of at least 25% in Plateau-Central and Sahel; 28% in Nord; and 38% in Centre-Nord. Outside of this central area, which has been the core of SWC promotion projects for 30 years or more, and within the remaining study area that receives less than 700 mm rainfall per year, adoption rates were a modest 10-20%. These adoption rates are a minimum estimate derived from the use of anti-erosion measures, predominantly stone and earth bunds, *zai* pits and windbreaks, in fields surveyed for the annual agricultural survey and represent the proportion of cultivated land enhanced with SWC. The increase in the peripheral provinces, though modest (10-15% adoption), is heartening as some doubled their 1993 rates. The Sahel region, in particular, has by far had the largest increase from around 5% up to 25% adoption. Such a large expansion of SWC measures in an arid environment, particularly if used to rehabilitate degraded land (e.g., Reij et al. 2009), would agree with and explain the evidence of "greening of the Sahel" that has been analyzed through remote sensing (e.g., Haglund et al. 2011). Therefore, we speculate that the government support and emphasis on promoting SWC to counter erosion, with the help of the large international projects, has been successful beyond the original geographical scope of the projects. There is also clear evidence of a drop in rates of uptake across the 700 mm threshold of annual rainfall. In the southernmost provinces of Mouhoun and Est, which receive 700-900 mm of rainfall per year, adoption has remained minimal (Appendix A3), which is a consequence of SWC being less productive in higher rainfall regimes where the in-situ rainwater harvesting technologies (stone bunds, *zai*) retain too much water and cause waterlogging (IEG 2011; Barbier et al. 2009; Roose et al. 1999). Crops may be lost from flooding in more seasons than they benefit from the rainwater harvesting. However, vegetative barriers, as opposed to mineral barriers, are suggested as a means of benefitting from SWC in higher rainfall regimes as they are porous and will use excess water, although they can still cause waterlogging (Spaan 2003; Zougmoré et al. 2009). Vegetative barriers were excluded from this study as competing for water in semi-arid and arid regions, but warrant further study.

Comparing SWC adoption to yield changes, poverty and food security proved somewhat more relevant than for small reservoirs, as the time series overlap well (1980s-2006). Unfortunately, the concrete data on SWC adoption is limited to two data points (1993 and 2006), which limits the potential of the analyses. Obtaining access to more data points to fill out the SWC time series is key to confirming the initial findings made in this study. Regional yields of major rain-fed cereals have improved over the period 1984-2008, indicating a 1-4% increase per year for normalized 5-year moving averages. Millet presents the most coherent improvements, almost doubling in yield across the study area, as does sorghum in Nord, Centre-Nord and Sahel where SWC has been most widely adopted. Furthermore, yield per capita has increased consistently in Nord. Comparing the magnitude and timing of increases in millet and sorghum yields with SWC adoption suggests closely comparable rates of increase in Nord, Centre-Nord and Mouhoun, which supports the hypothesis that the introduction, adoption and uptake of SWC is successful in improving yields and ultimately livelihoods. Although still increasing together in Sahel and Plateau-Central, the expansion of SWC adoption has far outstripped yields, growing 10% - 12% per year compared to yields (1%-4%). Firstly, yields in these two regions are more variable than in the rest of the study area, which depresses the average rate of increase. Furthermore, these two regions are the most constrained for land (Plateau-Central) and water (Sahel), and thus lower yields could be expected. Further data, to extend the time series as well as to fill in gaps, will be important for producing a detailed multiple regression analysis that illuminates how SWC adoption interacts with yield, together with other constraining and enabling factors.

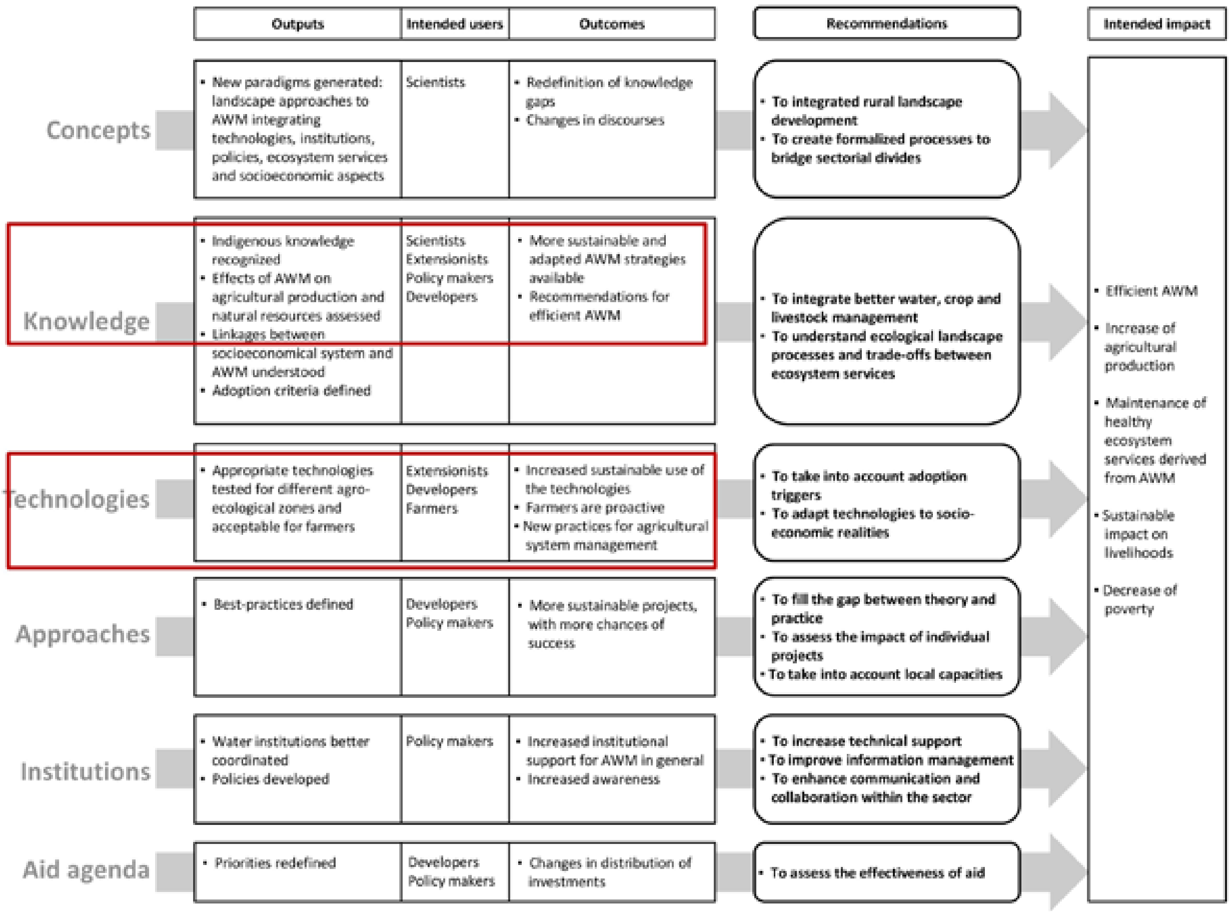
The available measurements of regional poverty levels, ownership of agricultural equipment and food security suggest overall improvements over the past 20 years. However, greater detail in the time series is still required to assess how significant these improvements have been and whether a strong relation can be determined in relation to the normalized yield and outscaling of AWM technologies such as small reservoirs and SWC. Although the SWC statistics do overlap with the poverty statistics, both datasets are only represented by a few data points (1993, 2003, 2005/6), presenting snapshots rather than trends. For example, both 2003 and 2007 yielded very good harvests, whereas in 2005 late rains led to very poor harvests nation wide and low food sufficiency (D'haen 2012, p69), a fact reflected in the worsening of poverty indicators. Greater detail in both time series would allow an assessment to be made as to whether areas with higher SWC adoption were buffered against the crisis in 2005 or not. However, the limited data available suggests that a positive linkage exists. This indicates that, while AWM adoption is intuitively important to poverty reduction, the link between improved yields and reduced poverty levels is very complex and indirect. Hence, more data and analysis is required to shed light on the interaction at the regional level. The benefits of AWM have been proven in field trials. However, more data is required to conclusively link widespread regional AWM adoption to improved regional yield.

Outside the core area of Nord and Centre-Nord, Sahel, in particular, has higher and more consistent yield improvements in rain-fed cereals and rice compared to the other regions. This may be an indirect benefit of both small reservoirs and SWC measures retaining water in a landscape with highly temporal variation of rainfall and thereby contributing to groundwater storage. However, this is an issue for more detailed, future research.

Attribution of impact

This study provides a starting point for exploring the link between improving agriculture (AWM adoption) and achieving widespread impact on livelihoods, in the form of regionally improved food security and poverty reduction, via increased yields. However, the study has only analyzed the start- and end points in the outcome-impact pathway (Figure 12). It has also only covered a limited number of aspects of the pathway. Douxchamps et al. (2014) explain how achieving sustainable impact from AWM uptake and outscaling is contingent on the successful achievement several other components, beyond simply introducing the AWM technology. Complementary "levers of change" by a range of actors include reinforcing the knowledge base, providing institutional support and using best practices in implementation approach – all set within a conceptual understanding of landscape approaches, with active communication and integration between actors. Furthermore, AWM adoption is one strategy among many factors contributing to enhancing yield, food security and income. For example, rainfall variability is an overriding determinant of actual productivity, with short-term and long-term periodicity clearly evident in the yield data. Moreover, adopting AWM interventions is only one of several options for changing the management of the cropping system to achieve better yields; others include adding fertilizers, managing pest and weeds, using hybrid varieties of seeds and implementing best and most timely mix of crop management strategies.

Figure 12: Impact pathway for the various aspects of the evolution of AWM projects



Source: Douxchamps et al. 2014. Highlight added by author.

Examples of the drivers of AWM adoption from the other components beyond the technology itself (its effectiveness for improving yield) include the significant external investments, in the order of USD 641 million, which have been allocated over the period 1970 to 2009 toward agricultural water management projects, including SWC, in conjunction with long-term, government-driven programmes (Sidibé 2005; Douxchamps et al. 2014). Similar support may be driving fertilizer distribution or microcredit promotion in particular regions, which needs to be investigated in association to AWM adoption to scale. Are the multiple system interventions enabling yield impact to scale? Or can AWM adoption as a single intervention alone be the contributor to the yield gains? Similarly, as in Botoni and Reij (2009) and Douxchamps et al. (2014), nonfarm income (e.g., remittances), population dynamics, national politics and infrastructure development, including changes in access to markets and information, are all part of the other necessary components for sustainable impact. Roads accessible during all seasons are critical for providing access to markets and their absence therefore hinders the sale of excess production and access to inputs to improve production (e.g., Fan et al. 2004).

Full exploration of the contribution to specific development goals by AWM adoption at a societal scale would require multiple regressions analyses with a more substantive datasets. This was out of the scope of this study due to the lack of consistent data on development as well as on AWM adoption across regions. Such an analysis is a critical next step in gaining a better understanding of how to achieve sustainable impact on livelihoods from agricultural development and investments.

6. Key Messages and Recommendations

The purpose of this study is to synthesize evidence on adoption of AWM interventions and the contribution to development goals such as yield increase, food security and poverty alleviation. It aims to develop proof of the often assumed causalities between AWM development and yield improvements to scale, to complement the case study literature (e.g., Sawadogo 2011; Reij et al. 2005) that shows, at the field-scale, how successful AWM technologies can be at farmer and community scale. The study set out to provide a sub-national overview of AWM adoption and its impact on yield and poverty in Burkina Faso.

The preliminary study has shown that

- Soil and water conservation (SWC) technologies have expanded substantially in the study area of north central Burkina Faso between 1980 and 2005 in provinces receiving 700 mm mean annual rainfall or less, with evidence of adoption rates of at least 25-40% coverage of cultivated area in Centre-Nord, Nord, Plateau-Central and Sahel, and a minimum of 10-20% in the rest of the study area

- There has been a gradual increase in regional yields of around 3% per year from the 1980s to 2008, leading to a 150%-200% increase in absolute yields over 30 years until 2010

- Rates of increase between rain-fed cereal yields and SWC adoption in Nord and Centre-Nord are particularly aligned, and there is a close correlation between rice productivity and small reservoir expansion in Nord, Centre-Nord and Sahel

- Poverty and food security indicators suggest improvements in the well-being of farmers since the 1990s with an average 25% reduction in poverty incidence across the study area and an estimated 4% per year increase in food security in Nord and Plateau Central

- To attribute AWM adoption to the outcomes in development is likely an oversimplification. AWM adoption should be further analyzed, taking at least rainfall patterns, crop/seed use and fertilizer management into account over the same time, controlling for co-benefits in yields

Achieving impact on food security and poverty alleviation via AWM uptake and outscaling is a product of multiple inter-dependent components (technology, knowledge, approaches, institutions, concepts) and just one of many strategies to achieving livelihood improvement. More data and long-term analysis is needed to illuminate the AWM impact pathway at provincial and regional scale to clarify levers of change and "best bet" investments in rural development. Further analysis of the regional yield trends and more detailed time series for household wealth and food security indicators is needed to further explore the causal evidence of AWM development and rural food security gains or poverty alleviation effects at a sub-national scale. This review, therefore, provides a starting point for future work.

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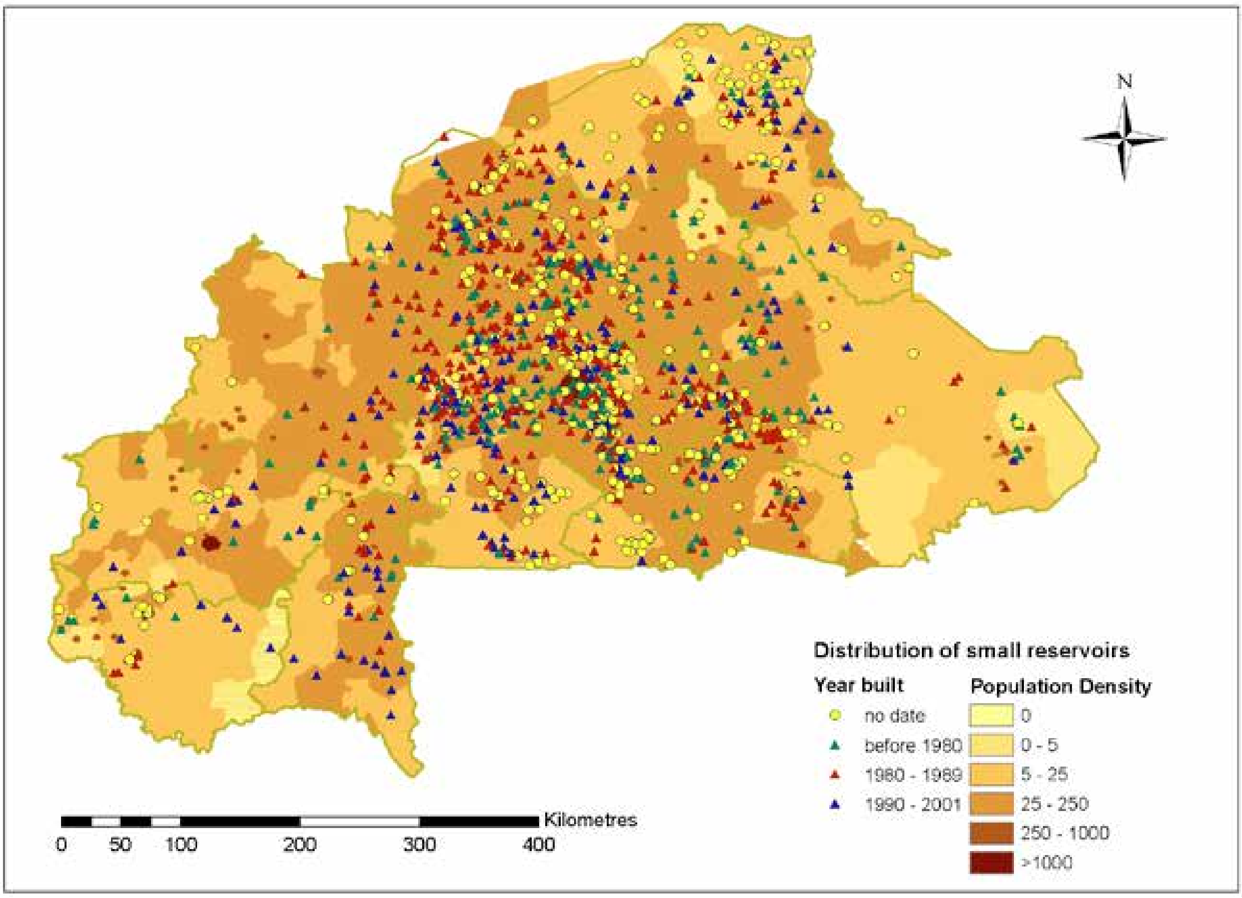
Appendices

A1. Small Reservoirs Mapped With Population Density

Figure 13: Distribution of small reservoirs against population density, according to date of construction
(Drawn from Cecchi 2008 (reservoirs); CIESIN et al. 2011 (population density). Includes 381 reservoirs with no recorded construction date. 234 reservoirs were built before 1980; 463 were built in the 1980s; 243 were built in the 1990s.



A2. Literature Review

The most relevant published articles found in database searches, reporting the use and/or impact of soil and water conservation technologies in Burkina Faso:

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5. Reij, C., G. Tappan and M. Smale 2009a. Agroenvironmental Transformation in the Sahel: Another kind of 'Green Revolution'. IFPRI Discussion Paper, 00914. Washington, D.C.: International Food Policy Research Institute (IFPRI).

6. Reij, C., G. Tappan and M. Smale 2009b. Re-Greening the Sahel: Farmer-led innovation in Burkina Faso and Niger. In: Millions fed Proven successes in agricultural development. Washington, D.C.: International Food Policy Research Institute (IFPRI).

A3. SWC Distribution by Province, 1993* and 2006

Note: * In 1993, the old boundaries were still in effect, and only 30 of the present 43 provinces existed.
Data Sources: National Agricultural Surveys for 1993 (INSD 1994) and 2006/7 (MAHRH and DGPSA 2007).

Province	Region	% any SWC 1993	% any SWC 2006
Sahel			
Oudalan	Sahel	2.1	25.6
Seno	Sahel	8.9	25.4
Soum	Sahel	8.2	6.9
Yagha	Sahel		24.4
Centre-Nord			
Bam	Centre-Nord	17.7	34.8
Namentenga	Centre-Nord	5.2	16.0
Sanmatenga	Centre-Nord	22.8	35.9
Plateau-Central			
Ganzourgou	Plateau-Central	12.0	18.7
Oubritenga	Plateau-Central	8.4	24.8
Kourweogo	Plateau-Central		21.7
Nord			
Loroum	Nord		17.2
Passore	Nord	18.9	19.7
Yatenga	Nord	16.3	23.1
Zondoma	Nord		27.8
Est			
Gnagna	Est	3.2	15.2
Gourma	Est	3.0	6.2
Komandjoari	Est		11.2
Kompienga	Est		3.5
Tapoa	Est	0.7	4.0
Mouhoun			
Bale	Mouhoun		3.5
Banwa	Mouhoun		0.4
Kossi	Mouhoun	5.5	6.6
Mouhoun	Mouhoun	7.0	3.8
Nayala	Mouhoun		18.1
Sourou	Mouhoun	7.6	16.2

A4. SWC Sites Recorded in Literature, shown in Figure 4

Village	Province	Region	Time period	Reference
Ziga	Yatenga	Nord	1986-87-90	Roose and Rodriguez (1990)
Ziga	Yatenga	Nord	2005	Masse et al. (2011)
Ziga	Yatenga	Nord	2007	Belemvire et al. (2008)
Boukere	Yatenga	Nord	1986-87-90	Roose and Rodriguez (1990)
Segue	Yatenga	Nord	1986-87-90	Roose and Rodriguez (1990)
Pouyango	Yatenga	Nord	1992, 1993	Roose et al. (1999)
Taonsogo	Yatenga	Nord	1992, 1993	Roose et al. (1999)
Kirsi Village	Yatenga	Nord	1992-1996	Barry et al. (2008)
Saria Agricultural Research Station	Boulkiemde	Centre-Ouest	2000-2003	Barry et al. (2008)
Pougyanou Village	Passore	Nord	1998-1999	Barry et al. (2008)
Ranawa	Zondoma	Nord	1980-2001	Hien and Ouedraogo (2001)
Recko	Yatenga	Nord	1992	Atampugre (1993)
Boulounga	Yatenga	Nord	1992	Atampugre (1993)
Longa	Yatenga	Nord	1992	Atampugre (1993)
Noogo	Yatenga	Nord	1992	Atampugre (1993)
Ranawa	Zondoma	Nord	1992	Atampugre (1993)
Sologom-Noore	Zondoma	Nord	1992	Atampugre (1993)
Rawounde	Zondoma	Nord	1992	Atampugre (1993)
Mogom	Yatenga	Nord	1992	Atampugre (1993)
Iria	Yatenga	Nord	1992	Atampugre (1993)
Gonsin	Yatenga	Nord	1992	Atampugre (1993)
Rimassa	Loroum	Nord	1992	Atampugre (1993)
Tanghin-Baongo	Loroum	Nord	1992	Atampugre (1993)
Tougi-bouli	Loroum	Nord	1992	Atampugre (1993)
Lelly	Seno	Sahel		Some et al. (2000)
Thialel	Seno	Sahel		Some et al. (2000)
Gangol	Seno	Sahel		Some et al. (2000)
Kishi-Beiga	Oudalan	Sahel		Some et al. (2000)
Gorom-Gorom	Oudalan	Sahel		Some et al. (2000)
Boroni	Yatenga	Nord		Some et al. (2000)
Tiebelga	Yatenga	Nord		Some et al. (2000)
Bakou	Yatenga	Nord		Some et al. (2000)
Rim	Yatenga	Nord		Some et al. (2000)
Sissamba	Yatenga	Nord		Some et al. (2000)
Doure	Zondoma	Nord		Some et al. (2000)
Kera	Zondoma	Nord		Some et al. (2000)
Biliga	Bam	Centre-Nord		Some et al. (2000)
Rissiam	Bam	Centre-Nord		Some et al. (2000)
Goungla	Bam	Centre-Nord		Some et al. (2000)
Kirsi	Passore	Nord		Some et al. (2000)

Village	Province	Region	Time period	Reference
Magombouli	Yatenga	Nord	2003/2004	Sidibé (2005)
Noogo	Yatenga	Nord	2003/2004	Sidibé (2005)
Ranawa	Zondoma	Nord	2007	Belemvire et al. (2008)
Solgomnore	Zondoma	Nord	2007	Belemvire et al. (2008)
Doure	Zondoma	Nord	2007	Belemvire et al. (2008)
Salaga	Zondoma	Nord	2007	Belemvire et al. (2008)
Kire	Yatenga	Nord	2007	Belemvire et al. (2008)
Fili	Yatenga	Nord	2007	Belemvire et al. (2008)
Waganda	Yatenga	Nord	2007	Belemvire et al. (2008)
Bilinga	Yatenga	Nord	2007	Belemvire et al. (2008)
Sonh	Yatenga	Nord	2007	Belemvire et al. (2008)
Rissiam	Bam	Centre-Nord	2007	Belemvire et al. (2008)
Boalin	Bam	Centre-Nord	2007	Belemvire et al. (2008)
Sankonde	Bam	Centre-Nord	2007	Belemvire et al. (2008)
Gonse	Bam	Centre-Nord	2007	Belemvire et al. (2008)
Noh	Bam	Centre-Nord	2007	Belemvire et al. (2008)
Tensobdogo	Bam	Centre-Nord	2007	Belemvire et al. (2008)
Loungo	Bam	Centre-Nord	2007	Belemvire et al. (2008)
Safi	Bam	Centre-Nord	2007	Belemvire et al. (2008)
Tougou	Yatenga	Nord	2004/2006	Barbier et al. (2009)
Yalka	Bam	Centre-Nord	1980-2004	Neubert et al. (2000)
Kaya region	Sanmatenga	Centre-Nord		Reij et al. (2009)
Tidmaren	Oudalan	Sahel	1978	IFPRI (2006)
Bissiga Forest	Oubritenga	Plateau-Central	1986-	Hien (1995)
Yabo Research Centre	Sanmatenga	Centre-Nord	1982-	Hien (1995)
Samboanli	Gnagna	Est	1990-	Mazzucato and Niemeijer (2000)
Pentouangou	Gourma	Est	1990-	Mazzucato and Niemeijer (2000)

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