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Agroecology-based aggradation-conservation agriculture (ABACO): Targeting innovations to combat soil degradation and food insecurity in semi-arid Africa

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ABSTRACT

Smallholder farmers in semi-arid Africa are in an increasingly vulnerable position due to the direct and indirect effects of climate change, demographic pressure and resource degradation. Conservation agriculture (CA) is promoted as an alternative to restore soil productivity through increased water and nutrient use efficiencies in these regions. However, adoption of CA is low due to a number of technical reasons, but fundamentally due to the fact that CA has been often promoted as a package, without proper adaptation to local circumstances. Farmers engagement in designing and implementing locally suited CA practices, as part of a long term strategy of soil rehabilitation is the core approach followed by the ABACO initiative, which brings together scientists and practitioners from West, East and Southern Africa coordinated through the African Conservation Tillage Network (www.act-africa.org). ABACO relies on agro-ecologically intensive measures for soil rehabilitation and increased water productivity in semi-arid regions, implemented, tested and disseminated through local co-innovation platforms. Rather than using rigid definitions of CA approaches that might not work in all sites, ABACO proposes to explore best engagement approaches for different sites. Simulation modelling is used as a support of long-term cross scale tradeoffs analysis from field to farms and territories, in order to inform effective policy-making. Preliminary results form the field are used here to illustrate and discuss the principles of ABACO, which may apply as well to regions other than semi-arid Africa.

1. Introduction

Poor soil fertility and land degradation are major limitations to food security in sub-Saharan Africa, placing many smallholder farmers in a vulnerable position. Rural poverty and the environment in developing countries have been linked as a 'downward spiral' by many, with population growth, economic marginalisation, and more recently climatic variability and change leading to environmental degradation (Scherr, 2000). The rural poor, and rural poor women even more so, who depend on agriculture for their livelihood and food security are particular vulnerable to such a downward spiral as they have limited access to inputs (e.g. fertilisers, irrigation) to improve soil productivity. These processes are particularly severe in semi-arid areas, where rainfall variability exacerbates crop failure risks and resource degradation, often forcing farmers to abandon their land or liquidate their assets to face unfavourable periods.

Conservation agriculture (CA) is increasingly promoted as an alternative to address soil degradation resulting from agricultural practices that deplete the organic matter and nutrient content of the soil, aiming at higher crop productivity with lower production costs (e.g. Kassam et al., 2009). In areas of climatic variability, CA

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may represent a low-investment strategy to increase water productivity and mitigate risks, by breaking the vicious cycle of low rainfall, poor yields, low investment and soil degradation. In spite of experimental evidence showing increased water productivity and crop yields under CA, its adoption by smallholder farmers in sub-Saharan Africa seems to be hampered by (Giller et al., 2009): (i) concerns on initial yield decreases often observed (or perceived) with CA; (ii) lack of sufficient biomass for effective mulching due to poor crop productivity or to competing uses for crop residues in crop-livestock systems; (iii) increased labour requirements when herbicides are not used, putting an extra burden on female labour for weeding; (iv) Lack of access to, and use of, external inputs such as mineral fertilisers and herbicides. A fundamental problem with the adoption of CA is its promotion as an indivisible package that farmers find hard to adopt in full, ignoring farmers' participation in the design/selection of CA alternatives, overlooking the fact that the process through which innovation emerges are complex and non-linear (i.e., not as unidirectional research-extension-farmer flows).

It has become evident that conservation agriculture has to be tailored to local conditions to make it more suitable to resource-constrained smallholder farmers in sub-Saharan Africa (Giller et al., 2011). This is best done by collaborating with local smallholders, both male and female, improving their innovation capacity, sharing technological knowledge in co-innovation platforms, and overcoming adoption barriers through gender-sensitive technological solutions and supportive policy measures.

2. The ABACO initiative

An EU-funded[1] project on agro-ecology based aggradation-conservation agriculture (ABACO, 2011–2014) for semi-arid regions emerged as a need for *action* identified during the implementation of the CA2Africa initiative (Corbeels, 2011), which brought together a large number of partners working on CA in Africa, including those from international research centres, and the African Conservation Tillage (ACT) network. ABACO aims at establishing site-specific co-innovation platforms that rely on agroecology principles and aggradative measures to restore soil productivity in semi-arid regions of sub-Saharan Africa. This is done by fulfilling the following specific objectives: (1) to target CA to smallholder farmers by studying which principles of CA, and under which conditions, contribute to the effects sought in terms of food production and land rehabilitation in the face of climatic variability; (2) to involve farmers, researchers, extension agents and NGOs in co-innovation platforms to promote the adaptation/appropriation of technologies by local communities; (3) to assess the social and economic viability and tradeoffs of implementing CA at farm and village scales, and across scenarios, to inform policies; (4) to promote dissemination of targeted CA alternatives and approaches through divulgation, training and capacity development. Fig. 1 sketches the various ABACO activities and their interrelation; our target areas in West, East and Southern Africa are briefly described in Table 1. If widespread adoption of CA is to be achieved in semi-arid Africa, current technical knowledge and innovations should be targeted to meet the particular demands and constraints of smallholder farmers. The promotion of CA benefits should be based on:

i. Rehabilitation of degraded soils to restore biomass productivity, in order to secure the various functions of CA that depend on above and belowground plant biomass.
ii. Increased water productivity and soil water buffering capacity to face risks associated with climate variability, creating more conducive conditions for farmers' investments.
iii. Intensifying agroecological functions to capitalise on natural interactions, increase resource use efficiency at farm scale and reduce dependence on external inputs.
iv. Embedding these principles in sustainable innovation support systems that recognise the complexity and non-linearity of agricultural innovation processes.
v. The institutionalization of enabling policies and market conditions so as to facilitate uptake and promotion of CA among smallholder farmers.

The implementation of these five principles should be done while embracing the diversity of situations that characterise semi-arid African agriculture. So-called 'one-size-fits-all' policies do not provide adequate solutions to poverty and degradation problems in sub-Saharan Africa (Ruben and Pender, 2004). There are no universally significant factors that affect CA adoption and therefore tailored approaches to promote this practice are needed (Knowler and Bradshaw, 2007). Such approaches should contain the following elements: education and technical assistance, building social capital, and financial assistance if appropriate. Gender, as a cross-cutting variable, should be an integral part of the approach. The provision of gender-sensitive safety nets may be a good measure to take, because of the risk of reduced yields at the early stage of CA introduction, in order to realize the long-term benefits of CA. Governments use macro-economic policy, trade regulations, input subsidies, or education and extension to alter the decision-making environment in which farmers choose one practice over another. The success in promoting CA practices in certain developing regions, particularly Latin America, is noteworthy, and policy has played an important role. However not all policy instruments have worked in the same way or have given positive results everywhere. Therefore policy research is necessary in the differing socio-ecological environments to enable identification of right policy incentives to target beneficiaries and address differentiated needs. There shall be a need to get answers as to how to create conducive policy environments and incentives for CA adoption. ABACO intends to search and recommend policies that will govern processes to support CA innovations.

3. Aggradation-conservation agriculture in semiarid areas

The term 'aggradation' has been coined in physical geography to refer to the raise in grade or level of a river valley or a stream bed by depositing detritus or sediments. Aggradation is also used in soil physical chemistry to refer to the neo-formation of clay minerals, which is gradual, and the aggraded clays may have the same lattice than the original but not necessarily the same properties. Aggradation in forest ecology refers to the phase of re-colonisation of open spaces in forest after disturbance. Here, we use these *analogies* to refer to the gradual rehabilitation of degraded soils. ABACO's approach of aggradation-conservation agriculture consists of implementing measures that have been traditionally promoted as soil and water conservation, water harvesting technologies or (indigenous) agroforestry, during an initial phase of soil restoration or 'greening' (cf. Lahmar et al., 2012). Only when a minimum efficiency of nutrient and water capture has been achieved to allow increasing primary productivity, the three principles of CA may become effective: zero tillage, permanent soil cover and crop rotation. Particularly in dry environments, and under rainfed

[1] ABACO is an EU-funded project (DCI-FOOD 2010/230-178). The project is implemented during 2011–2014. This paper has been produced with the financial assistance of the European Union. The contents of this paper are the sole responsibility of the authors and can under no circumstances be regarded as reflecting the position of the European Union.

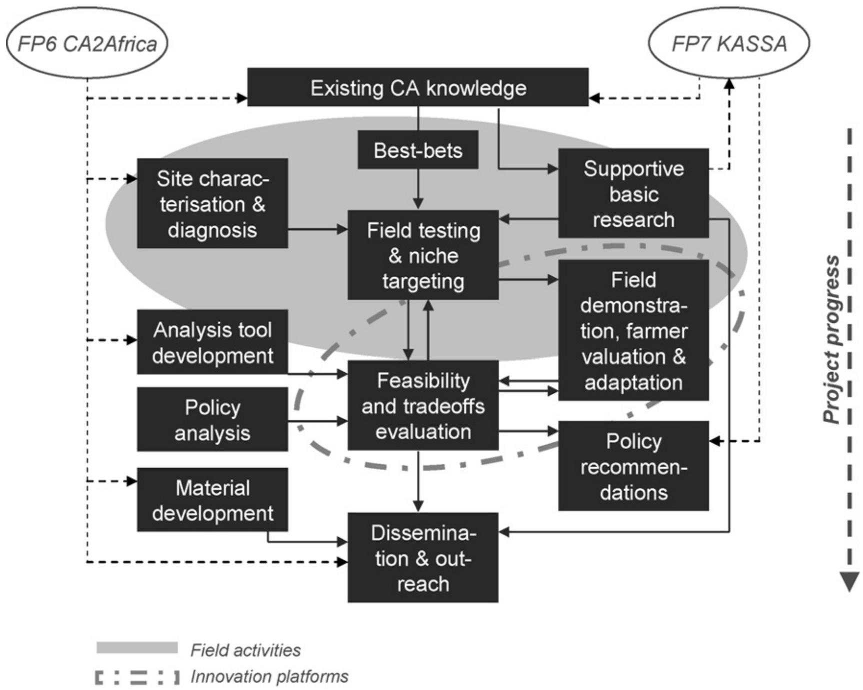

Fig. 1. Project activities and links with other EU funded initiatives. Existing CA knowledge in Africa and worldwide, plus analysis of current experiences, leads to the selection of strategic 'best-bets' to be targeted to diagnosed CA 'niches', field tested, and adapted by local communities. Supportive research is conducted to bridge knowledge gaps on agroecological and social determinants of CA adoption, contributing to our global knowledge frameworks. Integrated simulation models and other tools are used to evaluate the technical and socioeconomic feasibility of implementing targeted and farmer-valuated CA alternatives. This is done by evaluating tradeoffs, externalities and agroecological service functions from field to regional scales, and through analysis of policy, demographic, climatic and market risk scenarios. The outcome will be used to support dissemination and policy recommendations.

agriculture, the response of soil productivity to soil restorative measures may exhibit a faceted pattern as shown in Fig. 2. This pattern is characterised by an initial response to increased water availability (i.e., the 'greening' effect) with a slight loss in water productivity (or use efficiency), followed by a response to increased soil fertility once nutrients become available (resulting in greater water productivity).

Rehabilitating degraded soils, depending on the extent and type of the degradation process, may require sustained efforts for long

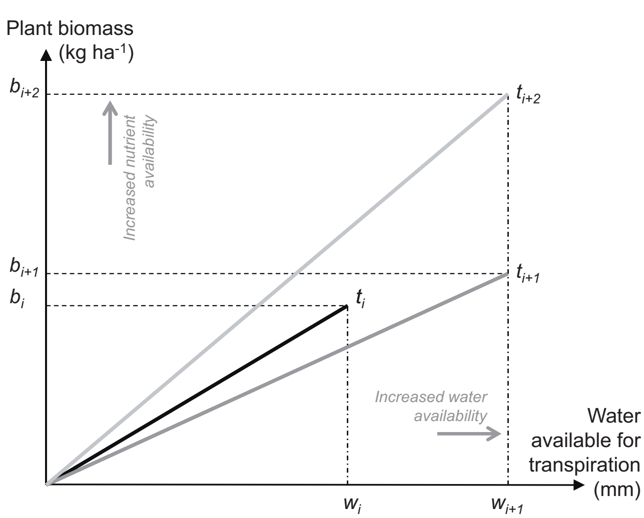

Fig. 2. Scheme representing the faceted impact of aggradation-conservation agriculture on water productivity. Crops that used the available water w_i to produce an amount of biomass b_i under the baseline conditions (t_i) may exhibit a less than proportional increase in biomass (b_{i+1}) as a result of increased water availability (w_{i+1}). Once nutrients become available (t_{i+2}), water can be used more efficiently to produce greater amounts of biomass (b_{i+2}).

periods of time, and responses to interventions may be weak. Slow and weak responses to soil restoration are a disincentive to smallholder farmers. The theoretical curves drawn in Fig. 3 illustrate what has been termed 'hysteresis' (h) of land rehabilitation, represented by the deviation between the trajectories of soil degradation and rehabilitation (purposely plotted towards the opposite direction) (cf. Tittonell et al., 2008). The various technologies and measures that may fall under the general umbrella of CA should be strategically targeted according to the phase in which the system is, either in degradation, rehabilitation or stabilization. Situations (fields) that allow hysteretic, fast responsiveness are typically those that farmers prioritize for the allocation of their scarce resources (labour included), as the perceived returns to their efforts are more attractive and less risky (e.g. Tittonell et al., 2007). On the other extreme, severely degraded fields that exhibit weak hysteresis and slow responsiveness are often considered to be non-resilient, and may require profound reconversion of land use rather than investments to increase productivity under the current land use. The intermediate situations between these two extremes are those that may be targeted with agroecology based aggradation-conservation agriculture.

A gradual increase in water productivity during the aggradation phase is the result of two interrelated processes that are classically ascribed to CA:

(a) *Enlargement of the soil moisture reservoir*: No-tillage and intercropping with cover crops may often result in an effective enlargement of the rootzone in space and time, as well as an increased soil moisture holding capacity as a consequence of the build up of soil organic matter. In particular for degraded sandy/coarse soils, this may amount over time to an additional increase of soil moisture holding capacity of 40% (http://hydrolab.arsusda.gov/soilwater/Index.htm).

Table 1
Project target sites.

Site (country)	Demography and markets	Agroecological conditions	Farming systems
West Africa			
Yilou (Burkina Faso) Sahelian zone	Population density: 70 inhabitants km-2 Links to local and regional markets, possibility of exporting	Rainfall is uni-modal, annual average of less than 700 mm Dominant soils are Lixisols (WRB, 2006), with frequent patches of degraded and unproductive land	Cereals, millet and sorghum, intercropped with cowpea and groundnut Free grazing livestock is omnipresen
Koumbia (Burkina Faso) Sudano-Sahelian zone	Population density: 50–300 inhabitants km-2 Markets: readily available local, regional and export	Rainfall ranging between 700 and 1000 mm Sudano-Sahelian savannah, Lixisols and Luvisols	Cotton-sorghum and cotton-maize rotations Free grazing livestock and transhumancy
East Africa			
Laikipia and Mbeere districts (Kenya)	Population density up to 800 inhabitants km-2 Local markets of legumes and cereals	Rainfall: bimodal, 700–2000 mm Altitudes between 900 and 1700 m.a.s.l. Soils: Nitisols, Acrisols, Vertisols and Ferralsols	Major exports: tea, coffee, sugar Annual crops: cereal-legume cropping systems
Arusha, Manyara and Mbeya regions (Tanzania)	Average population density of 52 inhabitants km-2 Weekly open markets and sales to individual traders at give away prices	Rainfall: bimodal 400–1000 mm Altitude ranges from 1000 to 1900 m.a.s.l. Poor shallow soils on summits and slopes. Clay soils of moderate fertility in valleys	Maize-based, with pigeon peas, beans and lablab Cattle and goats are main livestock, oxen till more than 50% of the land
Southern Africa			
Goneso and Makwarimba wards in Wedza district (Zimbabwe)	Population 40–60 inhabitants km-2 Moderate access to markets in Makwarimba and poor in Goneso	Rainfall: uni-modal, 450–750 mm Altitudes of 1100–1300 m.a.s.l. Soils are granitic coarse sands with mostly less than 10% clay, and known for deficiencies in P and N in addition to low moisture retention capacity	Main crops are maize, groundnuts and sweet potato; no systematic crop rotations. Strong crop-livestock interactions. Livestock graze freely during the dry seasons and are a major form of insurance and source of livelihood
V anduzi and Machipanda PA's of Manica district (Mozambique)	Population 45 inhabitants km-2 Access to markets is poor, and is aggravated by poor infrastructure	Rainfall: uni-modal, 800–1200 mm Deep red clayey soils, P and N remain *the most limiting* nutrients	Maize, cowpea, common beans, groundnut, pigeon pea <50% own cattle Large areas of land (>3 ha)
Lake Alaotra (Madagascar)	Population 100 inhabitants km-2 Rice basket: more than 100 kg person-1 year-1 consumed at national level Migration: Sihanaka (early migration) and Merina ethnic groups (recent migration)	Rainfall: uni-modal, 1200 mm poorly distributed, with extreme variability (500–1500 mm) and frequent dry spells Irrigated low lands, alluvial plains and sloping hill sides at 740 m.a.s.l. Rich alluvial soils and poor Oxisols on slopes	Irrigated and rainfed rice-based farming system Herded livestock and cut-n-carry dairy systems

(b) *Increased rainwater infiltration and reduced evaporation losses*: The application of mulch can drastically increase the infiltration and storage of rainwater (up to 50% – e.g. Scopel et al., 1998) and reduce unproductive soil evaporation losses (up to 25% – e.g. Allen et al., 1998), particularly during the initial and development stages of the crop.

These effects may in some situations take long to induce substantial crop yield advantages that could motivate smallholder farmers to implement CA. A number of practical questions concerning the seasonal management of water productivity in semi-arid areas remain unexplored, and these are central to the research component of the ABACO initiative: CA technologies need to be evaluated on their *seasonal* water balance in order to optimize water storage capacity and reduce evaporation during low sensitive growth stages, thereby maximising soil moisture buffer capacity during highly water stress sensitive stages. The impact of cover crops on the pre-seasonal depletion of the soil moisture reservoir and its effect on the seasonal water balance must also be evaluated. Soil moisture retention and depletion processes impact

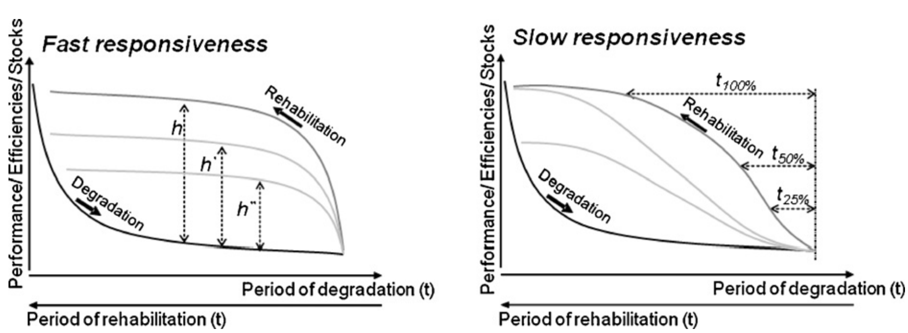

Fig. 3. Theoretical schemes representing the concept of hysteresis (h) of land rehabilitation. After having undergone a degradation phase, the response of the agroecosystem to rehabilitation measures may be fast or slow, and exhibit weak or strong hysteresis (i.e., h, h' or h''). The periods $t_{25\%}$, $t_{50\%}$ and $t_{100\%}$ represent the delay necessary to achieve 25–100% of the original performance, efficiency or stock level. Measures to restore productivity may be hysteretic or not, and exhibit fast or slow responsiveness, depending on the indicator chosen to characterise the response (productivity, efficiencies, stocks), on the type of measure(s) implemented to restore productivity, on the biophysical properties of the agroecosystem, and on the behaviour of external drivers (e.g. rainfall).

on the capacity of CA alternatives to retain and provide additional water for productive transpiration (cf. trajectory t_{i+1}, b_{i+1}, Fig. 2). As nutrient deficiencies limit water productivity (i.e., the slopes of the linear biomass-transpiration relation in Fig. 2), any enhancement of nutrient availability for the crop will have a multiplier effect on crop production: more water is made available for productive transpiration, and each unit transpired water leads to greater biomass production. The time frame and extent to which these benefit will materialize, however, may be dependent on the cropping system and soil characteristics.

4. Intensification of agroecological services and tradeoffs

Increasing agroecosystem primary productivity implies intensifying the basic agroecological functions of photosynthesis, water capture and nutrient cycling. ABACO seeks to enhance ecological functions and services through biodiversity management in order to increase resource use efficiency, reducing the need for external (synthetic) inputs. Diversification of the cropping system takes place through (i) use of intercrops (space) and cover crops or crop rotations (time) associated with the main food or commercial crops; (ii) making use of species of the native flora as source of biomass (transfers) or as 'islands' or fertility (cf. Lahmar et al., 2012). Cover and companion crops are generally crucial for the global efficiency of CA, through biomass production during and off the main season, nitrogen fixation in the case of legumes, soil cover when standing off as mulch, and their potential for weed suppression in some cases.

The most suitable systems will be those crop rotations that best fit within production objectives and constraints of farmers in a given region, meeting both technical and socio-economic criteria to facilitate their cost-effective and large-scale adoption and multiplication. In particular African farmers often face serious tradeoffs in resource allocation or in biomass valorisation within their farm,

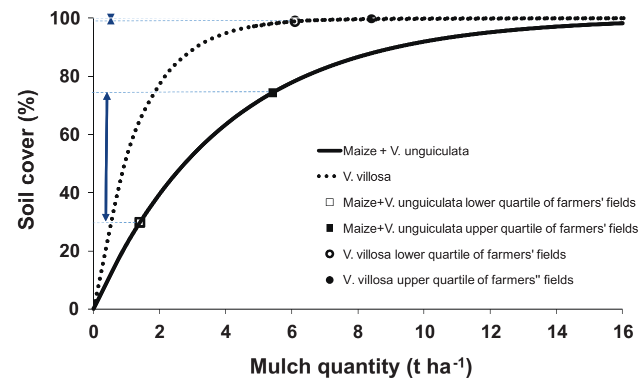

Fig. 4. Relation between mulch quantity and soil covering for two different cover crops residue at Lake Alaotra (Madagascar) and diversity of farmers' fields situations at planting for the subsequent season (number of fields: maize + *V. unguiculata*, $n = 17$; *V. villosa*, $n = 21$).
Adapted from Naudin et al. (2011).

especially between cropping and livestock activities. The short-term economic value obtained from livestock (e.g. milk production) represents a relevant criterion which influences farmers' decision. Their choice usually has strong consequences on some of the agroecological functions of CA and their sustainability. For example, as illustrated in Fig. 4 for the Lake Alaotra region in Madagascar, the choice of cover crop or intercrop species and cultivars according to their uses and farmers' preferences may interfere on the ability of the system to ensure soil cover and related agroecological functions. Maize productivity during a first year of CA was virtually not affected by the type of legume intercropped with it during the relatively dry 2010–2011 season in this region (Table 2), but maize impacted differently on the companion legume. *Stylosanthes*, with a slow initial growth suffered more from maize competition than

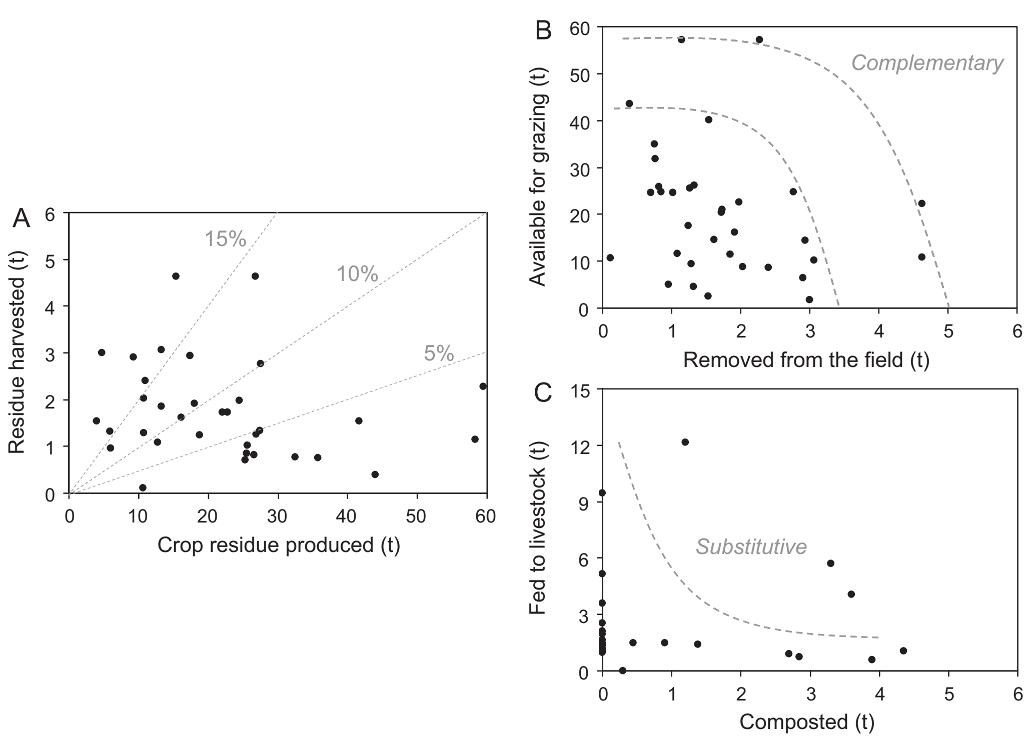

Fig. 5. Partitioning of crop residue biomass at village scale at Koumbia, Burkina Faso. (A) Total crop residue produced in a season versus crop residue harvested from the village fields; (B) residue harvested versus residue remaining, available for grazing during the dry season; (C) harvested residue used for composting with animal manure versus fed to livestock.
Source: Andrieu (2011).

Table 2
Yields and biomass productivity ($t\,ha^{-1}$) of two maize-legume intercrops under CA during the 2010–2011 season at Lake Aloatra, Madagascar.

Biomass component	Maize + *Dolichos*	Maize + *Stylosanthes*
Maize grain	3.9	3.9
Maize stover	3.3	2.7
Total legume	4.9	1.8
Total aboveground	12.3	8.5

Dolichos, which is already well installed when the maize canopy starts to close. This makes maize + *Dolichos* a more interesting cropping system to produce biomass that can be partly used to feed livestock.

The positive (services) and negative (externalities) impacts of the various CA technologies should be assessed through scenario analysis at different spatio-temporal scales. Tradeoffs between competing uses of biomass often operate at the scale of entire village territories, but opportunities for synergy may also be there. Fig. 5 illustrates this with an example from one of the ABACO target sites in Burkina Faso. From the total amount of crop residue produced at village scale farmers harvest currently up to 30% for other uses. The amounts left in the field are still substantial to sustain the village herd during the dry season. The tradeoffs are more severe (substitutive) in the allocation of residues harvested between livestock feeding and composting with manure, and probably insufficient for both objectives. If residues were left in the fields and grazed rationally, the remaining soil cover might still be significant to ensure e.g. protection against water and wind erosion (e.g. a 30% soil cover leads to drastic reduction in water runoff – Scopel et al., 1998). Such tradeoffs at farm and village scale are tackled through scenario analysis using bio-economic simulation models, to account for long term dynamics in climate, demography and soil degradation/rehabilitation while considering the short term objectives of factor and labour productivity.

5. Co-innovation platforms: the Learning Centre

The emergence and diffusion of knowledge elements (technical, scientific) and their translation into production processes and practices describe feedback mechanisms and interactions between science, learning, policy and technology demand (Edquist, 1997). This opposes the traditional linear model of knowledge transfer in agriculture, the research-extension-farmer continuum, through which most technologies are promoted. The participation of farmers in technology development through action research, with a solid involvement of researchers in iteration (co-innovation), has been shown as a pre-requisite to the adoption of soil improving technologies (Misiko and Tittonell, 2011; Misiko et al., 2011). ABACO works through co-innovation platforms that allow multi-directional knowledge transfer and iteration between the various stakeholders, male and female, involved in local agriculture. ABACO adopts a definition of co-innovation platform which is a flexible and informal (i.e., minimum or no formal constitution needed), dynamic, multi-stakeholder partnership working together to develop and use CA technologies and processes to improve livelihoods.

The form of co-innovation platform selected is the Learning Centre (LC), a concept developed by the Soil Fertility Consortium for Southern Africa (SOFECSA). LCs revolve around participatory adaptive experimentation with communities and a range of stakeholders, emphasising on enhancement of crop production and other robust risk-management practices for sustained resilience to different shocks (Mapfumo et al., 2008). Also core to the LC approach is that the activities have to align with or recognise farmer experiences. LCs are defined as 'field-based interactive

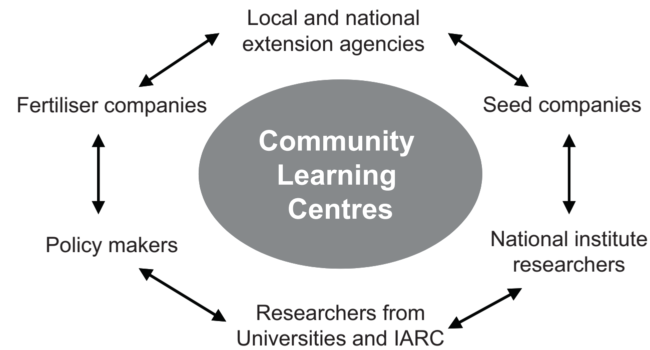

Fig. 6. Schematic representation of stakeholder involvement at the Learning Centres. The Learning Centre is the nucleus in an environment where information relay is non-linear (IARC – international agricultural research centres).
Source: Chikowo et al. (2011).

platforms integrating local, conventional, and emerging knowledge on superior agricultural innovations requiring promotion or farm level adaptive testing to address complex local problems through active participation of an alliance of researchers, service providers, farmers and other relevant stakeholders' (Mapfumo, 2009). Stakeholder involvement at LCs is diverse, with the LC itself being the nucleus in an environment where information relay is non-linear among all stakeholders (Fig. 6). In this sense, the LC is broader and more flexible in its approach than the farmer field school. Private companies can embrace the LC concept as an out-reach approach to market their products. The linear and top-down approaches associated with traditional 'demonstrations' employed by these companies and other extension agencies are replaced by the farmer-driven LC approach. Through facilitation of local leaders and extension, researchers from different institutions, host communities, and individual farmers are organised into LC management committees. Successful mobilization of farmers and service providers in Zimbabwe resulted in a rapid increase of climate change adaptation Learning Centres from six to 42 over three seasons, reaching out to over 3000 farmers (Chikowo et al., 2011). These committees then spearhead effective learning by organising field-days, learning tours and related events where farmers and stakeholders are able to evaluate different technical options for crop production.

6. Concluding remarks

The ABACO initiative places strong emphasis on local farmer selection and adaptation of CA technologies and principles. This does not guarantee that all technical, environmental and socio-economic constraints to CA in Africa would be automatically solved. The few examples of typical tradeoffs shown here, from the scale of the plot and the competition between associated species, to the village scale impact of crop residue allocation to mulching or livestock feeding, indicate that challenges are multi-dimensional. The filters through which farmers select suitable technologies, however, are more complex than their sheer technical performance and therefore sensitive to wider scale constraints. While engaging with local communities and other stakeholders through Learning Centres, we also aim at creating local awareness of such constraints to seek compromise solutions. Some of such solutions will require conducive policy environments, as seen in other parts of the world. Within this wider perspective, ABACO does not aim to be yet another project trying to promote CA in Africa, but a platform through which some of the positive aspects of CA innovations that may fit within smallholder systems can be put to work in its semi-arid regions.

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