Food Sec. (2013) 5:751–767
DOI 10.1007/s12571-013-0305-5

ORIGINAL PAPER

An integrated agro-ecosystem and livelihood systems approach for the poor and vulnerable in dry areas

Maarten van Ginkel · Jeff Sayer · Fergus Sinclair · Aden Aw-Hassan · Deborah Bossio · Peter Craufurd · Mohammed El Mourid · Nasri Haddad · David Hoisington · Nancy Johnson · Carlos León Velarde · Víctor Mares · Andrew Mude · Ali Nefzaoui · Andrew Noble · K. P. C. Rao · Rachid Serraj · Shirley Tarawali · Raymond Vodouhe · Rodomiro Ortiz

Received: 3 March 2013 / Accepted: 1 October 2013 / Published online: 8 November 2013

Abstract More than 400 million people in the developing world depend on dryland agriculture for their livelihoods. Dryland agriculture involves a complex combination of productive components: staple crops, vegetables, livestock, trees and fish interacting principally with rangeland, cultivated areas and watercourses. Managing risk and enhancing productivity through diversification and sustainable intensification is critical to securing and improving rural livelihoods. The main biophysical constraints are natural resource limitations and degradation, particularly water scarcity and encroaching desertification. Social and economic limitations, such as poor access to markets and inputs, weak governance and lack of information about alternative production technologies also limit the options available to farmers. Past efforts to address these constraints by focusing on individual components have either not been successful or are now facing a declining rate of

M. van Ginkel (✉) · A. Aw-Hassan
International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo-Damascus Highway, Tel Hadya, Aleppo, Syrian Arab Republic
e-mail: m.vanginkel@cgiar.org

J. Sayer
Center for Tropical Environmental and Sustainability Science, School of Environmental and Earth Sciences, James Cook University, Cairns 4870, Queensland, Australia

F. Sinclair
World Agroforestry Centre, United Nations Avenue, Gigiri, P.O. Box 30677, Nairobi 00100, Kenya

F. Sinclair
Bangor University, Wales, UK

D. Bossio
Centro Internacional de Agricultura Tropical, P.O. Box 823, Nairobi, Kenya

P. Craufurd · D. Hoisington
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, 502324 Andhra Pradesh, India

M. El Mourid · A. Nefzaoui
ICARDA, No. 1 Rue des Oliviers, El Menzeh V, 2037, B.P. 435, El Menzah 1, 1004 Tunis, Tunisia

N. Haddad
ICARDA, P.O. Box 950764, Amman 11195, Jordan

N. Johnson · A. Mude · S. Tarawali
International Livestock Research Institute, P.O. Box 30709, Nairobi 00100, Kenya

C. L. Velarde · V. Mares
Centro Internacional de la Papa, Av. La Molina 1895, La Molina, Lima, Peru

A. Noble
International Water Management Institute, P.O. Box 2075, Colombo, Sri Lanka

K. P. C. Rao
ICRISAT, PO Box: 39063, Nairobi, Kenya

R. Serraj
Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy

R. Vodouhe
Bioversity International, c/o IITA/Benin Research Station, 08 B.P. 0932, Cotonou, Benin

R. Ortiz
Swedish University of Agricultural Sciences, Box 101, SE-230 53 Alnarp, Sweden

impact, indicating the need for new integrated approaches to research for development of dryland systems. This article outlines the characteristics of such an approach, integrating agro-ecosystem and livelihoods approaches and presents a range of empirical examples of its application in dryland contexts. The authors draw attention to new insights about the design of research required to accelerate impact by integrating across disciplines and scales.

Keywords Dryland agriculture · Managing risk · Building resilience · Sustainable intensification

Introduction

In the face of complexity, many research efforts address a component of the problem rather than attempting to deal with all of its dimensions. Interventions based on such sectoral work tend to rely on narrow perspectives, unrealistic extrapolations, untested assumptions and misapplied narratives, and have often failed to provide lasting benefits to rural households (Lopez-Ridaura et al. 2007; Giller et al. 2006; Pretty et al. 2006; Twomlow et al. 2008). Much agricultural research, in particular, has tended to focus on addressing specific production constraints, without taking into account the constellation of social, economic and institutional factors that influence adoption (Kiptot et al. 2007).

Research on underlying causes of unsustainable land management in drylands has included: broad diagnostic assessments (Binswanger et al. 1989); studies of property rights and collective action in both sedentary and pastoral systems (Agrawal 2001; Place and Hazell 1993); encroachment by external interests (Lane 1998); population pressure and poverty (Grepperud 1996; Pender et al. 2001; Templeton and Scherr 1999; Tiffen et al. 1994); drought as a driver and trigger of desertification (Dregne 2000); access to markets and infrastructure (Binswanger and McIntire 1987; Pender et al. 2006); economic returns to conservation practices (Cramb et al. 2000; Gautam and Anderson 1999; Shiferaw and Holden 1998, 2001); extension approaches (Cramb et al. 2000; Clay et al. 1998); factor market imperfections (Holden et al. 1998, 2001; Krishna 2002; Pender and Kerr 1998); social capital (Antle et al. 2006); and irreversibility thresholds (Bauer and Stringer 2008). Despite the excellence of much of this research, its disciplinary focus has often resulted in promotion of interventions that have not been widely adopted (Sietz et al. 2011).

This paper argues that an integrated approach to improving livelihoods and the agro-ecosystems upon which they depend can overcome many of these shortcomings and deliver interventions that are widely appropriate, applicable and adoptable across the world's drylands. The innovations in approach proposed here, are to combine vertical and horizontal integration and to acknowledge and address fine scale variation in the contextual factors that govern adoption of interventions. In the present context vertical integration implies a nested scale approach (field, farm, landscape and region), where large scaling domains are identified across which contextual variation in drivers of adoption are understood, mapped and addressed by facilitating local adaptation. Horizontal integration relates to working across disciplines and sectors (agriculture, forestry, markets, environment, water and energy). The enabling policy and institutional requirements for innovation are addressed across scales. The authors present a framework for this integrated approach, and then demonstrate its utility through four case studies where the approach has been applied. From this, they draw lessons for practitioners of research for development, particularly those working in the drylands.

Drylands: context

According to the UN, (http://www.un.org/en/events/desertification_decade/whynow.shtml-accessed 18 August 2013), globally drylands occupy some 6.09 billion ha (60.9 million square km), with a population of 2.1 billion people, nearly half of which are the poorest and most vulnerable and marginalized in the world.

The agro-ecosystems in dry areas comprise a diverse and complex mix of pastoral, agropastoral, rainfed and irrigated farming practices. Farmers and pastoralists employ a diverse mix of food, fodder and fibre crops, vegetables, rangeland and pasture species, fruit and fuelwood trees, medicinal plants, livestock and fish to meet their food and livelihoods needs. Pastoralists and farmers have developed these practices over centuries, adapting them to the limited resources and variable climate that characterize dry areas. Agricultural production systems in the drylands face not only persistent water scarcity and frequent drought, but also high climatic variability, land degradation, desertification and widespread poverty. These constraints are expected to intensify as a result of climate change.

The dry areas are home to several important centres of origin and diversity of crops, vegetables, livestock, trees and fish, and most traditional farming systems maintain agrobiodiversity in the form of crop landraces, local animal breeds, pastoral flora and other native and wild species. These genetic resources can provide breeders with the traits needed to adapt plants and animals to heterogeneous and changing environments (Fowler and Hodgkin 2004), and are an important buffer against the effects of climate change and desertification (Maestre et al. 2012). However, land degradation and pressure on natural habitats threaten biodiversity in dry areas and farmer behaviour, if not directed otherwise, will generally result in decline in species diversity to meet immediate production objectives (Harvey et al. 2011).

Drylands are also generally economically and politically marginalized because they are perceived to have low production potential and are generally sparsely populated. Investment strategies tend to favour high potential or densely populated areas, although there is evidence that returns to investment in infrastructure can be high in less-favoured areas (Fan and Hazell 2001; Pender and Hazel 2000). Many smallholders in dry areas have poor access to markets for their products and to inputs such as improved seed, fertilizer and information about production technologies. There are often gender differences in access to inputs, rural services, information and technology that disadvantage women (World Bank et al. 2009). Investments in human capital (education, ability to access market information, health etc.) have been shown to enhance the uptake of new information and technology, while investment in social capital (networking, reciprocity, collective action and institutions) enhances their spread (Bandiera and Rasul 2006; Coppock et al. 2011; Lapar and Ehui 2004). Greater market access and institutional arrangements that confer ability to take collective action can improve management of environmental risk.

Many dryland systems could produce more food sustainably, in spite of the constraints indicated above. The agricultural productivity of drylands in much of sub-Saharan Africa, South Asia, West Asia, North Africa and Central Asia is far below potential, and relatively quick wins appear feasible (Burney et al. 2011; Cooper et al. 2009; Garrity et al. 2011; Quiroz et al. 2003; Wani et al. 2009). With appropriate incentives, the provision of other ecosystem services from drylands could also be enhanced, and rewards for environmental services are beginning to be used to promote biodiversity and wildlife conservation, and provision of watershed services. Sequestration of carbon in soils may be an important co-benefit of preserving rangelands (Sommer and de Pauw 2010).

Dryland systems are heterogeneous, which means the development challenges and trajectories to address these vary at fine scale. We view the spectrum of development challenges facing livelihood systems as a gradient (Fig. 1). At one end are livelihoods systems with a low asset base, where the key challenge is to mitigate vulnerability or risk and increase resilience. At the other end are livelihoods systems with an asset base sufficient to take advantage of opportunities for intensifying production in response to market opportunities. The challenges for these intensifiable livelihood systems relate to environmental sustainability, equity and economic growth as well as agricultural productivity. Food security, poverty reduction and natural resource management are important everywhere along the spectrum. They may be addressed in different sequences depending not only on the starting point but also on the surrounding institutional, political and environmental circumstances.

Numerous interventions are available, or are being developed, that can be leveraged and combined. But these alone

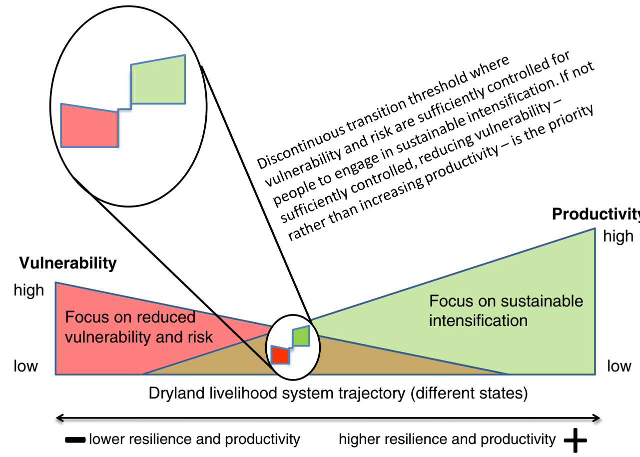

Fig. 1 Focus: reduced vulnerability and risk, or sustainable intensification

will be unlikely to achieve significant impacts on poverty, food security and the environment at scale. Integration and capacity strengthening mechanisms are also needed for local successes to be scaled up and out. These need to be targeted to regional and local stakeholders, including socially disadvantaged groups, as well as those who influence policy, delivery of technologies, access to markets, equity and economic balances. This underscores the importance of a horizontally and vertically integrated approach, which we propose as a new core value for research on dryland agriculture.

Integrated systems approaches

The multifaceted constraints facing dryland agricultural systems call for broad-based, integrated approaches addressing the full range of socioeconomic and biophysical constraints that farmers and pastoralists in drylands typically face.

This requires innovative approaches that bring together all participants in the impact pathway, from primary producers to policy-makers, to develop technologies, resource management strategies and institutional arrangements that: reduce demand for water per unit crop area and livestock unit; improve water capture and storage; increase productivity per unit of water and land at farm and landscape scales; enhance the capacity of communities and the most marginalized actors within them; and strengthen institutional arrangements to build resilience of livelihoods and increase system productivity through diversification and sustainable intensification.

Such approaches aim to identify, quantify and address the driving forces and interactions that shape and constrain farming systems and the management of natural resources (Lockeretz and Boehncke 2000; Roetter et al. 2000). By doing so, they help to identify researchable issues and generate testable research hypotheses, and to ensure that the groundwork is done to put in place all the necessary institutions and delivery mechanisms to support the scaling up and out of successful innovations. This includes addressing the policy environment in which the systems operate. Many policy-related constraints, such as poor infrastructure (roads) limiting access to markets, state control of input and output markets, distorted prices, poor delivery of services, lack of legal frameworks for producer associations and inadequate finance, can directly affect resource poor farmers' ability to benefit from opportunities created by systems research. Similarly, fiscal and monetary policies at the macroeconomic level may have negative impacts on the agricultural sector. Therefore, interactions and dialogue with policy-makers is a critical component of the integrated research approach proposed.

Reynolds et al. (2007) reviewed lessons learned about the functioning of dryland agro-ecosystems and the livelihood systems of those people whose living depends on them, and proposed a synthetic framework to identify and address the constraints facing these regions and the people living there. Their "Dryland Development Paradigm" (DDP) focuses on a concise set of systems-oriented principles to help identify and synthesize priority issues to be addressed by research, management and policy communities.

The DDP identifies five core principles:

1. Human–environmental (H–E) systems are coupled, dynamic and co-adapting. Thus, research, development and policy efforts must address both biophysical and socio-economic aspects of the dryland system simultaneously if they are to make a lasting and positive impact.
2. A limited suite of "slow" variables (e.g. soil fertility) are critical determinants of H-E system dynamics. "Fast" variables (e.g. rainfall, pest or disease outbreaks, crop yield) are poor indicators of fundamental changes such as land degradation or the need for intervention.
3. Thresholds in key slow variables define different states of H–E systems. Crossing a threshold in one domain (e.g. ecological, social or economic) or scale (household, village, region) may trigger shifts in other domains or at other scales.
4. H–E systems are hierarchical, nested and networked across multiple scales. Research and intervention must be targeted to the appropriate scale and recognize linkages and relationships within the system if they are to be effective.
5. The maintenance of a body of up-to-date environmental knowledge, combining both local and science-based knowledge, is key to functional co-adaptation of H–E systems.

The traditional, linear research-for-development impact pathway includes four steps: research activity, outputs, outcomes and impact. In contrast, following the proposed integrated agro-ecosystem and livelihood systems approach, embeds research within the context of development practice and engages with farming communities and a range of development partners in a medium- to long-term co-learning framework (Coe et al. 2013). This involves working with rural people to establish what impacts are needed, then defines what outcomes will deliver these impacts, then identifies what outputs (if adopted) will produce the desired outcomes, and finally determines what research will lead to these outputs, thus following the impact pathway backwards. A portfolio of potential technical and policy interventions can be drawn upon and their deployment sequenced in ways that fit local conditions. Information on technology performance, user perspectives and livelihood issues feeds back into research. This results in an iterative research and development cycle, with continuous improvement in options available to farmers and more refined understanding of how they need to be customized to suit local, fine scale variation in context. Such an impact pathway is demand-driven, focused and results-oriented. With each iteration, options become better targeted to users' needs, leading to greater impacts on poverty reduction, food security and the environment. The end result of this iterative approach is appropriate, effective, demand-driven and results-oriented research 'in' rather than, 'for' development. Monitoring, evaluation and learning are integral to the process.

The following four case studies illustrate the application of this integrated agro-ecosystem and livelihood systems approach in areas with critical levels of rural poverty, land degradation, high climatic risk and food insecurity in Africa, Latin America and South Asia. They were selected on the basis of the outputs, outcomes and impacts they produced, which are attributable to the systems approach used.

Case studies

Improving crop–livestock production systems in low-rainfall areas of the Mashreq and Maghreb

Crop–livestock systems in the Mashreq and Maghreb are characterized by severe shortages of livestock feed, low crop productivity, low rainfall, soil erosion and declining soil fertility. Small ruminants (sheep and goats) provide much of the income that farmers and nomadic or semi-nomadic herders obtain (Alary et al. 2007). Growing demand for animal products has encouraged increases in flock size and numbers, especially at the drier end of the arable farming spectrum, where native pasture lands provide free grazing (Aw-Hassan et al. 2010). These pastures once met much of the feed needs of the flocks but today demand exceeds supply, not only because there are more livestock, but also because productivity has declined as a result of overgrazing, ploughing of rangeland, fuelwood harvesting and soil erosion.

Until recently, uptake of improved crop–livestock production options has been slow, and this has been attributed to the lack of an enabling policy and institutional environment (Ehui et al. 2003). Land tenure policies (both formal and traditional), poor access to credit, policies antagonistic to mechanization and lack of veterinary services have constrained adoption of intensification options. This context highlighted the need for a program that integrated research on policy and institutional alternatives with that on technologies and management practices.

The ICARDA-led collaborative project in the Mashreq/Maghreb region adopted a community-based integrated systems approach, involving natural, biological and social sciences to identify and address the constraints facing dryland production systems in the region. A participatory community-based methodology (a combination of Rapid Rural Appraisal and Participatory Rural Appraisal), developed through consultation with all stakeholders, consisted of characterization of the community; diagnosis; planning and programming; institutional set-up; implementation; and, monitoring and evaluation (Fig. 2). The project involved broad-based multidisciplinary teams and engaged with stakeholders along the entire impact pathway, including national-level policy-makers, local officials and the grassroots community. This ensured a holistic approach to constraint analysis and identification of possible interventions and their interactions, across individual, household and national policy levels. The core of the methodology was effective communication, with all stakeholders negotiating the community development plan on an equal basis, thereby integrating both local and introduced knowledge.

Major constraints that were identified, included shortages of livestock feed at crucial times of the year, which were both caused by, and contributed to, declining soil fertility and land degradation. Interventions were developed to increase feed and forage production by enhancing on-farm feed production and crop management, and identifying complementary feed sources.

Grazing dual-purpose barley and vetch provided additional feed and growing these crops in rotation improved soil fertility and the sustainability of the production system. Barley yields were increased by applying fertilizer (e.g. 92 kg P_2O_5 ha^{-1} increased grain yield by >20 %) while reducing the seeding rate to 100 kg ha^{-1} reduced costs by about US$ 33 ha^{-1} without reducing yield. Feed blocks made from agro-industrial by-products provided an alternative source of feed, as did saltbush (*Atriplex* spp.) and spineless cactus (*Opuntia* spp.) alley-cropped between plots of barley. The latter also reduced erosion and run-off, increased soil moisture retention, and reduced purchase of feed concentrates by up to 72 %. Subsidies enhanced technology uptake in Tunisia (Shideed et al. 2007): farmers who received a subsidy to invest in *Opuntia* alley farming achieved an internal rate of return (IRR) of 53 %, compared with 17 % for farmers without the subsidy. In Morocco, estimated IRR was 29 % with a time horizon of 2015, assuming constant adoption at the 2005 rate.

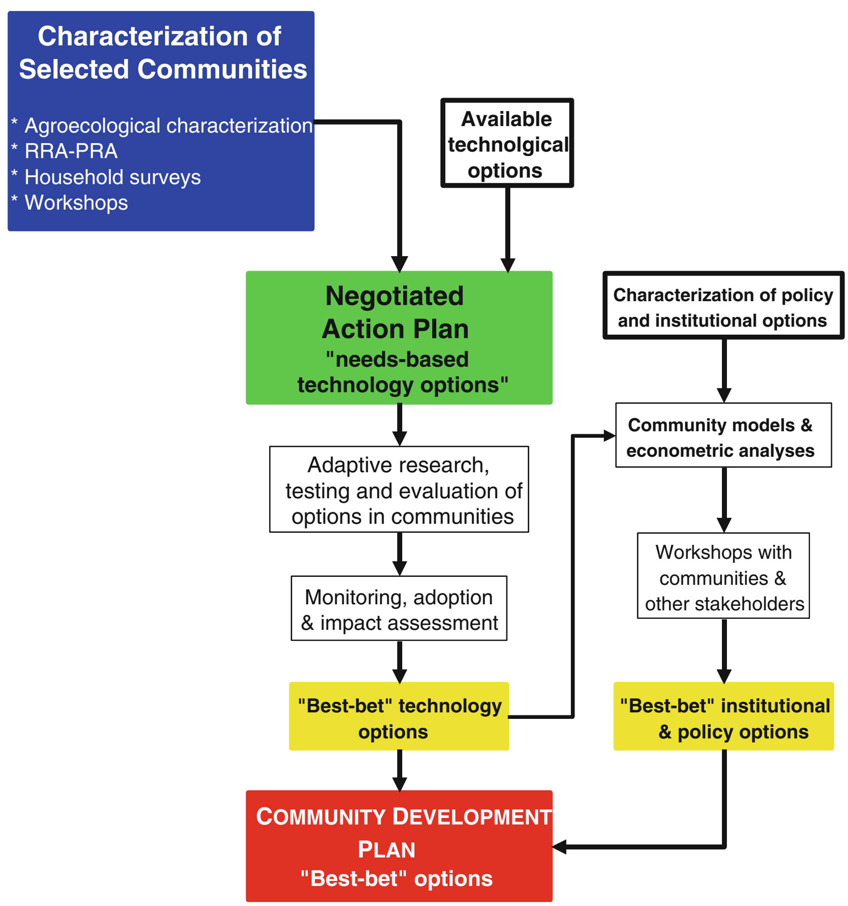

Fig. 2 A schematic of the main steps in a participatory community approach for improving crop–livestock production systems in low-rainfall areas of the Mashreq and Maghreb

The environmental benefits of *Atriplex* alley cropping were estimated at US$ 425 ha^{-1}, well above the subsidy given to farmers (US$ 250–300 ha^{-1}). This form of alley cropping has been out-scaled by the International Fund for Agricultural Development (IFAD).

Key lessons from this work include the following: participatory characterization of communities builds cooperation and trust among stakeholders; recognition of local know-how is important for successful diagnosis; development plans approved and tested by communities help mobilize resources and ease project implementation; the ability of communities to identify appropriate technical solutions or solve internal conflicts – particularly relating to property rights and land use – and the importance of income-generating activities should not be underestimated; and the success and sustainability of the process depend on promotion of elected community-based organizations that provide a link between communities and other actors, e.g. government and non-governmental agencies and donors.

Reducing risk and vulnerability in pastoral dryland systems in Africa

Pastoralists in the arid and semi-arid lands of Kenya have been badly hit by droughts in recent years, resulting in massive losses of the livestock on which their livelihoods depend. These communities have become increasingly dependent on food aid and other short-term emergency relief efforts.

A research project in the Kenyan rangelands led by the International Livestock Research Institute (ILRI) employed an integrated agro-ecosystems and livelihoods approach to study local pastoral production systems. This identified a possible role for index-based livestock insurance (IBLI) to protect and stabilize the livelihoods of pastoralists in the region (http://www.ilri.org/indexbasedlivestockinsurance). The project conducted extensive survey work and worked with the target community in a participatory process to identify constraints and possible entry points. Once IBLI was identified as a candidate intervention, the project worked to: identify institutional innovations needed to support this new concept in insurance provision and financial service delivery; established partnerships with commercial entities, regulatory bodies and other agencies; established novel public–private agreements for market-mediated provision of the product; and, initiated extension and marketing efforts to educate the target clientele on a previously alien concept and new product (Lybbert et al. 2010; Matsaert et al. 2011; McPeak et al. 2010; Notenbaert et al. 2009; Ouma et al. 2011).

IBLI-type products represent a promising and exciting innovation for managing risks of climate extremes that vulnerable pastoralists face (Chantarat et al. 2007, 2008; Mude et al. 2009). The IBLI contract is based on a unique innovation in insurance design that makes the risk-management benefits of formal insurance accessible to smallholder farmers and pastoralists in remote locations. The general idea is that policyholders are compensated based on a clear, measurable outcome that neither insurer nor policyholder can influence but is highly correlated with the targeted risk. In the case of IBLI, the underlying risk of drought-related livestock mortality is insured based on a remotely sensed normalized differentiated vegetation index (NDVI). This predicts area-average livestock mortality though an empirically derived response function that relates forage availability (with NDVI as a proxy) to livestock losses (Chantarat et al. 2007, 2012).

In January 2010, after a 2-year research and design period, a pilot IBLI product was launched for individual pastoralists in the arid and semi-arid Marsabit District of northern Kenya. Policies were sold on a commercial basis with Equity Bank, Kenya's fastest growing commercial bank, providing agency services for a local underwriter, UAP Insurance Co. UAP then ceded a portion of the risk to the international reinsurer, SwissRe.

While an important objective of the programme was to test IBLI's commercial viability, an equally important objective was to understand and quantify the welfare impacts that IBLI has among communities that have traditionally been the main recipients of food aid, cash aid and other publically funded responses to severe droughts (McPeak et al. 2012). To this end, a research agenda was designed around impact assessments using a set of 925 households visited annually since before the launch of the programme in 2009. This investigated the potential economic and social returns to IBLI provision in systems where livestock represents the key productive asset and the dominant source of income and where drought-related losses represent more than 75 % of livestock mortality. Hypotheses tested included the following: (a) IBLI can stabilize asset accumulation and enhance economic growth by improving incentives for households to build their asset base; (b) by providing indemnity payments after an asset shock, IBLI can stem the downward spiral of vulnerable households into poverty; and (c) IBLI can stimulate the provision of credit for ancillary investment by collateralizing a previously risky asset.

Sustained adoption is the ultimate proof of concept and, while initial sales surpassed expectations, a subsequent slump in sales gives cause for concern. Frequent engagement with the clients and their representatives, efforts to monitor and evaluate progress and on-going analysis have offered insight into the key challenges that need resolving in order to build credibility, stimulate uptake and develop a cost-effective delivery infrastructure for sustainable market-mediated provision – whether publically supported or fully commercial. These emerging lessons have formed the core insights from the continuing pilot that have shaped the design of a second phase of selective expansion that commenced in July 2012.

Based on four interdependent pillars, the agenda builds upon the integrated multi-disciplinary and cross-stakeholder research and implementation platform that has characterized the IBLI programme. The first pillar seeks to deepen the understanding of IBLI impacts through continued rigorous assessments of the behavioural, welfare and environmental impacts of IBLI on the target population and to investigate how IBLI can complement other existing interventions in credit market deepening, supplemental feed provisioning and the like. The second pillar focuses on the development of institutions, policies and capacities (e.g. regulation, information dissemination, marketing or extension) necessary to increase the cost efficiency of provision and target incentives appropriately. The third pillar focuses exclusively on contract design and seeks to improve both the methods and the data used in a quest for more precise risk-coverage and to facilitate scale-out for the design of IBLI products covering all of northern Kenya and later the Greater Horn of Africa. Finally, the forth pillar zooms out to start investigating the potential of leveraging the index concept to design climate catastrophe insurance for meso- and macro-level clients, namely county and national governments, non-governmental organizations, donors and other entities responsible for responding to emergency situations.

Integrated watershed development in South Asia

The productivity and sustainability of a dryland agro-ecosystem depend on the quality and reliability of water resources. Effects of in situ practices (e.g. broad-beds and furrows, and contour bunds) and ex situ interventions (e.g. check dams, gully plugs and infiltration pits) on groundwater levels, runoff and soil loss in a micro-watershed of about 400 ha have been assessed at Kothapally (Andhra Pradesh, India) since 2000. Modelling, using the Soil and Water Assessment Tool (swatmodel.tamu.edu), showed that implementing the full suite of in situ and ex situ interventions reduced outflows from the watershed significantly in dry years, that occur about 30 to 40 % of the time (Garg et al. 2012). The analysis also suggests that in situ interventions are most appropriate for locations with a high probability of dry years, as there is little runoff to be captured by ex situ interventions. However, information on the downstream effects of watershed interventions on livelihoods and ecosystem services is lacking and research is urgently needed.

Research in watersheds has pioneered the use of stratified participatory soil sampling and mapping of soil nutrient status (Sahrawat et al. 2008). Soils in semi-arid environments in India are commonly deficient in sulfur (82 % of 28,270 fields sampled), boron (68 %) and zinc (62 %), phosphorus (46 %) and potassium (16 %) (Sahrawat et al. 2010). Applying these elements with nitrogen in a balanced fertilizer can increase maize grain and peanut pod yield by 40 % in farmers' fields, as noted in farmer-participatory on farm research trials conducted in Karnataka, India. The scale of operation was 10 small nucleus areas and 33 satellite watersheds during 2005–2006 to 2008–2009, rising to 0.21 million ha during 2009–2010 and 1.54 million ha during 2010–2011. The treatments under study were farmer's practice (FP) of application of N, P and K only, or balanced nutrition (BN) comprising FP inputs plus S + B + Zn. State level nutrient recommendations were modified based on soil testing, where a full dose of a nutrient was given when more than 50 % of farms were deficient and a half dose where fewer than 50 % of farms were deficient. Similarly, for the diagnosed deficiencies of S, B and Zn, a general recommendation (practiced in alternate years) of 30 kg S (through gypsum), 10 kg Zn and 0.5 kg B per hectare were applied. Soil testing and recommendations were at 'block' level (comprising a cluster of villages).

Watershed research by many organizations has evolved over the last 40 years from a technology supply push (TSP) approach to a livelihood-driven and natural resource systems-based approach (Shambu Prasad et al. 2005; Wani et al. 2009, 2011). It was realized that farmers were not adopting technology packages promoted using TSP and that a different, more holistic approach was required. Crucially, introduction of new technologies must be based on incentives. In India, for example, higher groundwater levels achieved through technology interventions such as check dams lead to observably higher water levels in open wells (Garg and Wani 2012). The increase in water availability for irrigation and crop diversification has proved to be sufficient incentive for small-scale farmers to adopt improved watershed technologies. Lessons have also been learned about how to enable target groups to diversify production and seek new markets, and the use of community-based mechanisms to improve resource allocation at various scales, from farm to landscape. The Government of India has now implemented policies to support integrated watershed management (GOI 2008).

Such integrated systems approaches are, of course, dynamic and involve trade-offs that need to be understood. For example, changing from keeping cattle to keeping buffaloes increases demand for fodder, could reduce the availability of manure as livestock numbers decline, and may increase work for women. These trade-offs will have to be assessed and investments made in the social, institutional, and governance components if these approaches are to continue to be successful.

Achieving sustainable rural development in the Peru–Bolivia Altiplano through improvement of Andean agriculture

The Altiplano of Peru and Bolivia is one of the world's poorest areas (Quiroz et al. 2003). High climatic variability, high altitude, land fragmentation and limited access to markets and financial resources drive highly diverse and complex farming and livelihoods systems in which the main goal is the minimization of production risk. Potato provides food security; livestock are important for income and asset building. These systems also maintain native potato germplasm. Farming is carried out on family smallholdings and communal land. Secondary activities include trade and temporary migration for non-agricultural work.

An integrated systems approach was used to enhance agricultural productivity, family income and the resilience of these farming systems (Li Pun et al. 2006). The objectives were: to improve access to markets; to strengthen women's participation in household decision-making and control of family income; and to improve child nutrition. The sequence of actions included: selection of communities; establishment of a baseline; participatory selection of specific interventions; participatory work in the testing, validation and implementation of activities; and monitoring and evaluation (León-Velarde et al. 2008). Interventions were selected based on: the climate and the human and natural resources of the region; and the competitive advantage of production options (markets, potential productivity, potential contribution to income, potential contribution to food security and nutrition, potential for the involvement of family members, potential for women's empowerment and their participation in decision making, income generation and income disposal).

The work was conducted with 8,399 beneficiaries in 129 rural communities. Biological and socioeconomic baselines were established through a systematic survey in 2006. The sustainability of farming in an adverse and changing climate was analysed. To enhance the systems, other crops, livestock value-added activities and alternative sources of income, such as trout farming and handicrafts, were identified and integrated into the farming and livelihood systems through a participatory process.

The project promoted organic quinoa production, an activity with a high-income generation potential. A total of 1,175 families participated. Annual net family income generated by quinoa increased from US$ 72 in 2006 to US$ 700 in 2010–2011 as a result of an increase in the area planted to organic quinoa, higher yields and exports. However, local per capita consumption of quinoa decreased because more of the crop was exported.

Milk production was initially found to be limited by feed shortages during the dry season, lack of traditional dairy products and weak markets. To address these constraints, the programme introduced alfalfa and forage oats to provide additional feed, and established producer groups and production hubs linked to small cheese factories run by the producers themselves. Cheese and other dairy products such as yogurt were marketed locally.

A total of 129 ha of alfalfa and 290 ha of oats were established on the farms of the producer groups. Small silos were used to store feed for the dry season. On average, 612 t of silage was produced each year, enough to supplement 1,334 producing cows for 153 days (3 kg cow^{-1} d^{-1}). Producer groups sold milk daily to 14 cheese factories. Increased production and sales raised annual dairy income per family from a baseline of US$ 29 to US$ 767 by 2011. The cheese factories generated an average yearly income of US$ 3,328 per participant family, showing the importance of value-added produce. Two of the 14 cheese factories promoted by the project through a credit programme are building new plants with a better technical design. The availability of dairy by-products prompted women to fatten and sell pigs. By the end of the project, 30 % of suppliers of milk to the cheese factories had adopted this practice.

Before the programme started, few farmers raised trout. The project organized 84 families in seven groups, and provided training and credit to start trout farms. The groups planned and managed the production process, built the basic infrastructure, standardized the product, managed production costs, and marketed their produce. Over five years, the farms produced a total of 4421 t of trout with a gross value exceeding US$ 11 million. Annual income per participating family ranged from US$ 784 to US$ 7788. The activity created 5 to 16 permanent jobs per year per producer, plus 10 temporary jobs per month per producer. Women's participation was close to 48 %.

Production of vegetables in both family and school greenhouses contributed not only to family income but also improved nutrition. Greenhouses were constructed with the active participation of mothers and schoolchildren. By 2011, 185 greenhouses with a total roofed area of 14,676 m^2 were in operation with the direct participation of 175 families. A sample of 29 % of the greenhouses showed a production of 13,250 kg of 29 different species. Of this, 80 % was for home consumption, collectively saving families US$ 10, 159 by no longer having to buy vegetables from the market.

The availability of credit was crucial to adoption of the interventions. The project provided credit through supervised revolving funds and technical assistance. A total of US$ 172,226 was mobilized in 4.6 cycles of operation, with a repayment rate higher than 90 %. In Puno, the average credit was US$ 790 with average monthly interest rates of 2 %. Over the life of the project, participants' livelihood capital increased from 0.27 to 0.43.

Discussion

The case studies presented here show how an integrated approach, applied along entire impact pathways, can sustain and build on past gains. The concept of integration here is broader than previously conceived in farming systems research (Collinson 2000), incorporating both a participatory approach (Chambers et al. 1989) and nested scale agro-ecosystem (Jackson et al. 2013) and institutional aspects (Clark et al. 2011). There has been a recent resurgence of interest in systems research in agricultural development (Keating et al. 2010), echoing the application of general system theory in agriculture, pioneered several decades ago (Spedding 1979; Conway 1987). Critically, from a dryland perspective, this resurgence puts new emphasis on managing risk and on making efficient use of land and water resources, referred to as 'eco-efficiency'. Consideration of risk places a premium on smallholder innovations that can increase productivity without concomitant increase in variability of outcomes, as the IBLI case study illustrates. Eco-efficiency focuses on maintaining natural capital, making use of renewable sources of inputs where possible and efficient use of those derived from fossil fuels, as the Mashreq and Maghreb case study illustrates. All four case studies embrace a view of livelihoods that transcends a narrow focus on farming to consider how agriculture is embedded within a broader livelihood context (Carney 2002). The combination of explicit systems analysis and participatory approaches, evident in all four case studies, marks a turning point. Since the 1980s, the predominant trend has been for participatory approaches to replace more formal farming systems research, with the systems understanding and local knowledge becoming increasingly implicit, through the involvement of farmers in the research process (Farrington 1988; Pretty 1995). In contrast, research on broader aspects of natural resource management has embraced a systems approach (Sayer and Campbell 2004) and explicit treatment of local knowledge (Sinclair and Walker 1998; Joshi et al. 2004) but tended to increasingly focus at landscape scales consistent with consideration of a range of ecosystem services manifest at these scales (Pagella and Sinclair 2013; Cerdan et al. 2012). At the same time, the focus of farmer participatory research has broadened to encompass a wider concept of innovation systems that includes markets and the institutional context within which innovation occurs (Scoones and Thompson 2009; Kilelu et al. 2013). This converges with the emphasis on social-ecological connections now dominant in resilience science (Walker et al. 2006). The key novelty of the integrated agro-ecosystem and livelihood approach, illustrated through the present case studies, is in combining all these different strands: systems analysis; participatory approaches; combined social, economic and ecological perspectives; multiple knowledge systems; the market, institutional and policy context; and, a nested scale agro-ecosystem approach that embraces risk and eco-efficiency.

The integrated agro-ecosystem approach, when aiming to mitigate vulnerability, reduce risk or increase resilience, acknowledges that farmers and (agro-)pastoralists in marginal dryland environments are in reality dealing with multiple inputs and outputs, opportunities and constraints. This complexity can no longer be approached in a purely reductionist way, but should involve the application of approaches for understanding dynamic, evolving, complex systems, including the trade-offs in various ecosystem services (Jackson et al. 2013). For example, the CGIAR System-wide Livestock Program (www.vlsp.org) adopted an integrated approach that analysed the trade-offs in mixed crop-livestock systems, to build synergies among the various research-for-development interventions (Wright et al. 2012). When adopting an integrated agro-ecosystem approach to take advantage of opportunities for intensifying production in response to markets, entry points are identified for a range of activities related to products, natural resources and markets. Interdisciplinary teams research the complex interactions between productivity and sustainability of smallholder farming systems. This research needs to include the study of critical gaps in food–feed and related natural resources research, as well as the policy environment suitable for system innovation.

The rangelands project in Kenya illustrates the way in which key interventions, which act as leverage points, can lead to profound system improvement through interactive effects within the system and spread successful innovations amongst households. The IBLI impact pathway involved a range of partners from the public and private sectors working on research, development and commercial applications of the products, in an iterative process with numerous feedbacks (Fig. 3). The long-term relationship between researchers and farmers allowed farmers and researchers together to determine how best to sequence interventions. Research (column 1) on IBLI began with the identification of drought-related livestock loss as a major cause of poverty among livestock-keeping households in target areas. Based on this evidence, research was undertaken on whether an index could be identified that correlates strongly with livestock mortality and was appropriate for use in an insurance product. Researchers also needed to understand current coping strategies and risk management options in potential target populations, and identify the organizations (public, private, non-governmental and civil society) involved in drought management, risk management, social protection or livestock production and marketing in the target areas.

Outcomes shown in Fig. 3 are divided into research outcomes and development outcomes (columns 2 and 3), depending on the researchers' level of direct involvement in and accountability for delivering them. Several outcomes appear as both. First let us consider the research outcomes (column 2). In the pilot or proof of concept phase, researchers were actively involved in the development of the insurance product and in securing regulatory approval. Once the product went to scale, researcher involvement declined, although a reduced

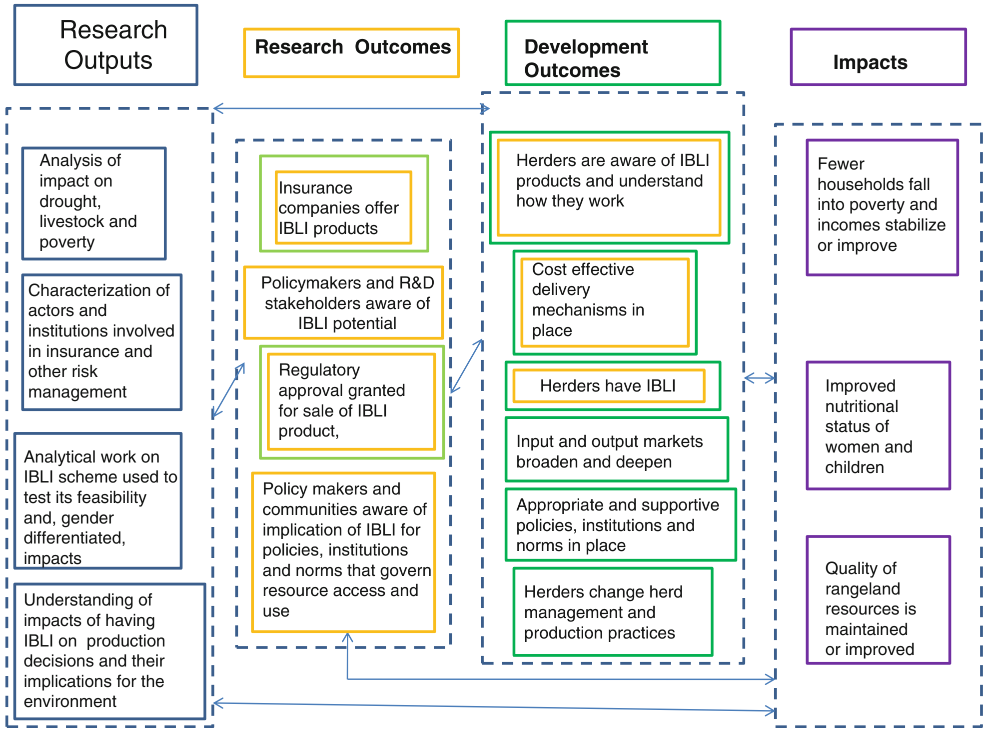

Fig. 3 Impact pathway for index-based livestock insurance

level of on-going engagement was retained to provide technical expertise. Similarly, in the development outcomes (column 3), researchers may be actively involved in designing and implementing awareness-raising approaches, delivery mechanisms and even providing herders with insurance (e.g. in the context of a randomized, controlled trial to assess impact) in a proof-of-concept phase, but this will not continue during scaling up. Other actors from the private, non-governmental or public sectors, or livestock keepers themselves, will need to deliver these outcomes if widespread impact is to be achieved. This highlights the importance identifying and describing the entire impact pathway and all the stakeholders involved, and engaging them in the research process from the beginning. The outcome related to markets reflects the fact that availability of insurance could provide livestock keepers with an incentive to invest in their herds (quantity or quality, as mentioned above) and thereby increase production. Insurance could also provide the means for doing so, since insured animals can be used as collateral. For this to happen, markets for financial services, agricultural and veterinary inputs and for livestock products need to be functional and responsive.

Integrated system research: a new challenge for international agriculture undertakings and partnerships

Integrated agro-ecosystems research can be understood differently among those from various disciplinary or professional backgrounds, and even among those sharing similar backgrounds. Setting or defining a common and transparent frame of reference is necessary to facilitate progress in implementing this approach, which is already generating innovations for dryland systems. These include, for example, micro-dosing of fertilizers, micro-dams in-field water harvesting, payments for environmental services, community institutions, community-based natural resource management, community-based livestock breeding, village-based seed and seedling enterprises, participatory market development, participatory research, micro-finance, production insurance, financial and social safety nets, alternative energy sources, mobile connectivity and the increasing recognition of empowering local communities by national governments.

Many CGIAR Consortium Centres (cgiar.org) have been participating as ‘knowledge’ partners in large-scale integrated agricultural research-for-development projects, providing technological backstopping and support for monitoring and evaluation, and learning, as illustrated by the case study on improving crop–livestock production systems in low-rainfall areas of the Mashreq and Maghreb. Though the lessons have yet to be systematized, these experiences have taught both research organizations and development partners a great deal about the challenges and benefits of working together, focused not just on agriculture but embracing a broader livelihood perspective. These experiences provide a foundation on which to build — some of the sites and partners may well be the same — as well as lessons about what works, what does not, and how things can be done better. This article takes stock of past experiences to draw lessons for an integrated agro-ecosystems and livelihood systems approach to be pursued.

The CGIAR Consortium has considerable experience with institutional innovations involving multiple stakeholders. Farmer participatory research has highlighted the value of involving end-users in the research process and provided models for engaging partners effectively. For example, work by the CGIAR Consortium and partners on participatory watershed management helped to integrate agriculture and natural resource management at landscape scale, providing lessons for similar processes elsewhere. More recently, the Challenge Programs for sub-Saharan Africa (http://www.fara-africa.org/our-projects/ssa-cp/) and Water & Food (http://waterandfood.org/) have used innovation platforms, social experimentation, and network theory to foster innovation, deliver impact on the ground, and generate global and regional public goods.

Partnerships are paramount for research targeting and delivering large-scale impacts in integrated agro-ecosystems research. In this regard, communications among partners and stakeholders plays a key role when engaging in new modes of working together, particularly when involving farming communities (including both women and men), national research and extension systems, policy makers, international and regional organizations, advanced research institutes, civil society and non-governmental organizations, the private sector, and development agencies. Iterative and participatory design and implementation through innovation platforms will ensure that priorities match those of stakeholders and encourage buy-in and support by policy makers, which will lead to strong local and national support, sustainable activities and high impact on livelihoods and the environment.

Conclusion

There is strong precedent for implementing an integrated agro-ecosystem and livelihood approach to sustainable development of dryland systems, and the case studies presented here provide proof of concept that this can be effective. We will be able to confirm the value of the underpinning principles advocated here when the approach has been applied more widely across sizeable scaling domains.

Clearly, for this approach to succeed, we will need to break vertical "silos" amongst organizations and engage in horizontal coordination amongst stakeholders and disciplinary areas, when interacting with farmers and other stakeholders along the impact pathway, as was done in the reported case studies. Such horizontal coordination includes engagement with policy-makers at all levels to ensure that a supportive policy environment is in place to allow farmers, pastoralists and other producers to benefit from opportunities created by development of innovations.

The multiplicity of interactions in these complex, integrated programmes also calls for careful sequencing of actions to strengthen capacity appropriately and avoid overwhelming stakeholders when scaling up and out.

References

Agrawal, A. (2001). Common property institutions and sustainable governance of resources. *World Development, 29*, 1649–1672.

Alary, V., Nefzaoui, A., & Ben Jemaa, M. (2007). Promoting the adoption of natural resource management technology in arid and semi-arid areas: modelling the impact of spineless cactus in alley cropping in Central Tunisia. *Agricultural Systems, 94*, 573–585.

Antle, J. M., Stoorvogel, J. J., & Valdivia, R. O. (2006). Multiple equilibria, soil conservation investments, and the resilience of agricultural systems. *Environment and Development Economics, 11*, 477–492.

Aw-Hassan, A., Shomo, F., & Iniguez, L. (2010). Trends in small ruminant meat production consumption gaps in West Asia and North Africa: Implications for intra-regional trade. *Outlook on Agriculture, 39*, 41–47.

Bandiera, O., & Rasul, I. (2006). Social networks and technology adoption in northern Mozambique. *The Economic Journal, 116*, 869–902.

Bauer, S., & Stringer, L. C. (2008). *Science and policy in the global governance of desertification; an analysis of institutional interplay under the United Nations convention to combat desertification. global governance working paper 35*. Amsterdam: The Global Governance Project.

Binswanger, H. P., & McIntire, J. (1987). Behavioral and material determinants of production relations in land abundant tropical agriculture. *Economic Development and Culture Change, 35*, 73–99.

Binswanger, H. P., McIntire, J., & Udry, C. (1989). Production relations in semi-arid African agriculture. In P. Bardhan (Ed.), *The economic theory of agrarian institutions* (pp. 122–144). Oxford: Clarendon.

Burney, J., Woltering, L., Burke, M., Naylor, R., & Pasternak, D. (2011). Solar-powered drip irrigation enhances food security in the Sudano–Sahel. *Proceedings of National Academy of Sciences, USA, 107*, 1848–1853.

Carney, D. (2002). *Sustainable livelihoods approaches: Progress and possibilities for change*. London: DFID.

Cerdan, C. R., Rebolledo, M. C., Soto, G., Rapidel, B., & Sinclair, F. L. (2012). Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems. *Agricultural Systems, 110*, 119–130.

Chambers, R., Pacey, A., & Thrupp, L. A. (1989). *Farmer first; farmer innovation and agricultural research*. London: Intermediate Technology Publications.

Chantarat, S., Barrett, C., Mude, A., & Turvey, C. (2007). Using weather index insurance to improve drought response for famine prevention. *American Journal of Agricultural Economics, 89*, 1262–1268.

Chantarat, S., Turvey, G., Mude, A., & Barrett, C. (2008). Improving humanitarian response to slow-onset disasters using famine-indexed weather derivatives. *Agricultural Finance Review, 68*, 169–195.

Chantarat, S., Mude, A., Barrett, C., & Carter, M. (2012). Designing index-based livestock insurance for managing asset risk in Northern Kenya. *Journal of Risk and Insurance*. doi:10.1111/j.1539-6975.2012.01463.x.

Clark, W.C., Tomich, T.P., van Noordwijk, M., et al., (2011). Boundary work for sustainable development: natural resource management at the Consultative Group on International Agricultural Research

(CGIAR). Proceedings of the National Academy of Sciences, 10.1073/pnas.0900231108

Clay, D. C., Reardon, T., & Kangasniemi, J. (1998). Sustainable intensification in the highland tropics: Rwandan farmers' investments in land conservation and soil fertility. *Economics Development and Cultural Change, 46*, 351–378.

Coe, R., Sinclair, F.L. and Barrios, E. (2013). Scaling up agroforestry requires a research 'in' rather than 'for' development paradigm. Current Opinion in Environmental Sustainability (in press).

Collinson, M. (2000). *A history of farming systems research*. Wallingford, UK: FAO and CABI Publishing.

Conway, G. (1987). The properties of agro-ecosystems. *Agricultural Systems, 24*, 95–117.

Cooper, P., Rao, K. P. C., Singh, P., Dimes, J., Traore, P. S., Rao, A. V. R. K., Dixit, P. & Twomlow, S. J. (2009). Farming with current and future climate risk: Advancing a 'hypothesis of hope' for rainfed agriculture in the semi-arid tropics. *Journal of SAT Agricultural Research 7,* http://ejournal.icrisat.org/Volume7/Agroecosystems/AES701.pdf Accessed May 19, 2012.

Coppock, D. L., Desta, S., Tezera, S., & Gebru, G. (2011). Capacity building helps pastoral women transform impoverished communities in Ethiopia. *Science, 334*, 1394–1398.

Cramb, R. A., Garcia, J. N. M., Gerrits, R. V., & Saguiguit, G. C. (2000). Conservation farming projects in the Philippine uplands: rhetoric and reality. *World Development, 28*, 911–927.

Dregne, H. E. (2000). Drought and desertification: exploring the linkages. In D. A. Wilhite (Ed.), *Drought: A global assessment* (Vol. I, pp. 231–240). London: Routledge.

Ehui, S. K., Ahmed, M. M., Berhanu, G., Benin, S. E., Nin-Pratt, A., & Lapar, M. L. (2003). *10 years of livestock policy analysis*. Nairobi: International Livestock Research Institute.

Fan, S., & Hazell, P. (2001). Returns to public investments in the less-favored areas of India and China. *American Journal of Agricultural Economics, 83*, 1217–1222.

Farrington, J. (1988). Farmer participatory research. *Experimental Agriculture, 24*, 269–279.

Fowler, C., & Hodgkin, T. (2004). Plant genetic resources for food and agriculture: assessing global availability. *Annual Review of Environment and Resources, 29*, 143–179.

Garg, K. K., & Wani, S. P. 2012. Opportunities to Build Groundwater Resilience in the Semi-Arid Tropics. Ground Water 2012, National GroundWater Association. doi: 10.1111/j.1745-6584.2012.01007.x

Garg, K. K., Karlberg, L., Barron, J., Wani, S. P., & Rockstrom, J. (2012b). Assessing impacts of agricultural water interventions in the Kothapally watershed, Southern India. *Hydrological Processes, 26*, 387–404.

Garrity, D. P., Akinnifesi, F. K., Ajayi, O. C., Weldesemayat, S. G., Mowo, J. G., Kalinganire, A., et al. (2011). Evergreen agriculture: a robust approach to sustainable food security in Africa. *Food Security, 2*, 197–214.

Gautam, M., & Anderson, J. R. (1999). *Reconsidering the evidence on returns to T&V extension in Kenya. Policy research working paper 2098*. Washington, DC: The World Bank Operations Evaluation Department.

Giller, K. E., Rowe, E. C., de Ridder, N., & van Keulen, H. (2006). Resource use dynamics and interactions in the tropics: scaling up in space and time. *Agricultural Systems, 88*, 8–27.

GOI. (2008). *Common guidelines for watershed development projects*. New Delhi: Department of Land Resources, Ministry of Rural Development.

Grepperud, S. (1996). Population pressure and land degradation: the case of Ethiopia. *Journal of Environmental Economics and Management, 30*, 18–33.

Harvey, C. A., Villanueva, C., Esquivel, H., Gómez, R., Ibrahim, M., Lopez, M., et al. (2011). Conservation value of dispersed tree cover threatened by pasture management. *Forest Ecology and Management, 261*(10), 1664–1674.

Holden, S. T., Shiferaw, B., & Wik, M. (1998). Poverty, market imperfections, and time preferences: of relevance for environmental policy? *Environment and Development Economics, 3*, 105–130.

Holden, S. T., Shiferaw, B., & Pender, J. (2001). Market imperfections and profitability of land use in the Ethiopian highlands: a comparison of selection models with heteroskedasticity. *Journal of Agricultural Economics, 52*, 53–70.

Jackson, B., Pagella, T., Sinclair, F., Orellana, B., Henshaw, A., Reynolds, B., et al. (2013). Polyscape: a GIS mapping toolbox providing efficient and spatially explicit landscape-scale evaluation of multiple ecosystem services. *Landscape and Urban Planning, 112*, 74–88.

Joshi, L., Shrestha, P. K., Moss, C., & Sinclair, F. L. (2004). Locally derived knowledge of soil fertility and its emerging role in integrated natural resource management. In M. van Noordwijk, G. Cadisch, & C. Ong (Eds.), *Below-ground interactions in tropical agroecosystems: concepts and models with multiple plant components* (pp. 17–39). Wallingford: CAB International.

Keating, B. A., Carberry, P. S., Bindraban, P. S., Asseng, S., Meinke, H., & Dixon, J. (2010). Eco-efficient agriculture: concepts, challenges and opportunities. *Crop Science, 50*, 109–119.

Kilelu, C. W., Klerkx, L., & Leeuwis, C. (2013). Unravelling the role of innovation platforms in supporting co-evolution of innovation: Contributions and tensions in a smallholder dairy development programme [Internet]. *Agricultural Systems, 118*, 65–77.

Kiptot, E., Hebinck, P., Franzel, S., & Richards, P. (2007). Adopters, testers or pseudo-adopters? dynamics of the use of improved tree fallows by farmers in western Kenya. *Agricultural Systems, 94*(2), 509–519.

Krishna, A. (2002). *Active social capital*. New York: Columbia University Press.

Lane, C. (1998). *Custodians of the commons*. London: Earthscan.

Lapar, M. L. A., & Ehui, S. K. (2004). Factors affecting adoption of dual-purpose forages in the Philippine uplands. *Agricultural Systems, 81*, 95–114.

León-Velarde, C. U., Quiroz, R. A., Valdivia, R. E., Reynoso, J., & Holle, M. (2008). *Evolving from farming systems research intro a more holistic rural development approach: experiences in the Andean Region. Natural Resources Management Division Working Paper 2008–1*. Lima: International Potato Center.

Li Pun, H. H., Mares, V., Quiroz, R., León Velarde, C. U., Valdivia, R., & Reynoso, J. (2006). Pursuing the millennium development goals in the Andean altiplano. *Mountain Research and Development, 26*, 15–19.

Lockeretz, W., & Boehncke, E. (2000). *Agricultural systems research*. Wallingford: CABI.

Lopez-Ridaura, S., van Keulen, H., & Giller, K. E. (2007). Designing and evaluating alternatives for more sustainable natural resource management in less favoured areas. In R. Ruben, J. Pender, & A. Kuyvenhaven (Eds.), *Sustainable poverty reduction in less-favored areas* (pp. 65–90). New York: Oxford University Press.

Lybbert, T., Galarza, F., McPeak, J., Barrett, C., Boucher, S., Carter, M., et al. (2010). Dynamic field experiments in development economics; risk valuation in Morocco, Kenya and Peru. *Agricultural and Resource Economics Review, 39*, 176–192.

Maestre, F. T., Quero, J. L., Gotelli, N. J., Escudero, A., Ochoa, V., Delgado-Baquerizo, M., et al. (2012). Plant species richness and ecosystem multifunctionality in global drylands. *Science, 335*, 214–218.

Matsaert, H., Kariuki, J., & Mude, A. (2011). Index-based insurance for Kenyan pastoralists: an innovations systems perspective. *Development in Practice, 21*, 343–356.

McPeak, J., Chantarat, S., & Mude, A. (2010). Explaining index-based livestock insurance to pastoralists. *Agricultural Finance Review, 70*, 333–352.
McPeak, J., Little, P., & Doss, C. (2012). *Risk and social change in an African rural economy: livelihoods in pastoralists communities*. London: Routledge.
Mude, A., Barrett, C., McPeak, J., Kaitho, R., & Kristjanson, P. (2009). Empirical forecasting of slow-onset disasters for improved emergency response. *Food Policy, 34*, 329–339.
Notenbaert, A., Mude, A., van de Steeg, J., & Kinyangi, J. (2009). Options for adapting to climate change in livestock-dominated farming systems in the greater horn of Africa. *Journal of Geography and Regional Planning, 3*(9), 234–239.
Ouma, R., Mude, A., & van de Steeg, J. (2011). Dealing with climate-related risks: some pioneering ideas for enhanced pastoral risk management in Africa. *Experimental Agriculture, 47*, 375–393.
Pagella, T.F. and Sinclair, F.L. (2013). Use of a new typology of mapping tools to assess their fitness for supporting management of ecosystem service provision. Landscape Ecology (in press).
Pender, J., & Hazel, P. (2000). *Promoting sustainable development in less-favored areas*. Washington, DC: International Food Policy Research Institute.
Pender, J., & Kerr, J. (1998). Determinants of farmers' indigenous soil and water conservation investments in India's semi-arid tropics. *Agricultural Economics, 19*, 113–125.
Pender, J., Gebremedhin, B., Benin, S., & Ehui, S. (2001). Strategies for sustainable development in the Ethiopian highlands. *American Journal of Agricultural Economics, 83*, 1231–1240.
Pender, J., Place, F., & Ehui, S. (Eds.). (2006). *Strategies for sustainable land management in the East African highlands*. Washington, DC: International Food Policy Research Institute.
Place, F., & Hazell, P. (1993). Productivity effects of indigenous land tenure systems in sub-Saharan Africa. *American Journal of Agricultural Economics, 75*, 10–19.
Pretty, J. N. (1995). Participatory learning for sustainable development. *World Development, 23*, 1247–1263.
Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine, R. E., Penning de Vries, F. W. T., et al. (2006). Resource-conserving agriculture increases yields in developing countries. *Environmental Science and Technology, 40*, 1114–1119.
Quiroz, R., Leon-Velarde, C., Valdivia, R., Zorogastua, F. P., Baigorria, G., Barreda, C., Reinoso, J., Holle, M. & Li Pun, H. (2003). Making and Difference to Andean Livelihoods through an Integrated Research Approach. In R. R. Harwood & A. H. Kassam (Eds.). *Towards integrated natural resources management research: examples research problems, approaches and partnerships in action in the CGIAR*. Rome: The interim Science Council and Centre Directors Committee on NRM, FAO, http://www.fao.org/WAIRDOCS/TAC/Y4953E/y4953e0a.htm Accessed May 20, 2012.
Reynolds, J. F., Stafford Smith, D. M., Lambin, E. F., Turner, B. L., II, Mortimore, M., Batterbury, S. P. J., et al. (2007). Global desertification: building a science for dryland development. *Science, 316*, 847–851.
Roetter, R. P., van Keulen, H., Laborte, A. G., Hoanh, C. T., & van Laar, H. H. (2000). *Systems research for optimizing future land use in South and Southeast Asia. Proceedings of the SysNet'99 International Symposium. SysNet Research Paper Series 2*. Los Baños: International Rice Research Institute.
Sahrawat, K. L., Rego, T. J., Wani, S. P., & Pardhasaradhi, G. (2008). Stretching soil sampling to watershed: evaluation of soil-test parameters in a semi-arid tropical watershed. *Communications in Soil Science and Plant Analysis, 39*, 2950–2960.
Sahrawat, K. L., Wani, S. P., Pardhasaradhi, G., & Murthy, K. (2010). Diagnosis of secondary and micronutrient deficiencies and their management in rainfed agroecosystems: case study from Indian semi-arid tropics. *Communications in Soil Science and Plant Analysis, 41*, 346–360.
Sayer, J., & Campbell, B. (2004). *The science of sustainable development: Local livelihoods and the global environment*. UK: Cambridge University Press.
Scoones, I., & Thompson, J. (2009). *Farmer first revisited: Innovation for agricultural research and development*. Oxford: ITDG Publishing.
Shambu Prasad, C., Hall, A. J., & Wani, S. P. (2005). *Institutional history of watershed research: the evolution of ICRISAT's work on natural resources in India. Global Theme on Agroecosystems Report No. 12. (35pp)*. Patancheru: International Crops Research Institute for the Semiarid Tropics.
Shideed, K., Alary, V., Laamari, A., Nefzaoui, A., & El Mourid, M. (2007). Ex post impact assessment of natural resource management technologies in crop-livestock systems in dry areas of Morocco and Tunisia. In H. Waibel & D. Zilberman (Eds.), *International research on natural resource management* (pp. 169–195). Wallingford: CAB International.
Shiferaw, B., & Holden, S. T. (1998). Resource degradation and adoption of land conservation technologies in the Ethiopian highlands: a case study in Andit Tid, North Shewa. *Agricultural Economics, 18*, 233–247.
Shiferaw, B., & Holden, S. T. (2001). Farm level benefits to investments for mitigating land degradation: empirical evidence from Ethiopia. *Environment and Development Economics, 6*, 335–358.
Sietz, D., Lüdeke, M. K. B., & Carsten, W. (2011). Categorisation of typical vulnerability patterns in global drylands. *Global Environmental Change, 21*, 431–440.
Sinclair, F. L., & Walker, D. H. (1998). Qualitative knowledge about complex agroecosystems. Part 1: a natural language approach to representation. *Agricultural Systems, 56*, 341–363.
Sommer, R., & de Pauw, E. (2010). Organic carbon in soils of Central Asia—status quo and potentials for sequestration. *Plant and Soil, 338*, 273–288.
Spedding, C. R. W. (1979). *An Introduction to agricultural systems*. London: Academic.
Templeton, S. R., & Scherr, S. J. (1999). Effects of demographic and related microeconomic change on land quality in hills and mountains of developing countries. *World Development, 27*, 903–918.
Tiffen, M., Mortimore, M., & Gichuki, F. (1994). *More people – less erosion: Environmental recovery in Kenya*. London: Wiley and Sons.
Twomlow, S., Shiferaw, B., Cooper, P., & Keatinge, J. D. H. (2008). Integrating genetics and natural resource management for technology targeting and greater impact of agricultural research in the semi-arid tropics. *Experimental Agriculture, 44*, 1–22.
Walker, B. H., J. M. Anderies, A. P. Kinzig, and P. Ryan. 2006. Exploring resilience in social-ecological systems through comparative studies and theory development: introduction to the special issue. Ecology and Society 11(1): 12. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art12/
Wani, S. P., Rockstrom, J., & Oweis, T. (2009). *Rainfed agriculture: Unlocking the potential. Comprehensive assessment of water management in agriculture*. Wallingford: CABI.
Wani, S. P., Rockstrom, J., & Sahrawat, K. L. (2011). *Integrated watershed management in rainfed agriculture*. Leiden: CRC Press.
World Bank, FAO, IFAD. (2009). *Gender in agriculture sourcebook*. Washington, DC: The International Bank for Reconstruction and Development.
Wright, I. A., Tarawali, S., Blümmel, M., Gerard, B., Teufel, N., & Herrero, M. (2012). Integrating crops and livestock in subtropical agricultural systems. *Journal of the Science of Food and Agriculture, 92*, 1010–1015. doi:10.1002/jsfa.4556.

Dr. Ir. Maarten van Ginkel studied plant genetics, breeding and pathology in the Netherlands and the USA. For 20 years he worked at CIMMYT as a wheat breeder, and as Head of Wheat Genetic Resources, based in Turkey, Mexico and Ethiopia. He co-developed more than 100 adopted varieties of wheat, targeted to developing countries. He published more than 80 ISI papers on wheat genetic research. These included disease resistance, abiotic stress tolerance, input efficiency, end-use quality, physiological selection tools, synthetic hexaploid wheat, and breeding/genetics simulation/modeling. He has been presently Deputy Director General for Research at ICARDA since 2007. He was awarded Fellow of the Crop Science Society of America, and International Service in Crop Science Award in 2009.

Aden A. Aw-Hassan is Principle Agricultural Economist and Director of Social, Economics and Policy Research Program at the International Center for Agricultural Research in the Dry Areas (ICARDA), since 2009, with research interests in economic impacts of climate change, rural livelihoods, market value chain research, and assessment of agricultural research impacts. Aden holds MSc from Utah State University in 1988, and PhD from Oklahoma State University. Aden has over 20 years of experience in agricultural research and development in developing countries; and also worked as extension service officer and Regional Manager of Extension Services in the mid 1980's and has accumulated practical experience in agricultural research systems in developing countries.

Jeff Sayer has pursued a career in natural resource management in Africa and Asia. He has worked for the International Union for Conservation of Nature and World Wildlife Fund. He was founding Director General of the Center for International Forestry Research with its headquarters in Indonesia. He is at present professor of Conservation and Development at James Cook University in Queensland Australia where he runs a graduate programme in sustainable development. He conducts field work in Indonesia and the Congo Basin. Jeff is a member of the Independent Science and Partnership council of the Consultative Group for International Agricultural Research.

Deborah Bossio is the Director of Soil Research at the International Center for Tropical Agriculture (CIAT). She has lived and worked in the Western United States, South America, South Asia, and East Africa, conducting research on sustainable agricultural development for more than 20 years. She is a Soil Scientist with broad-based experience in soil fertility, sustainable agriculture, land degradation, soil ecology and biology, soil carbon, and water management. She has a keen interest in ecosystem services and sustaining society's ecological foundations. Her team at CIAT focuses on restoring degraded lands, sustainable intensification of farming systems, and climate smart agriculture.

Fergus Sinclair is Science Domain Leader at the World Agroforestry Centre (ICRAF), is on the faculty at the College of Natural Sciences, Bangor University, Wales, UK and is a Visiting Professor at the Centre for Agricultural Research and Higher Education for Central America (CATIE). He has worked on measurement and modelling of interactions in agroforestey systems, embracing biophysical, social and economic aspects inover 30 countries and pioneered the development and use of systematic approaches to local knowledge acquisition. Recent research includes negotiation support tools for managing synergies and trade-offs amongst impacts of land use change on ecosystem services.

Peter Craufurd is the Director of the Resilient Dryland Systems Research Program at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India. He has lived and worked in Africa and Asia conducting research on agriculture, spanning heat tolerance to seed systems. Peter has authored and co-authored over 120 publications and supervised many MsC and PhD students.

Mohammed El Mourid As agronomist and crop physiologist, during the last thirty five years, I have developed an experience in crop production, irrigation, cropping systems, drought resistance in cereals, modeling, community development and technology transfer as well as in research management and coordination at national (Morocco) and international levels. Regional Coordinator for North Africa ICARDA since 1999, I have coordinated more than 50 regional and sub-regional research/development projects. I am also active member of several scientific and professional associations. I have been recipient of several awards and authored and co-authored more than 120 peer-reviewed publications, book chapters and conference papers.

Nasri Haddad is Professor, plant breeding and plant genetic resources at the University of Jordan. Worked for 20 years with the International Center for Agricultural Research in the Dry Areas (ICARDA) as the Regional Coordinator for West Asia, and Regional Coordinator for Nile Valley and Red Sea Regional Programs. Coordinate the Center's activities in 14 Countries. Editor of two books, author and co-author of 100 Refereed Journal papers. Worked 20 years in research for the improvement of food legumes and crops drought management. Has directly supervised 35 post-graduate students, including 10 PhD graduates.

David Hoisington is the Program Director for the Feed the Future Peanut and Mycotoxin Innovation Lab at the University of Georgia, Athens, Georgia, USA. Previously, he was the Deputy Director General for Research at the International Crops Research Institute for the Semi-Arid Tropics located near Hyderabad, India where he led the institute's global research for development activities in sorghum, millets, chickpea, groundnut and pigeonpea cropping systems. He has worked in agricultural research for nearly 25 years, published over 100 refereed journal articles, 30 book chapters and made numerous invited presentations at international conferences.

Nancy Johnson is an agricultural economist and Senior Research Fellow at the International Food Policy research Institute (IFPRI) where she leads evaluation and impact assessment for CGIAR Research Program on Agriculture for Nutrition and Health. She studies the economic, poverty and gender impacts of agricultural and natural resource management research and development, and has worked on crop and livestock improvement; land and water management; and institutional innovation in Latin America, Eastern and Southern Africa, and South and SE Asia.

Carlos U. Leon Velarde has worked as member of the Production Systems and the Environment Subprogram at CIP in Lima. He is an Animal Husbandry specialist with over 30 years experience in international agriculture research and development. In CIP he was coordinator of several projects within the approach of agricultural production systems identifying products with comparative advantage and market orientation. He has worked for CATIE and also as consultant for different international institutions related to agricultural research oriented to rural development. Carlos holds a M.Sc. in Animal Production from IICA-Turrialba, Costa Rica and a PhD in Animal Breeding from the Guelph University, Ontario, Canada.

Victor Mares is a member of the Production Systems and the Environment Sub-program at CIP in Lima. He is a Systems Agronomist with over 30 years experience in international agriculture research and development. He has worked for CATIE and CIP and also as a consultant for the Interamerican Development Bank, the World Bank, IFAD, FAO, CIDA, IDRC, ILRI and NARs in Mexico, Costa Rica, Honduras, Nicaragua, Panama, Colombia, Ecuador, Brazil, Peru, Kenya and Ethiopia. Victor holds a M.Sc. in Grassland Agronomy from the University of Wales, Aberystwyth, Wales, U.K. and a PhD in Crop Science from the University of Guelph, Ontario, Canada.

Andrew Mude is Principal Scientist at the International Livestock Research Institute based in Nairobi, Kenya, where he leads the effort to design, implement and evaluate Index Based Livestock Insurance (IBLI) products aimed at helping pastoralists better manage the significant drought-related livestock risks that they face. The program has won various awards including Kenya's Vision 2030 ICT Innovation Award and the Poverty Reduction, Equity and Growth Network (PEGNet) Best-Practice Award for most innovative project. Andrew sits on the Kenya National Agricultural Insurance Policy Taskforce and is a Mid-Career Fellow in Sustainability Science at the Sustainability Science Program at Harvard's Kennedy School. He completed his doctoral degree in Economics at Cornell University in 2006.

Ali Nefzaoui is a livestock and rangeland senior consultant at ICARDA and regional coordinator of the CRP Dryland systems for North Africa and West Asia. His main fields of expertise are ruminant management and nutrition, feed resources, community-based participatory research and technology transfer. Prior joining ICARDA, he has led research teams on livestock-forage-rangeland over 25 years at INRA Tunisia and as a professor at Tunisian universities. He coordinated several regional and international research projects in collaboration with IFAD, OFPRI, ACIAR, FAO and CGIAR. He is author/co-author of 160 peer-reviewed publications, book chapters and conference papers.

Andrew Noble is the Director of the Water, Land and Ecosystems research program, led by the International Water Management Institute (IWMI). He has a strong background in agronomy, soil chemistry and in commercial forest nutrition with a keen interest in addressing land and water resource degradation. Andrew has lived and worked in South Africa, Thailand, Malaysia, Thailand and Sri Lanka for the past 25 years and is the author and co-author of 218 peer-reviewed publications, book chapters and conference proceedings papers.

K.P.C. Rao is the Principal Scientist and Ethiopia Country Representative with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). He has lived and worked in Asia and Africa for 30 years conducting research on sustainable management of soil and water resources at both farm and watershed scales, managing climate-induced production risks and improving the livelihood resilience of farming communities. Rao has a strong background in modeling agricultural systems, is the author or coauthor of 40 peer-reviewed publications, book chapters and conference papers and has advised over 10 post-graduate students, including 2 PhD graduates.

Rachid Serraj is trained in crop physiology, soil fertility and agronomy. He has focused his research and teaching work on improving crop stress tolerance and sustainable management of natural resources in marginal and unfavorable environments. He gained extensive international experience working with various advanced research institutions in Europe and USA. He has joined the CGIAR first as principal scientist at ICRISAT, leading the drought research on the semi arid tropics crops, where he played an important role developing…, upland rice and rainfed production systems (with IRRI), and in drylands of West Asia and North Africa, leading ICARDA's program on sustainable intensification and diversification of production systems. He has published on a wide range of topics.

Shirley Tarawali is Director of Institutional Planning and Partnerships and secretary to the Board of Trustees at the International Livestock Research Institute (ILRI) Nairobi, Kenya. Previously, Shirley was Director of the People, Livestock and the Environment Theme at ILRI, Addis Ababa, Ethiopia with responsibilities spanning sub-Saharan Africa and Asia. Shirley holds a PhD in Plant Science from the University of London, UK and has over 25 years' experience in in crop livestock and pastoral systems research for development in Africa and Asia, has contributed to over 80 articles and currently serves on a number of international scientific and editorial committees.

Raymond Vodouhe As geneticist and plant breeder during the last thirty six years, I have developed experiences in germplasm collecting, characterizing, evaluating, conserving and crop improvement for resistance/tolerance to disease and drought and for adaptation to climate variation in humid tropics and dry land systems of West Africa. National rice programme leader, Director of national crop research Center (Benin Rep.), Regional Coordinator for Bioversity International for West and Central Africa since 1997 I have developed management skills and coordinated several research projects at national and international levels. I have authored and co-authored more than 80 peer-reviewed publications, book chapters and conference papers.

Rodomiro Ortiz is Chair Professor of Genetics and Plant Breeding at the Swedish University of Agricultural Sciences. He holds a PhD in Plant Breeding & Genetics from the Univ. Wisconsin-Madison, and worked as young researcher at UNALM (Perú) and Rutgers Univ., was scientist and director of various CGIAR Consortium Centers, and held a Nordic professorship on plant genetic resources at the then Royal Veterinary and Agricultural Univ. He has written > 700 reports, of which about 50% are journal articles or edited book chapters with h-index of 40. The CGIAR awarded to IITA the prestigious 1994 King Baudouin Award for the multidisciplinary research of the team working in plantain and banana improvement, in which he was program leader. In 2012, Plant Breeding Reviews dedicated him its vol. 36.