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Can monocultures be resilient? Assessment of buffer capacity in two agroindustrial cropping systems in Africa and South America

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Abstract

Background: Buffer capacity—the capacity of a social–ecological system to cushion stress and shocks—is often seen as an important dimension of social–ecological system resilience. While numerous studies have focused on other dimensions of resilience in social–ecological systems, literature on buffer capacity is scanty.

Methods: Two agroindustrial cropping systems were surveyed based on wheat in Kenya, and soybean in Bolivia. The study was carried out in 2017–2018 using mixed methods; interviews, questionnaires, and observation. Two groups of indicators were used (livelihood capitals and functional and response diversity indicators). The five livelihood capitals, and functional and response diversity indicators (number of crops rotated, landscape heterogeneity, and percentage of arable land under natural vegetation) were used. Resilience indicators were assessed using a five-point Likert scale.

Results: Both systems had high scores on physical, financial and human capitals, while the functional and response diversity scores were low. Both systems are found to be vulnerable to economic and climate change related shocks hence need to develop more diversified patterns to increase ecological resilience.

Conclusion: The two cropping systems overall capacity to withstand shocks—particularly related mainly to climate change and variability and economic shocks was extremely low for soybean system and low for wheat. The two systems were found to have low scores of functional and response diversity especially with regard to landscape heterogeneity, crop and breed diversity and percentage of vegetation cover on arable land.

Keywords: Buffer capacity, Resilience, Agroindustry, Monoculture, Kenya, Bolivia

Introduction

Wheat is an important staple crop that provides an estimated 20% of the total dietary calories and proteins globally [1]. However, wheat is among the most susceptible crops to risks, such as climate change [2]. Cushioning the crop against such risks and increasing productivity is critical to safeguard current and future food security. On the other hand, soybean is an important oil crop in the world also cultivated for animal feed, food (soy sauce

and tofu), and industrial products. Soybean is among the most import crop traded globally and accounts for a significant amount of total harvested land under annual and perennial crops [3]. The two crops are largely cultivated for commercial purposes under monoculture cropping systems and account for a significant share of commodities traded globally.

Monoculture production systems cover 80% of the world's more than 1.5 billion hectares of arable land [4] and are among the most important causes of environmental degradation. Several factors have contributed to expansion of agroindustrial cropping systems characterized by large-scale monocultures, including advancement in mechanisation, states' desire for self-sufficiency

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in food supply, specialised production, and improvement of crop varieties including biotechnology, and related policies, market pressures, and expectations of increasing incomes [5]. Agroindustrial cropping systems have had unparalleled negative impacts on biodiversity, soils, water, and climate change [6]. They are also prone to pests and diseases, deteriorating soil fertility and consequently declining yields in the long run [7].

Agricultural systems can be described as social–ecological systems due to their interaction between natural resources (soils, flora, fauna, air, and water) and social–economic and political factors linked through feedback mechanisms [8, 9]. Multiple internal and external drivers of changes affect agricultural systems, ranging from sudden shocks to long-term stressors [10–12]. Drivers of change include climate variability, soil degradation, pest outbreaks, economic and political crises, and land scarcity and pressure [10, 13]. Changes in food consumption patterns with increased demand for sustainably produced food has also become evident [14].

Resilience thinking applied to agricultural systems refers to the capacity to absorb (withstand, live with, accommodate), recover from, learn from, and adapt to shocks and trends (for example, climate change impacts, such as droughts; price fluctuation; water shortages and land degradation) while retaining their basic structure and functioning [15, 16]. In this study, we apply the concept of buffer capacity to the resilience of agricultural cropping systems. Our study is premised on the significance of resilient monocultures in supporting the food security of present and future generations. Buffer capacity is one resilience dimension, besides self-organisation, and the capacity for learning and adaptation [16, 17]; however, literature on buffer capacity of cropping systems is scarce.

Agroindustrial cropping systems such as those of wheat or soybeans often have adverse social, economic and environmental sustainability impacts [18–20]. In Bolivia and Brazil for instance, expansion of soybeans has contributed directly and indirectly to land degradation and deforestation rates that are among the highest in the world [21]. Excessive use of pesticides in agroindustrial systems causes soil, water and air pollution, loss of biodiversity and human health impacts [21]. Ecological effects of agrochemicals include the possibility of adverse impacts on health, resistance of pests and diseases, weed resistance, and possible production of environmental toxins that move through the food chain and affect beneficial organisms, such as pollinators [7, 22–24].

Agroindustry enterprises are producing, processing, and food packaging on a large scale, using modern equipment and methods. Although agroindustry enterprises have been sometimes credited with employment

opportunities for local communities, food security, and improved livelihoods [25], studies show that they often displace more workers than they employ [26]. Research results on agroindustry in the literature are mixed. Some studies attribute positive contributions to food security, livelihoods and employment [25], while on the other hand, agroindustry is often associated with environmental pollution, excessive abstraction of water resources in water catchment areas, low wages and poor work environments, land pressure, loss of biodiversity, and low agroecosystem services [27, 28].

A previous study on agroindustry in the two regions has shown vulnerability, including droughts, inundations, and extreme weather events [26, 28]. However, empirical knowledge on social–ecological resilience in industrial agriculture is still scarce. In this study we focus on buffer capacity as an important pillar of social–ecological resilience. We define buffer capacity as the capacity of a social–ecological system to cushion itself from possible risks and shocks [29]. The study addresses the following research questions: (a) which livelihood capitals are important in cushioning the agroindustrial cropping system against risks and shocks? (b) What is the level of landscape heterogeneity in the cropping system? (c) What is the intensity of crop rotation and crop diversity? (d) What is the percentage of the cropping system under vegetation? (e) What buffer capacity indicators help to explain social–ecological resilience of agroindustrial cropping systems?

The two case studies that we examine—wheat and soybean cropping systems in Kenya and Bolivia, respectively, have been found to be susceptible to various risks, especially those related to climate change and market dynamics [26]. Monocultures are widespread in South America and are perceived to be ‘modern’ agricultural systems, on the other hand, Africa’s colonial heritage is characterized by monocultures that continue to form a considerable part of the agricultural landscape, and expand in many regions.

Theoretical background

Buffer capacity of cropping systems

Agricultural systems face socio-economic, political, and ecological stress and shocks that may affect their functioning and thus food security [26], and capacity to cope with local and global environmental changes and support livelihoods [29]. Previous research in our study areas in Kenya and Bolivia has shown that shocks include price volatility for commodity crops, e.g., related to imports, stress from droughts, and the loss of soil fertility, and pests and diseases.

Cropping systems’ sensitivity to risks depends on exposure and on the “buffer” capacity to cushion stress and

shocks [30–32]. Buffer capacity enables the continuation of basic system functions in the face of stress and shocks, and reduces the intensity of shocks [29]. We consider buffer capacity in agricultural systems to be composed of peoples' access to and quality of livelihood assets [33], spatial and temporal heterogeneity of the system, and the presence of functional and response diversity [34, 35]. We also consider the ability of the agroindustrial cropping systems to buffer the ecological system promoting integration with trees, sustainable irrigation systems that conserve scarce water resources, and diversity of farm products and markets. This is described as “the diversity of responses to environmental change among species that contribute to the same ecosystem function” [35, 36].

One of the few studies on buffer capacity in agriculture on smallholder resilience in Kenya [32], analysed buffer capacity among smallholder farmers in a semi-arid environment. Using a livelihood resilience indicator framework, the study observed that households that had a higher buffer capacity were more likely to cope with risks [32]. Our study uses livelihood capitals, but in addition, applies indicators of functional and response diversity (landscape heterogeneity, percentage of arable land under vegetation, and diversity of crops and breeds) [33, 37, 38].

Indicators for buffer capacity

We used two groups of indicators (Table 1) to assess the buffer capacity of the two cropping systems. The indicators are: (1) indicators contributing to socio-economic buffer capacity, and (2) indicators associated to ecological buffer capacity [34, 39]. There are some studies on ecological buffer capacity, while others have applied indicators of ecosystems diversity and response diversity [37, 40] to measure social–ecological resilience of agroecosystems. However, literature on socio-economic variables to measure buffer capacity is scarce. We use livelihood capitals (physical, natural, social, human, and financial capitals) [37], functional and response diversity (landscape heterogeneity, crop and breeds diversity, comprising the intensity of crop rotation (measured by the number of crops rotated with the main crop), and percentage of arable land under vegetation [35, 41] (Table 1).

Materials and methods

Description of the study area

Agroindustrial wheat cropping system in Kenya involves large-scale rainfed commercial farming in the Counties Meru and Laikipia (Fig. 1). It also incorporates actors such as millers, retailers, and supermarkets in the surrounding urban and peri-urban areas of Nanyuki, Meru, Karatina, Nyeri and Nairobi. The wheat production zone receives rainfall ranging from 500 to 1270 mm with warm

temperatures between 15 and 20 °C. The soils in the wheat growing zones are mainly well-drained deep fertile volcanic soils. The landscape is gently sloping allowing mechanisation at an altitude of 1500–2900 m. Smallholder farmers in the region grow maize, beans, potatoes, and vegetables on farms of usually less than 2 ha. Wheat covered 14,000 ha ranking sixth among major crops in Meru County after maize, beans, potatoes, sorghum and pigeon peas. The largest wheat farm is 6000 ha with only 50% under cultivation [42]. Livestock production is an important activity on many of the wheat farms due to the large agricultural land which is often not utilized fully for cropping purposes. Smallholders also integrate crops with cattle, sheep, goats and poultry as a form of investment as well as a source of animal products.

Soybean covers more than one-third of Bolivia's total agricultural area (FAOSTAT 2020), and its agroindustrial production is concentrated in the Department of Santa Cruz. It spreads in the lowlands of the country and expands into the Amazon rainforest in the north–east and the Chiquitan dry forest in the south–east, and the Chaco region in the south of the Santa Cruz Department (Fig. 1). The annual precipitation is 700–1400 mm concentrated in one rainy season of 5–6 months with the highest rainfalls from January to March. Soil suitability for agricultural use is officially rated as very low in most parts, due to their vulnerability to accelerated degradation. Traditional local food production and consumption is based on a wide range of different corn varieties and Milpa systems (combinations of corn, beans, and squash); cassava, sweet potato, peanuts, vegetables, and fruits, often in mixed cropping systems and/or agroforestry home gardens.

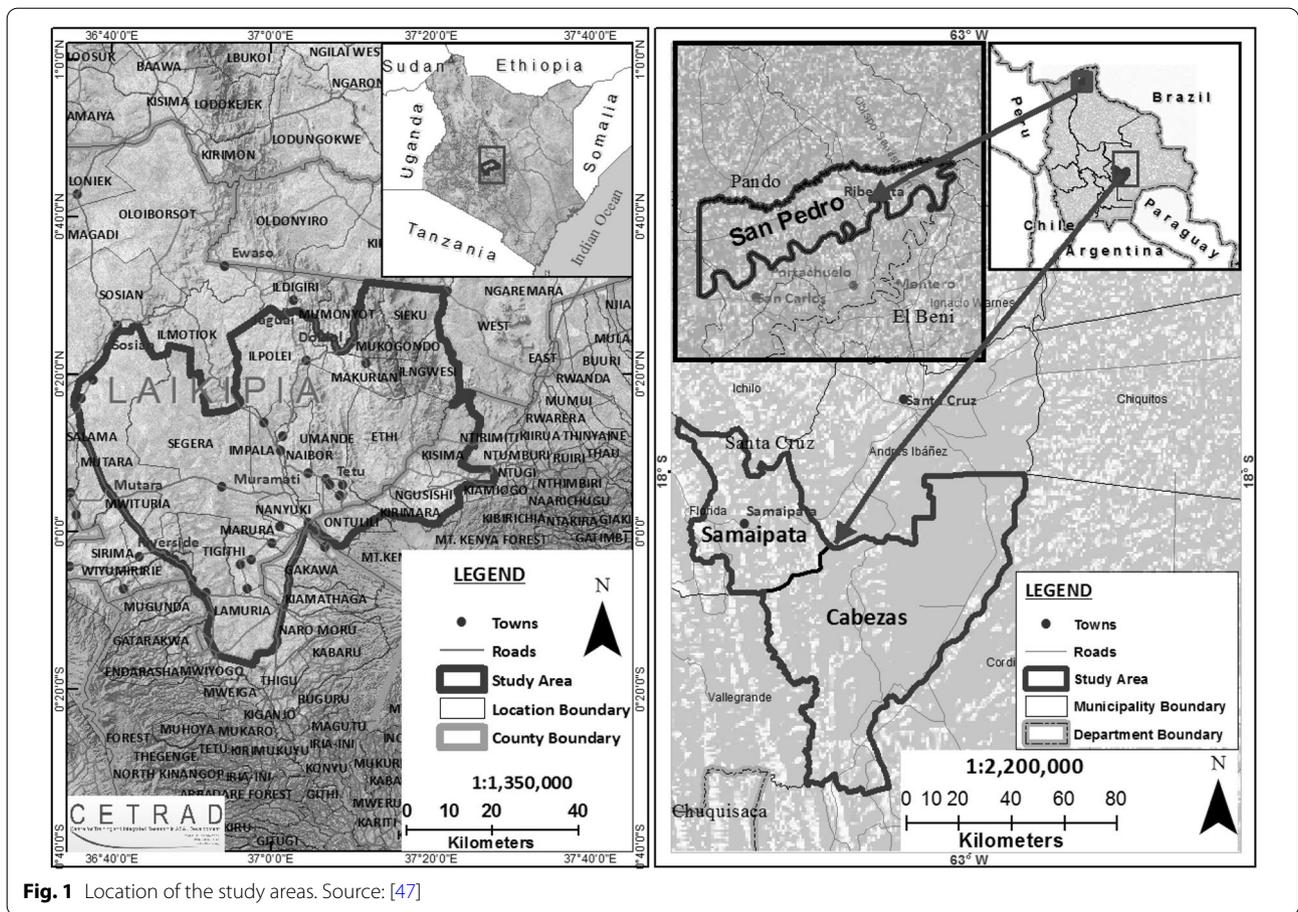
Several factors help to justify the choice of the two cropping systems. Both are agroindustrial cropping systems, that are highly specialized, important for national and global food value chains, produced under commercial investments in terms of capital, land area, and financial input (see [42]), and are intensive regarding the use of agrochemicals. Both cropping systems are surrounded by smallholders and indigenous communities practicing mixed farming largely for household consumption. The two countries lie within the tropics with numerous challenges of environmental degradation, food insecurity and vulnerability to climate change related shocks.

Data collection

In the selected agroindustrial cropping systems, we examined the capacity to withstand shocks by assessing buffer capacity using several indicators grouped into livelihood capitals and functional and response diversity indicators assessing both social–economic and ecological buffer capacity (Table 1). These variables have

Table 1 Indicators for buffer capacity

Indicators	Description	Rating criteria
Natural capital	Access to land, security of tenure, and access to water [37]	Farmers have sufficient land and feel secure, access to water using it 0 = inexistent, 1 = low, 2 = significant, 3 = high, 4 = desirable/ideal
Human capital	Years of experience, percentage of employment from the local community (helping build skills), education and experience, skilled permanent employees [42]	Average rating from: experience in the cropping system activity; education and skills 0 = inexistent, 1 = low, 2 = significant, 3 = high, 4 = desirable/ideal
Financial capital	Cropping system activities provide livable incomes; situation of access to credit, savings, debts, and shareholding [29]	Average rating from: the existence of on-farm and off-farm sources of income, levels of wages/incomes; food expenditures; Other expenditures; savings; debts; loans; state support; other support 0 = inexistent, 1 = low, 2 = significant, 3 = high, 4 = desirable/ideal
Social capital	Membership or participation in social networks [42]	0 = inexistent, 1 = low level of participation in networks and decision-making 2 = significant, 3 = high, 4 = desirable/ideal, production system actors feature similar bargaining power
Physical capital	Presence and capacity of bulk storage facilities; access to machinery and tools necessary for the system to function; access to transport [43]	Average rating from: the existence of housing and other installations; sanitary services; other services (water, electricity, gas, waste management; access to inputs, machinery and tools; access to transport) 0 = inexistent, 1 = low, 2 = significant, 3 = high, 4 = desirable/ideal
Diversity of Crops and breeds	The diversity of crops and breeds on farms, and/or in markets, and/or consumed related to the respective food system as a proxy for the Diversity of system components [41] Diversity of system components including seeds creates redundancy and Response diversity [34]	Average crop and breed species richness as a percentage of the maximum in the sample, transferred to a five-point Likert scale 0 = monocrop/ 4 = highest diversity found in the sample
Number of crops rotated with main crop	Extent of crop rotation, referring to the number of crops rotated with the main crop [44]	0 = non-existent 1 = Single crop 2 = Two crops 3 = three crops 4 = Multiple crops
Landscape heterogeneity	We use land cover classes in the cropping system to measure heterogeneity of the landscape. Land cover classes have been used to measure capacity of agroecosystem to provide ecosystem services [39, 45, 46]	0 = non-existent 1 = 0–33% of the maximum number found 2 = 33–66% of the maximum 3 = > 66% of the maximum 4 = Maximum of land cover classes found in the sample
Percentage of arable land under vegetation	Here we look specifically on natural and planted vegetation in the cropped area. Natural vegetation has been found to be important in buffering the agroecosystem [34]	0 = 0% 1 = < 33% 2 = 33–66% 3 = > 66% 4 = 100%



potential to cushion a food production system against environmental, social, and economic shocks, and thereby improving potential for more sustainable systems now and in the future.

The data for the parallel studies in Kenya and Bolivia was collected between 2017 and 2018. In Kenya, data were collected using semi-structured interviews with farm managers as well as other actors from both county and national governments, and NGOs. Six large-scale wheat farms were included in the study in Kenya out of a total of eight large farms in the study area. Large scale wheat farms have a land size of >200 ha (see [42]). In addition, we used questionnaires to collect data from 25 smallholders who are among the major consumers of wheat and its products. The respondents were selected using systematic sampling in villages in close proximity to wheat farms. We also interviewed representatives of two major millers in the study area. These are the only millers within the boundary of the study area. It was important to gather information about the capacity of the milling firms, quality and quantity of wheat received, reasons for importing wheat from outside the country, and prices of wheat and wheat products. Face-to-face interviews

with farm managers were conducted in English, while for smallholders, we sought the help of interpreters from the local community who translated the questions into the local Kikuyu and Meru languages. In Bolivia, we conducted 87 surveys with local households on livelihoods and food security, and 16 semi-structured interviews with different actors involved in the soybean cropping system. Surveys and interviews were conducted in Spanish. Purposeful sampling was used to select workers for interviews. Sometimes we applied snowball sampling to select workers—who are otherwise difficult to identify—who had worked for 5 years and above and had knowledge and experience about the production processes.

For landscape heterogeneity and percentage of arable land under vegetation, we used land cover classes of a typical farm analysed from the Africover Multipurpose Land Cover Database (Food and Agriculture Organization [48], in three wheat farms in Kenya and three soybean farms in Bolivia. Production level land cover classes included cropland, forest plantations/grasslands, and rural settlement [46]. From the land cover classes, we also calculated the classes under vegetation (grasslands, shrubs, and forests). The land cover classes were

determined through fieldwork [48] The more land cover classes a farm has the more heterogeneous the production system and the higher the possibility of harbouring biodiversity [48]. The results for the classification was then converted into a Likert scale to describe areas with low and high number of classes and comparisons made between agroindustrial cropping systems in Kenya and Bolivia. To assess functional and response diversity we used landscape heterogeneity (measured using land cover classes), percentage of farmland under natural vegetation, intensity of crop rotation (measured using number of crops rotated, and species diversity (crops and breeds).

Data analysis

The data was analysed using an ordinal, five-point Likert scale with values ranging from 0 (non-existent, 0%, or very low) to 4 (ideal, 100%, or very high). The scores and the analytical procedures were agreed upon by scientists involved in different aspects of the research on various topics related to social–ecological resilience. During a 3-day workshop held in each of the two countries, the scientists involved in social–ecological resilience aspect of the project held discussions and agreed on the scores

based on research results. Another workshop involving scientists, non-academic actors and other groups of actors from the study areas in the two countries was crucial in validating the results and evaluating the assessments. The scores were then summarized using spider diagrams.

Results

Livelihood capitals in the two cropping systems

Financial and physical capital received the highest score of 4 in Kenya (Fig. 2 and Table 2). This was attributed to the cropping system having diverse financial avenues (credit sources, shareholding, and savings) [42], in addition to having necessary infrastructure to leverage on market dynamics. However, wheat imports were five times more than local production, making wheat producers within Kenya susceptible to price fluctuations [49]. Wheat production was largely for domestic consumption and was sold to local Millers. Millers blended the hard varieties produced in the country with soft imported wheat in a 40:60 ratio to produce a flour quality that met local demands [49, 50]. In Bolivia, the soybean system also reached a high score of 3.3 for physical capital, while

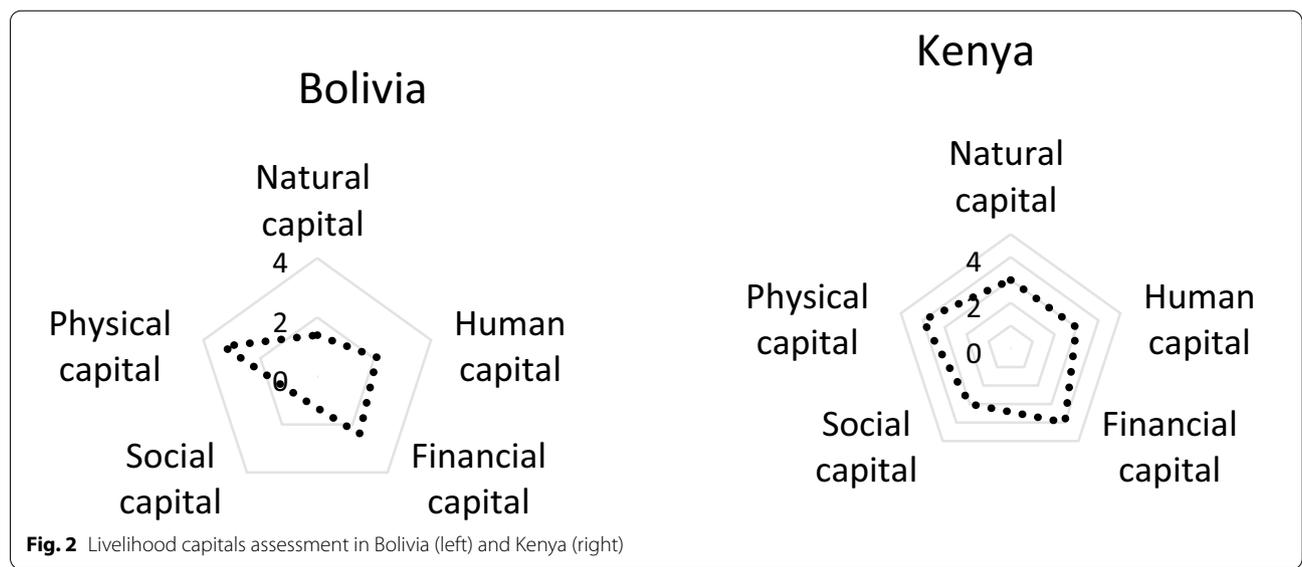


Fig. 2 Livelihood capitals assessment in Bolivia (left) and Kenya (right)

Table 2 Assessment scores

Case studies	Natural capital	Human capital	Financial capital	Social capital	Physical capital	Diversity of crops and breeds	Percentage of arable land under vegetation	Number of crops rotated	Landscape heterogeneity
Wheat (Kenya)	3	3	4	3	4	1	2	2	2
Soybean (Bolivia)	1.4	2.1	2.4	0.9	3.3	0.45	0.5	1	1.25

financial capital score was medium to high (2.5) (Table 2 and Fig. 2). The score for financial capital in the soybean cropping system was lowered by a high level of debts of soybean producers with input providers for seeds, fertilizer and pesticides.

Wheat and soybean cropping systems were characterized by advanced technologies from land preparation to post-harvest management. Both cropping systems were located along major highways, making it easy to procure inputs and transport farm products to the processing firms which were also located within the regions (Timau and Nanyuki towns in Kenya, San Pedro in Bolivia). Human resources within the enterprises were continuously upgraded to appraise on new technology which was largely imported.

Natural capital scored 3 in Kenya because of the following reasons: the companies had access to relatively large farms with secure tenure, did not use all the land for cultivation hence maintaining some natural areas. However, land and plants were negatively affected by heavy use of machinery, agrochemicals, and pesticides. As a counter measure to susceptibility to climate related risks, the wheat farms practiced conservation agriculture. Conservation agriculture was important in buffering the soils due to continuous soil cover (as a result of minimum tillage and retaining wheat straw on the farms) and crop rotation. Conservation agriculture is important in the study area in Kenya due to semi-arid nature of the environment [51], where some farms are located, and reported decline in rainfall. Secondly, large-scale wheat farming is rainfed, hence did not contribute to excessive abstraction of water from rivers and streams such as horticulture farms. Like in Bolivia, the locals were concerned about water and air pollution, the elimination of biodiversity and contamination from spraying of both wheat and soybeans. The soybean system had a low score of 1.4 as a result of its contribution to soil erosion, especially in areas where rotation is not practiced, soil compaction, and severe soil degradation.

Employment opportunities in agroindustrial cropping systems were affected by high levels of mechanization. Very few people with specialized skills were employed in the farms. The wages for the workers on wheat farms were above government national minimum wage for instance drivers for computerized tractors earned an average monthly wage of US\$ 300, while those in administration and management earned more than US\$ 700. In the soybean cropping system, average wages were US\$ 549. Input-sellers earned 220% more than this [26]. Agroindustrial systems have been said to displace workers (due to their capital-intensive nature) in regions, where unemployment is high. For instance, one study found that soybean cultivation displaces 11 agricultural

workers for every one person who finds employment in the sector [52].

Social capital scored 3 in Kenya and 0.9 in Bolivia (Fig. 2). The difference was attributed to a higher level of social networking among wheat farmers in Kenya than in Bolivia. Social self-organization was found to be an important process in building social capital [47]. The farmers are represented by the Cereal Growers Association, while the millers are represented by the Cereal Millers Association [47]. In addition, five large-scale wheat farms had another association which they used to procure inputs and sold their produce in bulk. Wheat farms in Kenya were also engaged with smallholder farmers to transfer technology in conservation agriculture and potatoes seed production used by both smallholder farmers and large scale commercial farmers [53, 54]. These initiatives cushioned the smallholder farmers against risks associated with climate variability, in addition to contributing to food security through potato seed security.

Functional and response diversity

The concepts of functional and response diversity have been applied widely by scholars as a measure of resilience [55] to assess the resilience of natural ecosystems. According to [36], functional diversity is “the variety of ecosystem services that components provide to the system,” while response diversity is defined as “the range of responses of these components to environmental change”. The results of functional and response diversity are explained using the following indicators; landscape heterogeneity, percentage of arable land under vegetation, and intensity of crop rotation, and crop diversity.

Landscape heterogeneity in the cropping systems

Landscape heterogeneity is important for ecological buffer capacity and can, for instance, be measured by the number of land cover classes in a cropping system. The wheat monoculture in Kenya had 12 land cover classes, out of which the three with the highest percentage were rainfed herbaceous grazing land (34%), rainfed herbaceous crop, fallow (32.5%), rainfed crop, and crop rotation (23%) [46]. The soybean cropping system had five land cover classes, out of which the three with highest percentage were rainfed herbaceous crop-soybean (89.2%), scattered trees with closed to open shrubs (5.64%), and rainfed vegetables (4.5%) [46]. This means that the wheat cropping system was more heterogeneous than the soybean system. In a previous study on food systems in the two countries it was observed that soybean monoculture had a lower Agroecosystem Service Capacity (ASC) index of 0.82 as compared to a slightly higher score for wheat (1.48) [46]. The results imply the low

capacity of the cropping systems to provide agroecosystem services.

The assessment scores for Kenya and Bolivia were low (2 and 1.25, respectively) an indication that the farms had very few different land cover classes making them unfriendly for biodiversity and agroecosystem services due to limited natural areas, and the intensive use of pesticides. Previous studies on landscape heterogeneity have recorded higher levels of heterogeneity in smallholder farms as compared to large-scale commercial enterprises [41]. Other studies also show that an increase of areas with natural vegetation on farms contributes to enhancement of biodiversity [32, 35].

Percentage of arable land under vegetation

The percentage of land under natural vegetation was 41% for the wheat cropping system rated as significant (2) and 5.6% in soybean system rated as very low (0.5) (Fig. 3). The high percentage of vegetation cover in wheat system was because of large land sizes which were often left fallow and used for grazing purposes [42]. Most farm managers interviewed in Kenya said they maintained vegetation as ‘buffer zones’ to recharge the farms in terms of water as well as maintain biodiversity that they said was important for proper functioning of the farms. The farms were required to maintain a minimum of 10% of the land under vegetation by law, however, due to large nature of the wheat farms only an estimated 50% of the arable land was used at a time to plant crops, while the rest comprised grazing areas and planted and natural forests—an observation made also by [42]—this means that they had more natural areas than the 10% minimum. However, the intensive use of pesticides observed on all farms compromised biodiversity which is important for ecological buffering of the cropping system. The smallholders interviewed also perceived the spraying in wheat farms to be affecting their farms negatively by contaminating river water and killing beneficial important insects. In Bolivia,

there were very little or no natural habitats in the cropping systems, which, in addition to intensive use of agrochemicals, contributed to disturbed ecosystems around the farms, making the landscape uninhabitable for most organisms.

In Bolivia, the legal 50-m-natural vegetation strip that has to be left standing and be protected around rivers and water bodies was in no case respected, and cultivation was happening until the shore. The soybean system was identified as one of the factors that contribute most to deforestation [56], displace indigenous communities [52], and negatively affect biodiversity [57].

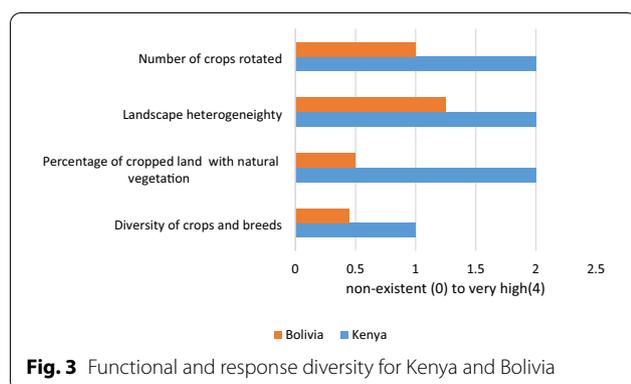
Intensity of crop rotation, and crop diversity

The wheat agroindustrial cropping system scored 2 for both crop rotation intensity and crop diversity, while the soybean system had much lower scores (1 and 0.45, respectively). In Kenya, wheat was often rotated with barley, canola, peas, Rhodes grass, seed potatoes, and oats (Fig. 4). In terms of diversity of breeds, three out of the six farms under study in Kenya, raised livestock especially for beef which was sold in hotels in Nairobi, while one farm had a fish pond. However, in our study area in Bolivia, crop rotation between soybeans and wheat was only marginally applied (on around 10% of the land).

Agroindustrial cropping systems and social–ecological resilience

The strongest indicators that contributed to buffer capacity of the two agroindustrial food cropping systems were physical capital and functional and response diversity (Fig. 5). However, in the wheat cropping system, there were additional indicators with high scores (natural, human, social, and financial capitals). This can be attributed to the value attached to wheat as an important crop for food security whose supply is limited hence efforts are made to cushion it against shocks. Vulnerability of the wheat cropping system and its value chain is likely to contribute to food insecurity especially among urban households. However, heavy reliance on imports cost the economy large sums money [49].

The lowest scores in both systems were crop rotation intensity, crop diversity, and spatial and temporal heterogeneity. Spatial and temporal heterogeneity was low in both contexts because of the contribution of both systems to deforestation as they expand the farms to meet increasing demand of food products. Intensive use of agrochemicals and energy was also perceived to be negatively impacting biodiversity, water, air and health [19, 26]. Table 3 provides a summary of the social–ecological resilience benefits associated with buffer capacity.



Crop Rotation in Wheat Agroindustrial Cropping System in Kenya	
System A	Green peas ⇨ Canola ⇨ Wheat ⇨ Barley
System B	Canola ⇨ Wheat ⇨ Rhodes grass
System C	Wheat ⇨ Potatoes ⇨ Green peas
System D	Wheat ⇨ Canola ⇨ Barley ⇨ Green peas

Fig. 4 Crop rotation in the wheat cropping system in Kenya

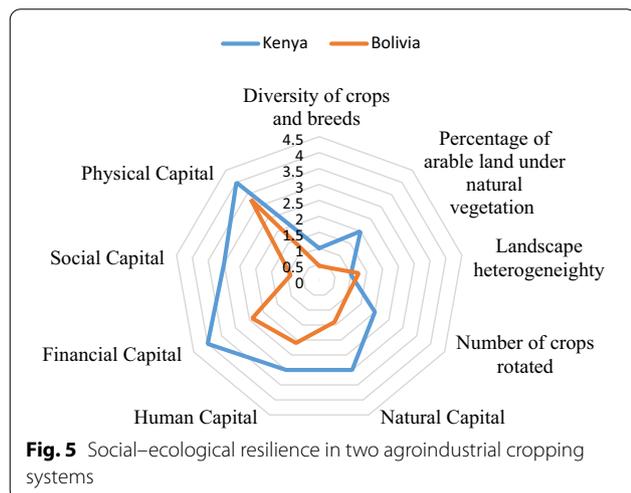


Fig. 5 Social-ecological resilience in two agroindustrial cropping systems

Discussion

Livelihood capitals are an important ‘buffer’ for agroecosystems supporting resilience against risks and shocks associated with environmental, social and economic uncertainty [33, 37]. Physical capital related to technology innovation has been found to be important in climate change adaptation and resilience [63] and in supporting food security. While the machinery-intensive nature of the agroindustrial cropping systems may not allow for more employment opportunities, trade-offs can be achieved through increasing technology transfer to smallholders and indigenous communities to increase yields and incomes while promoting sustainable production [53, 63]. The soybean agroindustrial system has an opportunity to improve on self-organisation to create necessary social capital to increase buffer capacity.

Crop diversity has been found to be an important indicator for agroecosystems functioning and resilience against shocks [41]. Apart from resilience, maintaining a degree of crop and breed diversity (polyculture) in agroecosystems has been found to contribute to increased productivity with long term benefits to food security and incomes [45, 58, 59, 64], while crop-livestock systems have potential to contribute to healthy soils [65], which in the long run improve productivity and food security. In addition, the two agroindustrial cropping systems can learn from the many existing examples on how monocultures can increase diversity by intercropping and crop rotation with beneficial outcomes for soils and productivity [44, 61, 64].

There are several areas for improvement in the two cropping systems. Bio-pesticides and organic fertilizers have emerged as eco-friendly alternatives to synthetic pesticides with potential to minimize adverse effects on natural and social environment [66]. More elaborate crop rotation systems and integration of vegetation elements that provide benefits both to the environment and to the crops may also have positive outcome to monocultures [44, 67].

Studies have suggested various ways of enhancing resilience in agroindustrial cropping systems that are characterized by monocultures. For instance, crop diversification helps to build resilience by suppressing pest outbreaks and dampening pathogen transmission as well as buffering crops from the effects of climate variability and climate change [68]. Agroecological practices, such as use of organic fertilizers, crop rotation, and mulch, offer potential for restoring degraded soils. Other alternatives are intercropping, minimum tillage, and the use of cover crops to reduce adverse impacts of

Table 3 Summary of benefits of buffer capacity

Buffer capacity indicator	Contribution to social–ecological resilience
Diversity of crops and breeds	<ul style="list-style-type: none"> • Improve soil fertility • Yield improvement [58] • Enhances agroecosystem productivity [12, 41] • Enhances ecological resilience • Improves food security [59]
Percentage of arable land under vegetation	<ul style="list-style-type: none"> • Vegetation provides habitat for biodiversity and pollinators [60] • Helps to recharge water system • Contributes to yield improvement • Improves livelihood resilience [37]
Landscape heterogeneity	<ul style="list-style-type: none"> • Improves crop yield [58] • Improves soil health • Improves provision of agroecosystem services [46]
Number of crops rotated	<ul style="list-style-type: none"> • Crop rotation supports soil health [44] • Improves productivity • Enhances soil carbon [61]
Livelihood Capitals (human, social, financial, natural, and physical capitals)	<ul style="list-style-type: none"> • Aggregation ensures economies of scale • Advocacy by the associations [47] • Multiple credit sources, shareholding, and savings cushions against price fluctuations, supports procurement of inputs and farm maintenance in event of shocks [62] • Human skills and knowledge important for efficient production • Proximity to roads, railway and airports important for procurement of inputs and sell of outputs • Water important for irrigation • Land for expansion of the farms and maintaining biodiversity

Source: Compiled by the Authors

the environment [65, 69, 70]. Maintaining natural habitats in cultivated areas has proven to have more beneficial effects to crops than the use of agrochemicals, for instance regarding the provision of beneficial insects for pollination [60]. Furthermore, the presence of natural vegetation within agricultural landscapes can have beneficial effects on crop yields [68], and food security. The intensive use of machinery and fossil fuels in monocultures has been associated with carbon emissions [70], which has potential to contribute to climate change.

Conclusion

Our study assessed buffer capacity as an important pillar of resilience in agroindustrial cropping systems. Even though the two systems have a certain level of resilience with regard to some indicators, e.g., related to finance and machinery, the systems' overall capacity to withstand shocks—particularly related mainly to climate change and variability and economic shocks was extremely low for soybean system and low for wheat. The two systems were found to have low scores of functional and response diversity especially with regard to landscape heterogeneity, crop and breed diversity and percentage of vegetation cover on arable land. The cropping systems have the potential to improve ecological buffer capacity by diversifying production systems, integration with biofertilizers and biopesticides [71], as well as increasing more

integration of arable land with natural vegetation. More elaborate crop rotation systems that enhance soil fertility, can help to buffer the agro-ecosystem in their transition to diversified, resilient cropping systems. Furthermore, the two cropping systems should also take advantage of existing networks to cushion themselves against market dynamics as they also leverage on quality products. Economic buffer may also be achieved by integration of imported inputs with local products, diversification of sources of finances, on-job training of workers in addition to taking advantage of experience about previous risks and shocks to develop more resilient cropping systems.

The availability of adequate physical infrastructure has been found in this study to help deal with price instabilities which is a major challenge for commercial systems. Companies and farmers' organisations can reduce vulnerability to price fluctuations by enhancing their storage capacities as observed in Kenya, where wheat companies have established silos. In addition, social self-organisation among producers can help to cushion against price instabilities by aggregating and selling in bulk while at the same time procuring inputs as a network. Policies and incentives supporting the transition to sustainable cropping systems are urgently needed not only to increase buffer capacity of agroindustrial monoculture systems,

but also to support sustainable use of scarce natural resources (mainly land and water).

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Authors' contributions

SM and JJ contributed equally in research design, data collection, data analysis, description and writing of the manuscript. Both authors read and approved the final manuscript.

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Data availability

All relevant data are within this article and any additional data is available upon request from the Corresponding Author.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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