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ORIGINAL ARTICLE

Buffer capacity: capturing a dimension of resilience to climate change in African smallholder agriculture

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Abstract Building resilience to climate change in agricultural production can ensure the functioning of agricultural-based livelihoods and reduce their vulnerability to climate change impacts. This paper thus explores how buffer capacity, a characteristic feature of resilience, can be conceptualised and used for assessing the resilience of smallholder agriculture to climate change. It uses the case of conservation agriculture farmers in a Kenyan region and examines how their practices contribute to buffer capacity. Surveys were used to collect data from 41 purposely selected conservation agriculture farmers in the Laikipia region of Kenya. Besides descriptive statistics, factor analysis was used to identify the key dimensions that characterise buffer capacity in the study context. The cluster of practices characterising buffer capacity in conservation agriculture include soil protection, adapted crops, intensification/irrigation, mechanisation and livelihood diversification. Various conservation practices increase buffer capacity, evaluated by farmers in economic, social, ecological and other dimensions. Through conservation agriculture, most farmers improved their productivity and incomes despite drought, improved their environment and social relations. Better-off farmers also reduced their need for labour, but this resulted in lesser income-earning opportunities for the poorer farmers, thus reducing the buffer capacity and resilience of the latter.

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Introduction

A high dependence on natural resources and rain-fed agriculture in a context of a changing climate, socio-economic pressures and low adaptive capacities make Africa's smallholder crop production vulnerable to climate change (IPCC 2007a; McIntyre et al. 2009). High rainfall variability in amount, time and location is common in African dry lands (Ogallo 1989) and poses a risk to maintaining and increasing agricultural production (Ifejika Speranza et al. 2008). The likely increase in rainfall variability projected for African drylands, a projected decrease in reliable growing days and an increase in season failure rates up to 2050 (IPCC 2007a; Jones and Thornton 2009) will exacerbate the already precarious climatic conditions for agricultural production.

Thus, building resilience offers a pathway to reduce the vulnerability of agricultural production to climate change. However, few studies have characterised resilience in the context of livelihoods-related environmental research. Resilience has three characteristic features, namely buffer capacity, self-organisation and capacity for learning, which also influence one another. While these three dimensions are important in general, this paper focuses on buffer capacity, with the aim to conceptualise it, and examines how conservation agriculture practices by farmers in Kenya contribute to buffer capacity and by extension to resilience.

Conservation agriculture

Conservation agriculture (CA) is "an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CA is characterised by three linked principles, namely: (1) Continuous minimum mechanical soil disturbance; (2) Permanent organic soil cover; (3) Diversification of crop species grown in sequences and/or associations" (FAO 2012a). To achieve minimal soil disturbance, no-tillage, minimum tillage or conservation tillage are common practices (see Baker et al. 2002 for details). Permanent organic soil cover is usually achieved through mulching or green manure. Appropriate crop associations and rotations are practised through mixed cropping of legumes with cereals (e.g. maize and pigeon peas). CA encompasses residue management, crop rotations, zero tillage, conservation tillage, direct planting/seeding and in some cases organic farming (FAO 2012b). "CA aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs" (FAO 2012b). Through these aims, CA can contribute to sustainable agriculture by increasing food productivity without having adverse effects on environmental goods and services (Pretty et al. 2006; FAO 2008; Hobbs et al. 2008).

CA also contributes to agroecology, which in a narrow sense refers to "the application of ecology in agriculture" but in a wider sense is "the ecology of food systems", thereby also incorporating socio-economic dimensions (Altieri 1989; Francis et al. 2003; Gliessman 2007; Wezel et al. 2009; De Schutter and Vanloqueren 2011). As a practice, agroecology refers to "a set of agricultural practices which aims at developing a more "environmental-friendly" or "sustainable" agriculture" (Wezel et al. 2009: 506). As it primarily aims at "solving the sustainability problem of agriculture" (Altieri 1989: 37), that is, how to maintain or increase productivity in the long-term without harming people or the environment, various CA practices can be components of an agroecology approach.

Depending on the social-ecological context, the practice of CA may have advantageous or disadvantageous aspects, and results obtained under experimental conditions may vary under farmer practice (Tittonell et al. 2008). In sub-Saharan Africa (SSA), CA can yield economic benefits such as reduced manual labour costs and saved time (although the findings of Siziba 2008 in Giller et al. 2009 contradict this general assumption). It can provide agronomic benefits such as improved soil productivity as well as environmental and social benefits such as reduced soil erosion, improved biodiversity, carbon sequestration and water quality. As farmers do not always adopt all principles of CA, it is difficult to identify or compare the contributions of CA as a package (Giller et al. 2009).

CA may also lead to a heavy dependence on herbicides to combat weeds, which are a major problem and the use of inorganic fertilisers during transition period from conventional tillage to CA, when yields are generally low (Giller et al. 2009). Compared to conventional tillage, CA practices save labour (h/ha) in planting and fertilisation, but requires more labour for weeding and harvesting (Siziba 2008 in Giller et al. 2009). Hence, CA in an SSA context can cause a shift in labour profiles and may increase the work burden for women who usually weed the farms (Siziba 2008). Giller et al. (2009) thus argue that the increased labour required for weeding in CA may outweigh the labour-saving gained by not ploughing, unless herbicides are used to control weeds. In the case of smallholder production, the practice of CA is constrained mainly by a lack of mulch due to poor productivity, opportunity costs of feeding livestock crop residues, farmers' resource constraints, limited access to, and use of external inputs (Schäfer 2008; Giller et al. 2009).

Despite these limitations, CA holds potential for combating soil degradation, improving agricultural productivity and securing farmer livelihoods, which are major challenges in sub-Saharan African smallholder conventional agriculture (FAO 2008). It has thus been chosen in this paper for analysis of how it contributes to smallholders' buffer capacity.

Resilience, buffer capacity and livelihoods

Resilience offers a perspective to identify and examine the factors, practices and processes that enable certain actors or social-ecological systems to moderate and overcome the adverse consequences of variability and change. While acknowledging other definitions of resilience, I use *resilience* to refer to the capacity (ability) of individuals, social groups or social-ecological systems to absorb (withstand, live with, accommodate) disturbances (for example, climate change impacts) while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to learn and adapt to change (cf. Carpenter et al. 2001; Berkes et al. 2003; Folke 2006; IPCC 2007b). Sustainability in agriculture reflects the ability over the long term, of an agricultural system, to maintain or improve natural resources, environmental quality, productivity, economic viability and remain socially desirable (Schaller 1993; Pretty 2008). As such, resilience (as defined above) is implicit in the concept of sustainability.

In applying resilience to livelihoods-oriented research, I first draw on livelihood concepts. A livelihood comprises the capabilities, assets and activities required for a means of living (Chambers and Conway 1992). A livelihood function refers to the benefits that livelihoods provide, such as food, income, insurance and poverty reduction (Chambers and Conway 1992; Dorward et al. 2001). Resilience in relation to livelihoods thus depends on actors' capacity and agency, and the framing social and natural conditions. Buffer capacity reflects many of these features.

Buffer capacity has several meanings depending on the scientific field—ecology, chemistry, medicine, engineering, information technology (cf. Jorgensen and Mejer 1977; Enginarlar et al. 2002). A general understanding of a buffer is that it cushions, softens and reduces shocks, neutralises intensity, decreases variation and resists change. Put simply, having buffer capacity means having the capacity to cushion change, and possibly to use the emerging opportunities to achieve better livelihood outcomes such as reducing poverty. However, buffer capacity is more than having livelihood assets, it is also about actions to maintain or increase assets. Carpenter et al. (2001) refer to buffer capacity as the amount of change the system can undergo and retain the same structure, function, identity and feedbacks on function and structure. I adapt this definition to livelihoods-related research to mean the ability to retain basic functions while tolerating disturbance, which by extension determines the ability to cope and adapt (cf. Adger 2000). Used for livelihoods, a livelihood is resilient if it can maintain its key functions (e.g. food, income, insurance, etc.) and absorb the impacts of disturbances without undergoing major declines in production and well-being.

Thus, research on resilience aims to identify those factors and processes that enable actors or social-ecological systems (SES) to overcome adversities (cf. Boyden and Cooper 2007). For SES where agriculture is resilient to climate change, the challenge is to maintain or increase resilience while for SESs where agriculture is vulnerable to climate change, the challenge is to reduce the vulnerability and build resilience. The latter is the case for most areas in SSA. Using buffer capacity, a constituent concept of the broader resilience concept for climate change adaptation research in relation to livelihoods, is challenging because few empirical studies have done so. This paper thus contributes to extending the fields of application of the concept to social science empirical research.

Methodology

Based on literature review, I first created a heuristic framework of what buffer capacity would entail in agro-pastoral smallholder CA production. The departing hypothesis is that CA practices have the potential to improve the buffer capacity of farmers because they conserve resources, improve soil fertility and productivity, and reduce soil erosion and labour costs. Secondly, using the framework, I designed a questionnaire for a survey of agro-pastoral farmers practicing CA and another questionnaire for support entities such as research, government and non-governmental organisations. The data presented in this study draw on the farmer survey—farmers' evaluation of contributions to buffer capacity. Thirdly, I analysed the data using descriptive statistics and content analysis, grouping impacts and clustering practices. I used factor analysis to identify clusters of practices, which aggregate the larger number of variables capturing buffer capacity among the sampled farmers. I then examined the relations between the identified clusters and the demographic, socioeconomic and geographic characteristics of the farmers. I expected that the identified clusters would provide information on the key dimensions to focus on in capturing buffer capacity in agro-pastoral contexts. Finally, I discuss the buffer capacity profiles, the clusters of practices and the likely trade-offs in improving and fostering resilience at individual farm level and the community level.

The study area

The 16 villages in which the sampled farmers live are located in the districts of Buuri, Laikipia East and Meru, generally the areas west and north-west of Mount Kenya (Fig. 1). The major urban centres for the villages are Nanyuki and Timau. The villages are part of the Laikipia plateau and its surrounding area, a transition zone between a wetter and a drier climate regime characterised by a tropical highland climate (Berger 1989) with altitudes around 2,000 m above sea level.

The area has two rainy seasons: the March–May rains and the October–November rains. This rainfall pattern is in addition to continental rainfall (July–August) caused by the Mount Kenya range stretching into some pockets of the area. The leeward position relative to Mount Kenya lowers rainfall in the area. Annual rainfall ranges from 400 to 750 mm and mean annual temperatures lie between 16 and 20 °C. Seasonal rainfall amounts during the March–May rains in areas around Nanyuki are about 170–260 mm while for the areas around Timau, it is between 115 and 140 mm (Berger 1989). Rainfall amounts in the October–November rains are usually higher, making this period the major cropping season for the area (Berger 1989). In some localities, it rains between the two seasons around July–August, up to an amount of 112–183 mm. Crop failures and lack of pasture due to low rainfall and frequent droughts are common such as experienced in 1984, 1999–2000, 2007 and 2008–2009. Climate change projections for the area indicate an increase in the frequency and intensity of extreme rainfall events leading to increased water availability and floods in certain months and lower rainfall in other months (Notter et al. 2007). The natural vegetation varies from dry savannah dominated by *Acacia themada* to dry acacia bush towards the north (Berger 1989). The population living below the Kenya national poverty line (Kshs. 1239.-per adult equivalent per month: ca. US$ 17) ranges from 30 to 40 % (Central Bureau of Statistics 2003).

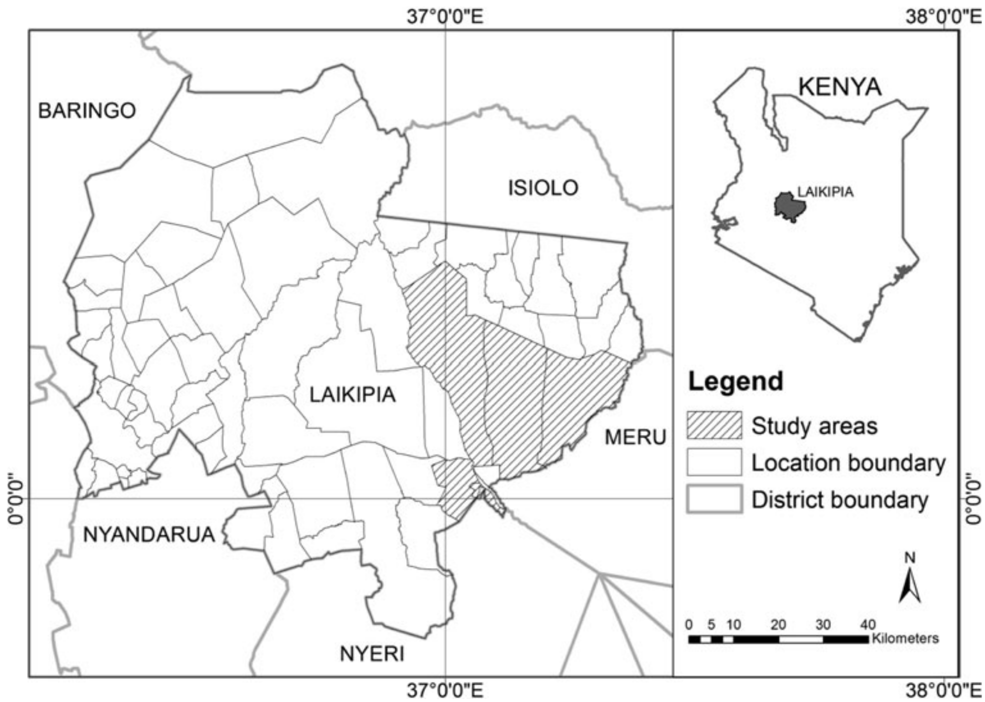


Fig. 1 The study area. *Source* Own design (CETRAD database 2012)

Operationalising buffer capacity and collecting data

At the farm level, the question is whether buffer capacities exist to cushion climate change impacts and whether adaptation strategies enhance the buffer capacity that allows the farmer to adapt to climate change (cf. Holling 2001). Borrowing from the concept of farm resilience developed by Milestad and Darnhofer (2003) and Milestad (2003) and integrating other literature (cf. Ifejika Speranza 2010), I captured the following features of buffer capacity into a framework:

(a) *Endowments/Entitlements*: condition and ownership of/access to assets and resources such as land, farm implements, livestock, labour, skills, social networks, also referred to as livelihood assets (cf. Chambers and Conway 1992; Bourdieu 1984, 1986).
(b) *Diversity/Diversification*: Variety of system components (biophysical, economic and social) and diversity of livelihood options that offer farmers a choice (flexibility) of adaptation and livelihood strategies (cf. Chambers and Conway 1992). For instance, mixed cropping can reduce the risk of drought-induced crop loss since not all crops are susceptible to drought to the same degree. Similarly, soils with more humus can absorb and retain more moisture than soils without.
(c) *Stewardship*: an ethic that embodies co-management of environmental resources to achieve long-term sustainability (cf. Berkes et al. 2000).

Assuming that buffer capacity is captured in endowments/entitlements, diversity and stewardship, the questions then are *in what ways and how much do farmer practices maintain or increase these capacities* (Table 1). The framework serves as basis for developing a questionnaire for assessing the contributions of CA-farmer practices to climate resilience (Table 1).

A questionnaire was designed covering the criteria and variables in Table 1, and the farmers were requested to rate how their various practices cushioned the impacts of climate variability and change or, in other words, contributed to building buffer capacity (and by extension resilience) to climate change. Some variables were later dropped as they were inadequately captured.

Farmers understood buffer capacity as comprising the resources and resource characteristics that protect farmers' livelihoods and their farms from climatic shocks and enable them to continue production (functioning) despite climatic hazards and their adverse impacts, in particular drought, which is the major climatic hazard in the area. Increasing such resources and resource characteristics through various farm practices thus increases buffer capacity. The criteria in Table 1 were translated into variables, for example those that reflect loss reduction, maintained or increased capabilities and assets. In addition to the specific contributions of each farming practice (e.g. increased soil moisture or income) and to summarise the various contributions to buffer capacity, the farmers were asked to score the contributions of their CA and related farm practices to the three sustainability and other dimensions,—economic, social and ecological. A measurement scale ranging from "1" (highly negative) to "7" (highly positive) was used. The weighing scheme was

Table 1 A framework for assessing the contributions of farm practices to resilience/buffer capacity to climate variability and change

Criteria/variables	Resilience check–buffer capacity dimension
	In what ways and how much does the adaptation practice …
Endowments/entitlements (livelihood assets)	Promote/promote access to the human, economic, social, physical and natural capital?
Diversity/diversification	Promote diversification or diversity?
Stewardship	Promote sustainable resources management in contrast to exploitation/mining of resources?

Source Author

explained to the farmers based on which the farmers scored the contributions of their practices to buffer capacity. They also provided explanations for the scores they gave. These explanations were later qualitatively analysed.

In choosing the variables, "definitions of CA in literature" as well as "CA as practised by the farmers as part of a crop-livestock (agro-pastoral) livelihood system", served as a basis. This explains why besides practices associated with CA such as no-till or mulching, for instance, livestock feeding, income diversification, use of inorganic fertiliser and pesticides are also analysed.

Data were collected in fieldwork in 2009. Forty-one conservation farmers (male: 66 %; female: 34 %; Age > 25 years) in 16 villages of Buuri (1), Laikipia East (34), Laikipia (1) and Meru districts (5) were interviewed. Conservation farmers refer to those that applied zero or minimum tillage in a part of or the whole farm. The farmers adoption of CA was driven by various processes including "own initiative", and participation in special extension and research projects. The farmers produce for subsistence and for local markets.

The respondents were purposefully sampled as they recently adopted CA in the past 3 years (6 farm seasons) and are as such illustrative of innovative farmers. 80 % of the respondents recently converted part of their conventional agriculture farm plots to conservation agro-pastoral production, while 20 % have converted their crop production fully to CA. Descriptive statistics and factor analysis were used to analyse the data.

In the following, the farmers' assessments are summarised into a resilience (buffer capacity) profile of their crop production using 13 variables depicting various farmer practices whose contribution to buffer capacity is analysed. Subsequently, the clusters of practices underlying buffer capacity in CA are discussed.

Results

Challenges of weather and climate to agricultural production in the study area

In order to contextualise the roles of weather and climate, the challenges they pose to agricultural production in the area were captured. Farmers reported the most limiting factors on agriculture to be deforestation (49 %; *own comment: not weather-based*), inadequate rains (29 %) and very high temperatures (17 %). They address these limitations through planting trees, adopting CA, constructing boreholes, dams and water pans, conserving water and practising irrigation. About 76 % of the farmers reported that rainfall pattern has changed and has become unpredictable while about 54 % reported rainfall amounts have decreased. Other changes reported are listed in Table 2.

Table 2 Multiple responses of farmers on changes in weather

Responses	Responses ($N = 41$)	Percentage of cases
Rainfall pattern changed–currently unpredictable	31	76
Rainfall amounts have reduced	22	54
Water shortage due to prolonged droughts	8	20
Rain seasons have interchanged	6	15
Frost affecting crops	5	12
Rains coming late	4	10
Sun is hotter/temperatures too high	4	10
Shortened rain periods	3	7
Poor rainfall distribution	3	7
Not much change	2	5

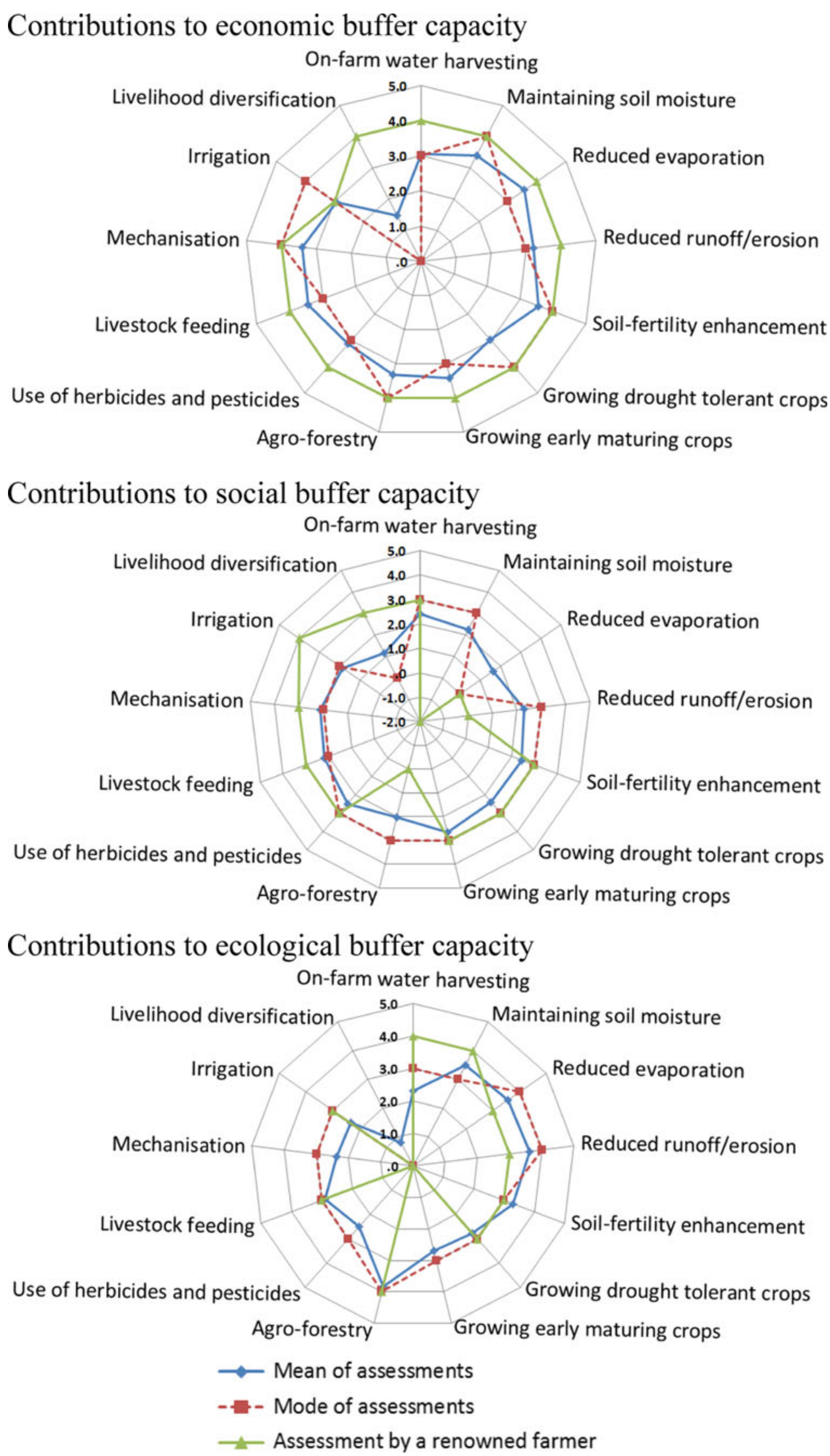
Source Own field work 2009

Contributions of integrated conservation farming practices to buffer capacity

Agricultural practices contribute in various ways to buffering farm production from the risks that weather and climate pose. Having such information provides insights on aspects to focus on in order to sustain or improve buffer capacity. Altogether, the ratings of farmers provide a resilience (buffer capacity) profile of their crop production, as summarised in Fig. 2.

Information provided in Fig. 2 shows (a) the mean and (b) mode of all farmer assessments (excluding those of a renowned farmer in the community) for a certain practice in the economic, social and ecological dimensions and (c) the assessment by a renowned farmer. While the mean

Fig. 2 Buffer capacity profiles–contributions to climate resilient crop production



is the average of the scores given by the farmers, the mode is the most frequently occurring score among the farmers. Displaying the assessments by a renowned farmer provides a benchmark to compare individual farmer or all farmer assessments. The renowned farmer's agronomic practices have contributed to increasing that farmer's income, maintaining farm natural resources, and raised the farmer's social standing in the community. Due to his achievements, extension officers, researchers and other farmers often consult this renowned farmer for his knowledge and expertise.

The links between Table 1 and Fig. 2 are as follows. Table 1 describes the general components of buffer capacity: endowments/entitlements, diversity/diversification and stewardship. These general components comprise various variables. For example, improved conditions of and access to the five livelihood capitals—human, natural, economic, social and physical capitals—capture endowments/entitlements. To provide an overview, the contributions of CA practices to these capitals as scored by farmers were summarised into social, economic and ecological buffer capacities (Fig. 2). It is important to note that the scores depicted in Fig. 2 are those made by the farmers, based on their experiences and perspectives. They may thus differ from an expert or field measurement of the contribution of the various agronomic practices to buffer capacity.

In the following, farmers' assessments of how much their practices buffer their crop production against the adverse impacts of climate variability and change are discussed.

On-farm water harvesting

Under dryland conditions and considering the projected increases in rainfall variability due to climate change (cf. Notter et al. 2007), a critical basis for achieving climate change buffer capacity is to maintain or increase on-farm water availability, a form of physical capital. About 81 % of the farmers do this, mainly through constructing a dam, water pan, water tanks, roof catchment or installing piped water. Through these approaches, the farmers access water for domestic use (32 %) and can practise irrigation with the harvested water (30 %) to produce food for subsistence and for sale. Subsequently, they reduced their production costs and increased their production and income from crop- and water sales. Those that rated the social benefits to be positive–very positive (51 %) perceived their social relations to improve through giving or selling water to their neighbours, or meeting with other people in water projects. 46 % of the farmers reported a positive–very positive contribution in the ecological dimension as the practice of ensuring on-farm water supply enabled them to grow trees and maintain soil moisture. On average, farmers rated the economic benefits they derive from on-farm water harvesting to be positive while the renowned farmer rated it to be very positive. Socially, positive benefits accrue from giving neighbours water. However, some farmers reported that water-harvesting practices reduced employment opportunities in the community as the need to supply farms water declined. Ecologically, the renowned farmer derives very positive benefits from on-farm water harvesting (Fig. 2) as this increases soil moisture and also enables him to practice irrigation. In contrast, famers on average derive little ecological benefits as the water harvested is not enough to practice irrigation and only lasts for a short period.

Maintaining soil moisture

The farmers improve water infiltration and maintain soil moisture, a natural capital, through mulching (59 %), ripping (20 %) and digging trenches and furrows (15 %), among other practices. Through these practices, farmers report that the soils retain more water (37 %), weed growth declines (15 %), soil fertility improves (17 %), trees and plants survive dry spells (24 %), harvests are secured during dry spells (29 %), and erosion declines (7 %). About 91 % of the farmers rated the economic benefits from these practises to be "medium–high": they increased their incomes through the increase in crop production. Farmers' assessments of the social benefits are much more diverse: they range from reduced labour, acting as a knowledge node for other farmers, to selling food to neighbours. Farmers perceive these activities to increase their social capital. All farmers positively rated the ecological benefits with 85 % arguing that their soil conservation practices control soil erosion, improve soil moisture and soil fertility.

Reducing run-off and erosion

Farmers grow Napier grass—*Pennisetum purpureum* (44 %), dig terraces and contours (37 %), apply mulch (24 %) and dig furrows and trenches (22 %). Other practices are planting cover crops and trees. Farmers report the multiple benefits from these practises: improved soil fertility and soil moisture, increased fodder and crop production. 68 % rated the economic gains to be "medium" (29 % high), due to higher yields, reduced production costs in terms of time and labour, lower costs of buying fodder for livestock, higher incomes and reduced household expenditure on food. Socially, 43 % rated the practices of reducing erosion and run-off "medium" as the practices reduced conflicts between neighbours over damage by run-off, although 30 % experienced no benefits from this practice. Ecologically, 50 % rated the practices to have a "high" (42 % medium) contribution to soil fertility, improved soil moisture and increased soil microorganisms.

Soil fertility enhancement practices

To improve soil fertility, most farmers (90 %) apply organic manure (livestock/green-/farmyard manure), while slightly over half of the farmers (61 %) used mineral fertilisers. About 42 % applied mulch while other practices such as crop rotation; cover crops, minimum tillage and terracing complemented the major practices. Through these practices, the farmers increased their yields compared to when they were practicing conventional farming. 62 % rated the economic gain "high" (32 % medium) due to reduced input costs, increased yields and incomes. Social benefits were found to be "medium"(33 % low), these include giving or selling products to neighbours, providing jobs for the locals, mutual learning and exchange among the farmers practicing CA. Having not to borrow from (bother) the neighbours, the improved self-reliance and social status were rated positively. Ecologically, 53 % rated the practices "medium" (42 % high). The practices maintained and improved soil texture and fertility and contributed to increasing vegetation. According to one farmer, "in the 1970s, there was no vegetation as there is now." However, farmers' assessments of the ecological benefits of fertiliser use varied widely. About a third of the farmers expressed their concerns that fertiliser use increases soil acidity while other farmers argued that fertiliser use secures soil fertility.

Growing drought tolerant crops

The farmers maintain high crop diversity. They listed 18 crops, which they grow that are drought tolerant. The most commonly grown crops were sweet potatoes, maize (*Duma*®, *Pioneer*®, *Simba*®, *Dekalb*®, *6-series*®), dolicos lab lab, cassava, beans, wheat and millet. Most farmers grew at least three combinations of the above-listed crops while about a third grew four combinations. Only very few farmers (3 %) source their seeds from own harvests. Although root crops do not fit the CA principle of no- or minimum tillage, the farmers have integrated them into their farming system. 47 % of the farmers rated the economic benefits of growing drought tolerant crops "high", (37 % medium). Growing such crops increased household food availability and reduced their expenditure on food and fodder. They also increased their incomes. 63 % rated the social benefits to be "medium", (19 % low) as they sold products or shared some products with their neighbours. Through farmer group meetings, they exchange knowledge and experiences, thereby increased their knowledge. The increased food production and food self-reliance increased their income and make them feel proud. 65 % rated the ecological benefits to be "medium" as they can reduce evaporation through cover crops and improved vegetation cover. However, 11 % each rated the benefits to be zero, low and high respectively.

Growing early-maturing crops

Early-maturing crops can secure enough rains from a short rainy season and are recommended for dryland farming. The farmers grow 19 varieties of early-maturing crops. Of these, 61 % grow Irish potatoes and beans, 39 % *Duma*® maize, 29 % *5-series*® maize, 22 % wheat, 24 % grow various vegetables (cabbages, onions, tomatoes, kales, courgettes and carrots), 15 % French peas and snow peas. Other maize varieties grown include, *Katumani*®, *Pioneer*®, *Dryland Hybrid*®, *Simba*® and *Dekalb*®. These early-maturing crops are a major source of income for about half of the farmers and help to increase household food availability. 49 % rate the economic benefits to be "medium" (46 % high): they earn incomes, have food readily available and have reduced the costs of buying food. 72 % rate the social benefits to be "medium", because selling seeds or food to the neighbours and to the community improves their social position and relations. As their practice of CA involves meeting other people, it provides them a platform for learning from one another, for exchange of ideas and advice. 71 % rate the ecological benefits to be "medium" as they could "green" the environment, improve the vegetative cover (by retention of crop biomass and use of fallow crops) and maintain soil fertility.

Agro-forestry practices

The farmers grow 26 different trees. Most farmers grow *Grevillea* (95 %). Others grow Cypress (59 %), White bottlebrush (49 %) and cedar (37 %). Other trees grown are pine and blue gum and some fruit trees (avocadoes, oranges, apples, peas and guava). Major reasons for growing trees are production of firewood (95 %), to serve as wind breaks (64 %), and for timber (62 %). Other reasons are for improving the environment—air, shade, beauty and for fencing. 50 % rated the economic benefits to be "high" (44 % medium), since products from the trees are consumed or used for construction, reduce the cost of fuel (firewood and charcoal), and fetch additional income. 37 % rated the social gains to be "medium" (29 % zero, 26 % low): through selling timber, firewood, honey and fruits to locals. Ecologically, 50 % assessed the benefits to be "high" (36 % medium): the trees serve as windbreaks, reduce evaporation and erosion.

Use of herbicides and pesticides

88 % use herbicides while 95 % use pesticides. In total, farmers use 15 and 37 different trademarks of herbicides and pesticides in their production, respectively. Major herbicides used include Gramoxone® (63 %), Roundup® (60 %) and Touchdown® (50 %). Karate® is the main pesticide used (74 %), followed by DyneAmic® (28 %), Dimethoate (23 %) and Triatrix® for livestock treatment (15 %). 50 % rate the economic benefits of using herbicides and pesticides to be "high", 41 % medium: they increased productivity, reduced losses from infestations and reduced weeding costs. 47 % assessed the social benefits as "medium" (33 % low): for some, the use of herbicides and pesticides reduced job availability, for others it reduced labour costs. 51 % rated the ecological contributions medium, although some 19 % rated them to be high and low, respectively. Some farmers expressed concerns about the proper use of the chemicals so as not to harm crops, humans or the environment.

Livestock feeding

Most cattle kept are hybrids and are under zero-grazing or combinations of zero-grazing with lesser free grazing. Farmers feed their cattle mainly Napier grass (87 %), maize stalks (67 %) and crop residues (21 %). As previously discussed, Napier grass also serves to control erosion. About 23 % practise free grazing. Other feeds are Rhode grass, sunflower, dairy meal and supplements. 49 % of the farmers rated the economic benefits of feeding livestock to be "average" (35 % high): they reduced the cost of maintenance and could increase income through milk sales. 47 % assessed the social benefits to be "average": through selling milk to neighbours and to dairy companies, they improved their social status and social relations in the community. 44 % rated the ecological benefits "average" (29 % high, 27 % zero): the manure produced by livestock boosts soil texture and fertility, thereby contributing to the goals of CA.

Mechanisation

Slightly over half the farmers (53 %) use ox-plough and ripper (53 %). Still, 35 % use hoes, 20 % cutlasses. About 28 % use ox-planter while 20 % use tractors and 20 % sprayers. The levels of mechanisation achieved have made farm work easier, reduced the time spent on farm work and reduced labour costs. 42 % therefore rated the economic benefits of using the ox-plough, ripper, ox-planter and tractors to be "high" (48 % medium) as mechanisation has reduced operation costs. 47 % assessed the social benefits to be "low" (29 % medium): they borrow or hire machines from one another and require less labour. 47 % judged the ecological benefits to be "medium" (31 % none and 19 % high), as the mechanisation forms used (ripper, ox-planter) minimise soil disturbance, thereby maintaining soil moisture and structure.

Irrigation

Of the 70 % irrigating their farms, 54 % use sprinklers to irrigate their plots, 22 % water their plants manually while 22 % use drip irrigation. A few farmers have constructed furrows or practice flood irrigation. 43 % rated the economic contributions of irrigation to be "high" (36 % medium): through irrigation, they increased yields and secured harvests even in dry seasons. 30 % rated the social contributions to be "medium" (26 % zero and low, respectively): they exchange ideas and knowledge with other farmers. 45 % assessed the ecological gains to be "high", (26 % very high). Through irrigation, the farmers improved vegetation cover, reduced pressure on river water and maintained soil moisture. In the profile, most farmers rate the economic benefits from irrigation to be high although on average, farmers including the renowned farmer rated it to be medium. Socially, the renowned farmer derives high benefits from irrigation as neighbours purchase food (economic benefits that translate to social benefits) from him but most farmers rated its social contributions to be neutral although a few find that irrigation reduced job opportunities, as less labour is required and increases conflicts during periods of water shortage. As one farmer explained, "It [irrigation] helps but during lack of water results in fighting in the community."

Livelihoods diversification

Only about 39 % of the farmers had additional incomes through salaried employment and business while 61 % concentrate on farming. Income diversification is very positive for climate resilience, particularly if based on non-farm, non-climate-related income sources. However, CA has triggered livelihood diversification among only 15 % of the farmers. The renowned farmer has been successful and has diversified into various enterprises such as fabricating own plough and planters for sale and rent to other farmers, selling milk from own livestock and introducing fish farming. Moreover, through practicing CA, most farmers (75 %) increased their farm incomes to various degrees. However, for 10 % of the farmers, the adoption of CA did not improve their incomes although it increased the amount of food they had available (which also saves them the costs of buying food).

CA at the farm level has mainly led to positive outcomes. Generally, most farmers agree that their practice of CA reduces costs of manual labour and therefore contributes highly in the economic dimension. In some cases, many farmers rate the contribution to social buffer capacity to be low because the practice of CA reduced job availability for those farmers who were hitherto dependent on casual jobs for additional incomes ("Less people are employed"; "People lack jobs", "locals run out of jobs", "Lead to people being idle"). These explanations lead to a hypothesis that needs to be substantiated with more data and further research, that, while at the farm-level CA leads to savings in labour costs, at the rural economy level, it may lead to decreased job opportunities for those farmers and other actors who were hitherto dependent on local jobs to earn additional incomes.

The contributions of farmers' CA practises are qualitatively summarised in Table 3 (rows of Table 3, also illustrated as scores in Fig. 2). The columns in Table 3 are the variables capturing the general components of buffer capacity as shown earlier in Table 1. Table 3 shows that in most cases, CA practices contribute in multiple ways to increasing economic, social and natural capitals. It is also in these three dimensions that some negative outcomes are experienced (e.g. conflicts, reduced employment opportunities, side effects of herbicides use). In some cases, CA practices increased human capital. Table 3 indicates that farmers' adoption of CA did not go hand in hand with increase in CA infrastructure (physical capital e.g. rippers, tractors, planters), and this can cause willing farmers to continue with conventional tillage (see also Schäfer 2008). Regarding diversity, while CA practices contributed to biodiversity, they seldom triggered livelihood diversification. Stewardship, while implicit in the CA practices was only explicitly captured in farmers' agro-forestry practices.

While the various practices discussed above, contribute to buffer capacity in different ways and to different degrees as illustrated in the profiles (Fig. 2; Table 3), identifying the main variables that characterise buffer capacity would reduce the number of variables to be captured and improve buffer capacity characterisation. This is undertaken in the following section using factor analysis.

Underlying factors of buffer capacity in conservation agriculture

To achieve a better understanding of the practices discussed above and to reduce complexity, factor analysis was used to reduce the 13 variables (Appendix) on buffer capacity into a smaller number of underlying factors (clusters of practices) that explain most of the variance in the larger set of the observed variables (Table 4). Using SPSS Statistics 17.0.0 (2008), a principal component analysis (PCA) with varimax rotation was used to extract the underlying factors. The Kaiser–Meyer–Olkin Measure of sampling adequacy was used to test the proportion of variance in ratings attributable to underlying factors. The KMO was 0.61, indicating the proportion of variance in the ratings that might be attributed to underlying factors. While KMO values close to 1.0 indicate that factor analysis might be useful for analysing the data, the 0.61 is only slightly

Table 3 A summary of the contributions of CA practices to buffer capacity

CA practices	Buffer capacity dimensions[a]							
	Human capital	Economic capital	Social capital	Natural capital	Physical capital	Livelihood diversification	Biodiversity	Stewardship
On-farm water harvesting		↑↓	↑	↑	↑		↑	
Maintaining soil moisture	↑	↑	↑	↑				
Reducing runoff and erosion		↑	↑	↑			↑	
Soil fertility enhancement practices	↑	↑	↑	↑↓			↑	
Growing drought tolerant crops	↑	↑	↑	↑			↑	
Growing early-maturing crops	↑	↑	↑	↑				
Agro-forestry practice		↑	↑	↑		↑		↑
Use of herbicides and pesticides		↑↓		↑↓				
Livestock feeding modes		↑	↑	↑		↑		
Mechanisation		↑		↑	↑			
Irrigation	↑	↑↓	↑↓	↑	↑			
Livelihood diversification		↑						

[a] Based on the framework in Table 1; ↑: Positive contributions; ↓: negative contributions

Table 4 Extracted factors underlying climate change buffer capacity in conservation agriculture (see "Appendix", Table 5 for details)

Factor loadings	Clusters of practices
	Factor 1: Soil protection (21 %)
.893	Maintaining soil moisture
.849	Soil fertility enhancement practices
.760	Reducing evaporation
.521	Agro-forestry
	Factor 2: Growing adapted crops (13 %)
.744	Growing drought tolerant crops
.606	Growing early-maturing crops
	Factor 3: Intensification/Irrigation (11 %)
.714	Irrigation
.633	Livestock feeding
.497	On-farm water harvesting
.452	Livelihood diversification
	Factor 4: Mechanisation (11 %)
.885	Mechanisation
.569	Agro-forestry
	Factor 5: Livelihood diversification (10 %)
.546	Livelihood diversification

above 0.50, so I decided to conduct an exploratory factor analysis. Bartlett's test of sphericity, ($\chi^2 = 126.38$, $p < 0.001$) indicated some existing correlations among the variables. Five components (Table 4) with Eigenvalues greater than 1 and explaining 67 % of the total variance were extracted. The first factor explains 21 % of the total variance, the second factor 13 %, and the third factor 11 %. The remaining factors four to five contributed 11 and 10 %s to the variance, respectively. I then identified the underlying factors from the rotated component matrix (Appendix). For ease of understanding, these factors are referred to as clusters of practices.

Factor 1 captures practices promoting soil protection, although agro-forestry practices load also for Factor 4 capturing mechanisation. Factor 2 captures growing adapted crops. Factor 3 correlates with irrigation, livestock production and water harvesting. While livelihood diversification correlates most highly with component 5, it also loads for component 3. Factor 3 indicates that those who practice irrigation are also likely to be those harvesting rain water and that the practice of rain water harvesting favours on-farm diversification such as sale of water or fish farming and favours livestock production through water availability and fodder production. Factor 4 captures mechanisation and agro-forestry. However, the relationship between mechanisation and agro-forestry is not explicit.

χ^2-tests conducted to examine the relationship between factors, demographic, socio-economic and geographic variables were not significant. Grouping the farmers according to the buffer capacity of their agronomic practices would provide information on how to target the individual farmers. Hierarchical Cluster Analysis, method furthest neighbour and option of squared Euclidean distance was used to group the respondents based on the scores of the factors. Various solutions ranging from 2 to 8 clusters were examined. However, the results were discarded due to the small size of the clusters and the difficulty to interpret the distinctive characteristics of certain clusters.

Discussion

Implications for fostering resilience through building buffer capacity

The analyses reveal interconnections between the economic, social, ecological and other dimensions of buffer capacities. While the objective of ensuring crop production despite climatic and other risks largely drives adaptations in the ecological sphere, such activities can increase economic and social buffer capacities. They extend farmer networks thus providing them a platform for exchanging skills and knowledge. The farmers perceive economic exchanges (selling to neighbours) to translate into social dividends (improved relations and social status). This contributes to their human capital and improves their social relations, which then become resources, which farmers may fall back on when needed.

While the economic benefits of agricultural practices are often obvious in the short term of within a season or at the end of the season at harvest period, the ecological benefits can stretch from the short term of a season (e.g. improved soil fertility) to the long term (e.g. planting trees). The social benefits such as improved social status and relations among farmers also become obvious in the short term but can also abruptly change. Hence, the analysis of buffer capacity or resilience requires periodic monitoring to assess whether a livelihood can function in the face of disturbances such as climate-related ones. One question in such monitoring is to what extent CA practises buffer farm production from droughts of various periodicities and magnitudes.

Methodological insights

While this analysis covered only farmer practices in crop production, methodologically, it shows that the concepts of buffer capacity and resilience can be made operational in empirical research and can provide insights on the effectiveness of adaptations to climate change. Expert assessments, quantitative models or field measurements can replace or complement the farmer assessments (Franke et al. 2011). However, analysis using only the five extracted components led to a 35 % loss of information. Increasing the sample or choosing other combinations of variables may compensate this drawback. Yet, the profiles provide an instrument to gauge the progress of crop production towards climate resilience. The profiles could be further developed and integrated into decision support systems for extension services in identifying the production spheres to improve farmers' buffer capacity.

The multiple outcomes from a single CA practice (e.g. mixed cereal-legumes cropping can increase soil moisture and fertility, yields, income) or the multiple CA practices leading to the same (e.g. mulching and mixed cropping leading to increased soil moisture), or different outcomes, reflect the complex nature of the farming system. These need to be accounted for in the choice of integrative methods.

The findings hint at inter-linkages between the three resilience components—buffer capacity, self-organisation and learning—for example, the farmers exchange knowledge gained from their practices with other farmers in their group. A comprehensive resilience profile integrating the three components thus has to ensure that the variables are not duplicated and their inter-linkages presented in a transparent manner. This aspect needs further research.

Building buffer capacity through conservation agriculture

CA is a fast growing farming system in Africa (Fowler and Rockstrom 2001). Field measurements in other African areas confirm the benefits of CA regarding reduced run-off, improved soil quality, crop performance and rain water use efficiency (cf. Araya et al. 2012; Ngwira et al. 2012), although these may vary depending on context (Baudron et al. 2011). However, farmers adapt CA practices to their biophysical and socio-cultural contexts (Giller et al. 2009; Lahmar et al. 2011). Farmers still grow root crops such as cassava and sweet potatoes, which are important famine crops, under adapted forms of CA where soil disturbance is unavoidable. Such adapted forms of CA need to be accounted for when promoting CA in other areas and to other farmers. The rationale is that farmers will always adapt recommended agricultural practices and technologies to their social and ecological contexts and may not be in a position to practise 100 % of what is recommended. Farmers' experimentation is therefore crucial for adapting farming practices to their context and for the success of such practices.

CA as practised in this crop-livestock system can have positive and negative effects: Some farmers are concerned about the negative effects of fertiliser, pesticides and herbicides use in their production. They seek ways through which they can increase the use efficiency and reduce negative effects. One such way is through mechanisation by using planters that also portion fertilisers needed for each plant. In using pesticides and herbicides, there is a need for closer examination of the products in the market. Farmers access 15 different herbicides trademarks and 37 different pesticides. Problems with herbicide application are major reasons for some farmers abandoning CA in the study area (Schäfer 2008). As no study was found on the safe use of these chemicals, it needs to be examined how the use of pesticides and herbicides can be improved so farmers use them without concerns about their own health and that of the environment. Extensions services may provide the relevant advice to farmers on the safe and efficient use of these farm inputs.

Moreover, the use of fertilisers, herbicides and pesticides can weaken system resilience and raises possible trade-offs between the various dimensions of sustainability and resilience. Farmers' use of these inputs currently increases buffer capacity and resilience (cushioning adverse effects, accommodating disturbances and ensuring functioning despite droughts and soil degradation). However, whether and how these practices and contributions to resilience can be maintained over the long-term, and without jeopardising environmental quality, farmer's health, and productivity, is questionable if adjustments are not made to improve their safe and efficient use. Although CA contributes to buffer capacity through increased incomes, farmers' continued use of these inputs also depends on their access to markets and on whether market dynamics enables farmers to continuously earn high enough incomes from their products sales relative to the high input prices. This also highlights the importance of the framing conditions (e.g. markets, drought severity, institutions, government policies), and how these influence farmer agency to be able to maintain resilience in the long term.

As the results show, farmers' agro-forestry practices are only minimally driven by climate considerations as they grow trees for fuel-wood and timber. Other studies in Kenya confirm this finding (Appiah and Pappinen 2010). Considering the "structural and implementation flaws (weak governance, corruption, inequity, repression, questionable environmental benefits)" of some Clean Development Mechanism- and Voluntary Carbon Projects in Africa (Environmental Justice Organisations, Liabilities and Trade 2012), caution is a necessary strategy to any intervention proposing payments for carbon sequestration to the farmers. Even where such negative effects are controlled, the findings suggest that such payments can only be additional but not the main drivers of farmer agro-forestry practices.

The success of farmers as depicted by their buffer capacity/resilience profiles indicates that with the right practices, farming in the drylands can become a more stable and profitable business. Governments should thus support farmers by improving the areas in the profile where their buffer capacities are low (e.g. CA triggered livelihood diversification), where knowledge is lacking or not implemented (e.g. safe herbicides use), and foster the best practices for which already solutions exist—through further training on CA techniques, material and input support or through incentives to mention a few. This may require a further analysis of the costs and benefits of the different practices, and their comparison among different practices.

Studies on how farm management practices deal with uncertainty highlight the importance of learning and local networks for building buffer capacity (Tengö and Belfrage 2004; Nyangena 2008). The foregoing analysis and an initial examination of other resilience dimensions (self-organisation and capacity to learn) in this study confirm the important role of other farmers and actors in a farmers' adaptation of and success in CA.

Yet, in certain cases, the rural economy (absent or malfunctioning policies, institutions and markets) constrains farmers' adaptive capacity (Lay et al. 2008), especially among resource poor-farmers (Shiferaw et al. 2009). This paper highlights the likely influence of CA on job availability. While the affected farmers are only a small proportion, the indication that increasing individual farm resilience may adversely affect the functioning of the rural economy needs further analysis. It also raises the importance of joint innovation processes that integrates various actors and focuses not only on fostering farmer experimentation and adaptation but also on how to make the framing conditions (market, policy and institutions) that influence farmer capacities and decisions more enabling (Shiferaw et al. 2009; Asenso-Okyere and Davis 2009; Hounkonnou et al. 2012). Hence, balancing farm-level innovations with their economy-wide implications is crucial to ensure that increases in farm-level resilience do not decrease the resilience of the rural economy.

Conclusion

This paper explores how buffer capacity and, by extension, resilience can be assessed for livelihoods exposed to climate risks. It used the case of CA in the frame of a crop-livestock system, to analyse how farmer practices contribute to building buffer capacity for dealing with the impacts of climate variability and climate change in economic, social, ecological and other dimensions. The clusters of CA practices contributing to buffer capacity in the study area include soil protection, adapted crops, intensification/irrigation, mechanisation and livelihood diversification.

By demonstrating how to characterise and analyse buffer capacity and, by extension, resilience, this paper contributes to extending the ways through which the concepts of resilience and buffer capacity can be made operational for empirical research. Thematically, it shows that the adoption of CA by farmers has improved their buffer capacity towards climate risks, such as droughts and water scarcity. However, trade-offs may arise between increasing the buffer capacity of individual farmers and that of the rural economy as labour-savings on-farm translates to reduced job availability in the rural economy.

While the study did not cover all farm practices, the buffer capacity profiles can be developed into a decision support system for extension organisations to enable them to quickly gain an overview of farmers' practices and improvement options. Field measurements and expert assessments can complement farmer assessments and need to be explored in future studies.

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Appendix

See Table 5.

Table 5 Rotated component matrix of the factors underlying buffer capacity

	Component				
	1	2	3	4	5
C10_NC_on-farm water availability	.206	−.562	.497	−.135	.217
C11_NC_Soil water content/Infiltration	.893	.000	.157	−.071	.090
C12_NC_Reduce runoff/erosion	.350	−.545	−.067	.133	.334
C13_NC_Reduce evaporation	.760	−.090	.110	.043	−.256
C14_NC_Soil fertility/yields	.849	.133	.061	.107	.127
C15_PC_Drought resistant crops/seeds	.105	.744	.167	−.203	.144
C16_PC_Early-maturing crops	.357	.606	.139	.369	.017
C18_NC_Agro-forestry_carbon sequestration	.521	.080	.139	.569	−.249
C20_NC_Livestock production	.102	.398	.633	.141	.046
C21_NC_Pesticides and herbicides use	.058	.068	.136	.028	−.816
C23_PC_intensification_mechanisation	−.040	−.100	.008	.885	.150
C24_PC_intensification_irrigation	.130	−.002	.714	−.017	−.148
C28_ Diversification	.020	.125	.452	.253	.546

Extraction method: principal component analysis

Rotation method: Varimax with Kaiser Normalisation

Rotation converged in 7 iterations

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