SECHERESSE

Research Article

Sécheresse 2013 ; 24 : 322–9

Agricultural innovations in small-scale farming systems of Sudano-Sahelian West Africa: Some prerequisites for success

Andreas Buerkert[1]
Eva Schlecht[2]

[1] University of Kassel
Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics
Steinstrasse 19
D-37213 Witzenhausen
Germany
<buerkert@uni-kassel.de>
[2] University of Kassel and Georg-August-Universität Göttingen
Animal Husbandry in the Tropics and Subtropics
Steinstrasse 19
D-37213 Witzenhausen
Germany
<schlecht@uni-kassel.de>

Abstract

Intensified land use leading to ever shorter fallow periods, overuse of crop residues and woody perennials for feed, as fire wood and construction material, and temporary overstocking of pastures have shaped our image of doomsday scenarios in Sudano-Sahelian West Africa. While the described phenomena have undoubtedly contributed to a widespread decline in soil productivity of the vast marginal agro-pastoral millet and sorghum based land use systems, a few, largely overlooked, innovations have allowed enhancing productivity across a range of agro-ecological and socio-economic conditions. These are worthwhile to analyse in order to better understand how the well-known constraints to farmers' investments in more sustainable agro-pastoral production systems can be overcome. Successful innovations such as the locally made 'charette', a donkey-drawn, single axe farm transport vehicle, and the counter-season cultivation and regional marketing of onion have transformed subsistence agriculture in Niger since the 1970s. More recently the use of small amounts of seed-placed mineral phosphorus fertilizer (propagated as 'microdosing' by NGOs, FAO and the Gates Foundation) in millet and sorghum, a sprawling use of urban and periurban land for the highly intensive production of vegetables, specialty crops and sometimes also milk, as well as the fattening of small ruminants for religious festivals provide opportunities to effectively strengthen poor people's livelihood strategies and enhance their food sovereignty, often without involvement of extension services. The factors which seem to determine the success of such approaches are (i) their capacity to enhance farmers' access to markets (secure sales and cash earning), (ii) the possibility to adopt an innovation with only small amounts of capital (low entrance fee), and (iii) limited risk of failure despite high rainfall variability (safe return on investment). These factors add to the recent spread of real-time information about consumer demands and prices for agricultural goods across the region which is largely the result of the mobile phone revolution in Africa.

Key words : agricultural change, cash earning, food security, innovation, sustainable development.

doi: 10.1684/sec.2013.0402

To cite this article: Buerkert A, Schlecht E, 2013. Agricultural innovations in small-scale farming systems of Sudano-Sahelian West Africa: Some prerequisites for success. *Sécheresse* 24: 322-9. doi: 10.1684/sec.2013.0402

Reprints : A. Buerkert

Résumé

Innovations agricoles dans les systèmes agraires des petits paysans de la zone soudano-sahélienne de l'Afrique de l'Ouest: les conditions du succès

L'intensification agricole qui conduit à une réduction des jachères, une sur-utilisation des résidus de récolte et des espèces pérennes pour l'alimentation du bétail et la construction, et le surpâturage temporaire dans certaines régions présentent un scénario catastrophe pour la zone soudano-sahélienne. Alors que les phénomènes qui sont décrits contribuent sans nul doute au déclin de la productivité des sols dans les grandes étendues des systèmes agropastoraux à base de mil et sorgho, quelques innovations, largement ignorées, ont pourtant contribué à augmenter la productivité à travers plusieurs contextes écologiques et socio-économiques. Celles-ci valent la peine d'être analysées pour comprendre comment des contraintes bien connues à l'investissement dans des systèmes de production durable peuvent être dépassées. Des innovations couvertes de succès, aussi simple qu'une charrette tirée par un âne, ou bien la culture d'oignons en contre-saison, ont transformé l'agriculture du Niger depuis 1970. Plus récemment, l'utilisation de petites quantités de fertilisant phosphaté (plus connu sous le nom de 'microdose') pour le mil et le sorgho, un usage grandissant des surfaces agricoles périurbaines et urbaines pour la culture maraichère, des cultures spécialisées, et parfois la production de lait, ou encore l'engraissage des petits ruminants avant les jours de fête sont autant de stratégies d'amélioration du niveau de vie, favorisant l'indépendance alimentaire, et cela souvent sans avoir à passer par les services de dissémination. Les facteurs qui semblent être derrière le succès de ces approches sont: i) leur capacité à améliorer l'accès aux marchés (pour assurer un revenu monétaire) ; ii) la possibilité d'adopter une innovation sans grand besoin en investissement (faible coût d'entrée) ; iii) un risque d'échec limité en dépit de la haute variabilité saisonnière (retour sur investissement assuré). Ces facteurs s'ajoutent au récent développement de l'information en temps réel sur la demande des consommateurs et les prix des biens agricoles dans la région, résultant essentiellement de la révolution de la téléphonie mobile en Afrique.

Mots clés : développement durable, innovation, liquidité immédiate, sécurité alimentaire, transformation agricole.

Little is known about the determinants of successful innovations that stimulate productivity increases and sustainability in agro-pastoral land use systems of Sudano-Sahelian West Africa. So far most approaches advocating technological packages have failed in an environment where crop production and animal husbandry are severely hampered by climatic unpredictability and major risks over space and time, such as patchy and late rains, intraseasonal dry spells, early termination of rainfalls, sand-storm related erosion and crop losses or floods (Leihner *et al.*, 1993; Sivakumar *et al.*, 1993; Michels *et al.*, 1995, 1998; Buerkert and Lamers, 1999; Mortimore and Adams, 2001) and the occurrence of yield-reducing insects and diseases. The major subsistence crops (staples) of the region, millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* Moench.), have – except for drought years – a well-known strong response to organic and mineral fertilizers (Bationo *et al.*, 1992; Bationo *et al.*, 1993; Bationo *et al.*, 1998), but their grain yields on the predominantly sandy soils remain with 150-800 kg/ha very low. Adding to the income insecurity of farm households is the fact that both crops fetch uncertain prices given a very inelastic market demand and strong seasonal speculation by wealthy middlemen. These factors make investments in effective soil amendments very risky at the farmer's level.

Based on an analysis of successful innovations we argue in this paper that it is the risk perception at the household level that hampers the broadcast application of manure and mineral P and N fertilizers in rainfed field crops, more than do lacking infrastructure, untimely input availability, or farmers' cash scarcity. Under these conditions only technologies or innovations that have low entrance fees and that enhance a household's subjective perception of resistance to high economic risk will be adopted. This typically holds also true for alternative technologies with very large potential gains that for an individual household, however, appear to carry a higher risk of rare, but potentially catastrophic failure.

The cases of 'charette' use and onion production in Niger

With a frame sometimes made of scrap metal, a floor of wood and third-hand tires, the 'charette' is the vehicle of choice for any poor Sudano-Sahelian farmer in West Africa. It can be built by the village blacksmith, needs only minimum maintenance and care, is light enough to rarely get stuck as it can be pushed rather easily across sandy or muddy areas, runs smoothly on paved as well as unpaved roads, and – given its simple steel axis – can be overloaded beyond imagination. Its multiple uses for agricultural transport, as a wedding wagon, and as a make-shift house to protect a travelling sleeper fit perfectly into the remarkable survival strategy of most Sudano-Sahelian farmers to make a living of almost nothing.

In 2012, about 300,000 Nigerien farmers grew – largely in the dry season – a total of 500,000 tons of onion bulbs (*Allium cepa* L.), leading to annual earnings of around 100 Million US$

(Federation of Market Garden Cooperatives of Niger, FCMN-Niyya, Niamey). Besides countrywide sales, onions from Niger are shipped throughout the area of the West African Economic and Monetary Union. Most of the crop is grown in many small and a few large shallow depressions in the southeast of Niger between Galmi and Diffa. In these lowlands, clays, removed through splash erosion from the vast surrounding Arenosols, have accumulated through a multitude of erosion and deposition events (Hoogmoed and Klaij, 1990). They allow the storage of water during the rainy season which together with the reliable supply of irrigation facilitates abundant plant growth during the following 7-8 dry months with high solar radiation. Interestingly, the intensive crop production that uses a combination of manure and mineral fertilizers purchased from neighbouring Nigeria, is largely in the hands of smallholders that are self-organized for effective irrigation management (Norman, 1997). Additional components of the onion value chain are the post-harvest storage of bulbs and direct or long-distance produce marketing with very little government involvement. Key factors for the apparent success of this production system were: i) the introduction of new high yielding onion varieties (e.g. 'Rouge de Galmi') in the 1970s; ii) the presence of agro-ecological niche environments with the steady availability of ground water at shallow depth; iii) an annual precipitation of 600-700 mm unimodally distributed during four months leading to the leaching of any irrigation-induced salt built-up during the dry season; and iv) reliable onion storage and marketing facilities allowing to add value to the fresh bulbs.

Both examples challenge the notion that small-scale Sudano-Sahelian farmers are predominantly subsistence-oriented and thus reluctant to adopt agricultural innovations, are unable to come up with the necessary cash to pay for investments in agricultural production and post-harvesting techniques, and have difficulties to self-organize.

Coping with and overcoming fertility constraints on rainfed Sudano-Sahelian soils

Since colonial times it is well known that the largely granite derived, geologically very old and eroded Sudano-Sahelian soils are notoriously low in chemical fertility, soil organic carbon (Corg), and water holding capacity. In his review, Pieri (1989) has summarized some of the most salient results of many decades of early research conducted by the Centre de coopération internationale en recherche agronomique pour le développement (Cirad) throughout West Africa. It has been repeatedly shown that once moisture constraints are overcome at about 350 mm annual precipitation, soil nitrogen (N) and available phosphorus (P) levels become the most important factors limiting plant growth (Penning de Vries and van Keulen, 1982; Breman and de Wit, 1983; Hiernaux *et al.*, 1990) and their removal can lead to large increases in the water use efficiency of crops (Bationo *et al.*, 1998). There has been and still is debate about the relative importance of N *versus* P for crop growth on Sudano-Sahelian soils. While experimental work in natural grasslands (pastures) and subsequent modelling has indicated an overall first limitation of N (Penning de Vries and van Keulen, 1982; Breman and de Wit, 1983), on-farm and on-station data with agricultural crops show a rather stringent, rainfall-dependent sequence of nutrient limitations within the region (review of Buerkert and Hiernaux, 1998):

In the southern Sahelian zone (300-600 mm annual precipitation, 60-100 days growing period), P has been found to be the most limiting nutrient for millet (Bationo *et al.*, 1992; Bationo *et al.*, 1993), groundnut (*Arachis hypogaea* L.; Hafner *et al.*, 1992) and cowpea (*Vigna unguiculata* Walp.; Buerkert, unpublished data), followed by N for millet, and molybdenum (Mo) for groundnut (Hafner *et al.*, 1992; Rebafka *et al.*, 1993b). However, mineral N application increases cereal yields in most years once P constraints are removed (positive interaction).

Results from the Sudanian zone (700-1,200 mm annual precipitation) showed cereal yield increases of similar magnitude for N and P (Uyovbisere and Lombim, 1991), whereas in the Guinean savannah zone (>1,200 mm annual rainfall) N was found to be the first growth-limiting nutrient (Halm and Dartey, 1991; Jallah *et al.*, 1991; Maduakor, 1991). There is little experimental evidence about potassium (K) limiting crop yields in the region, which may be explained by the considerable deposition of K-rich dusts with 'Harmattan' winds on Sahelian soils (Herrmann *et al.*, 1993). Data from Rebafka *et al.* (1994), however, show a 68-109% dry matter yield increase of millet after the application of 30 kg K/ha on plots with several years' history of complete residue removal.

Crop responses to sulphur (S) application in the Sudano-Sahelian zone have rarely been investigated, but long-term trials (Bationo and Mokwunye, 1991) clearly showed superior millet yields with single superphosphate (SSP) compared to triple superphosphate (TSP). From a more detailed study at six sites in semi-arid and sub-humid West Africa, Friesen (1991) reported grain yield increases of 10-65% in millet, sorghum, and maize after the application of 5 or 10 kg S/ha. There is consistent evidence of large effects of mineral fertilizers (including high quality rock phosphate applied directly or after partial acidulation; McClellan and Notholt, 1986; Bationo *et al.*, 1990) on crop yields with and without concomitant application of crop residues or manure. This has triggered numerous efforts by government extension and NGOs to promote blanket application of fertilizers *via* credit schemes, food for work programs, and other incentives. However, even after the large increase in grain prices and corresponding terms of trade between output and input costs during the world food crisis in 2007, fertilizer application to the subsistence crops millet, sorghum and cowpea on the acid sandy soils of West Africa has remained as negligible as before (Agwe *et al.*, 2007). Bationo *et al.* (2006) pointed out that as a consequence of low nutrient inputs during the last 35 years, annual per capita cereal production in sub-Saharan Africa has declined from 150 to 130 kg, whereas in Asia and Latin America it increased from 200 to 250 kg (FAO, 2001).

Rather than trying to overcome nutrient limitations to crop growth at the field level by rainfall-dependent risky investments in mineral fertilizers, Sudano-Sahelian cereal farmers have used effective coping strategies at the sub-field scale (a traditional way of 'precision agriculture') to confront declining crop yields after repeated use of newly cleared bush land. Placed application of manure and crop residues (*figure 1*) is frequent and the labour-intensive *zaÿ* cultivation technique (planting excavated soil pits filled with organic amendments) from the Central Mossi Plateau in Burkina Faso is the most often cited form of reclaiming degraded surfaces (Ouedraogo and Sawadogo, 2001; Kaboré and Reij, 2004; Reij *et al.*, 2005). Other precision farming techniques, such as the spatially limited application of twigs and leaves to catch Harmattan dust, and the (still rare) use of niche environments

Figure 1. Nigerien millet farmer practising traditional precision agriculture to effectively allocate manure and crop residues, scarce farm-internal soil amendments, to his field. Small insert: millet plant germinating from a cattle dropping on a bare laterite plateau.

under trees such as *Faidherbia albida* (Del.) A. Chev. (Payne *et al.*, 1998) in sometimes revitalised open parkland systems, are much more frequent than the broadcast application of organic amendments (Faye *et al.*, 2001; Mortimore *et al.*, 2001; Mortimore and Turner, 2005; Tappan and McGahuey, 2007). Altogether this indicates that subsistence farmers in Sudano-Sahelian West Africa, whose agro-ecological conditions and derived livelihood strategies are very fragile, would put too many eggs in one basket if they invested in inputs whose effects on crop growth they can hardly control in a particular year. Instead, they prefer production strategies that allow them to cope with the unpredictability of their bio-physical and socio-economic environment.

A strategy that has been spreading fast during the last decade is 'microdosing', the placed application of P and N with the seeds of millet and sorghum at planting (*figure 2* and *figure 3*). This low-cost approach was originally developed in a long-term collaborative project at ICRISAT Sahelian Centre in Niger. In this project Rebafka *et al.* (1993a) had tested the coating of millet seeds with ammonium phosphate at a rate of 100 g P/ha. Their data showed large increases in early millet growth and related effects on final stand density (escape from wind erosion). But given a total P uptake of about 4 kg/ha by millet planted at 10,000 planting hills/ha, the coating effect led to final yield increments of only about 10%. Similar effects were subsequently obtained by the placement of SSP at 0.5 kg P/ha with the seed at planting (Buerkert, 1995). Larger amounts of P coated to the seed led to poor germination due to seed burning and/or excessive water absorption by the coating substrate, a critical component for germination of millet on the light Arenosols dominating in the region. Placed P application at rates of 3, 5 and 7 kg P/ha (Muehlig-Versen *et al.*, 2003), in contrast, increased millet yield by up to 60%, but the fertiliser needed to be put sidewise of the seed to avoid direct contact between seedlings and the fertiliser granules, and subsequent damage to the roots. Based on these results, the effects of NPK (15-15-15) fertiliser placement at 4 kg P/ha (subsequently called 'microdosing') were examined in trials with millet, sorghum, maize, cowpea and groundnut at eight sites in West Africa. Under researcher controlled on-farm experimental conditions, microdosing with placed NPK yielded average dry matter increases of 70% for cereals and 74% for legumes (Buerkert and Hiernaux, 1998).

Subsequent economic analyses of input/output relationships demonstrated the profitability of the microdosing technology in Niger and Mali (Abdoulaye and Sanders, 2005; Vitale and Sanders, 2005). Since then this technology has been successfully tested on farm *via* ICRISAT, USAID, FAO, IFDC, and lately the Gates Foundation (Pender *et al.*, 2008; Tabo *et al.*, 2011) resulting in 360,000 farmers applying the technology across sub-Saharan West Africa in 2012. Following successful agronomic testing by Palé *et al.* (2009) in sorghum, Bagayoko *et al.* (2011) reported microdose fertilizer application to increase grain yields of pearl millet by 240-300 kg/ha on sandy soils across a broad range of climatic and soil conditions.

Over the years, the sustainability of the microdosing approach was repeatedly

Figure 2. Effects of microdosing in a farmer's field near Maradi (SE-Niger; Buerkert and Hiernaux, 1998).

Figure 3. Aerial view of the village of Banizoumbou (left) where farmers cultivate millet without external inputs and of Kara Bedji (right) where farmers used the microdosing technology (Buerkert and Hiernaux, 1998).

questioned given that only 4 kg P and 10-15 kg N/ha are typically applied with the small dosage of NP or NPK fertilizer used. This has again been pointed out by Breman (2012) in a recent report. An application rate of 4 kg P/ha corresponds to the P uptake and extraction at harvest of 1,300 kg millet grain/ha at an average concentration of 3.2 mg/g in Sahelian millet (Buerkert *et al.*, 1998). Such grain yield is much higher than the 500-1,000 kg/ha typically obtained by Sahelian millet farmers even with microdosing. At the same time N uptake by 1,300 kg grain/ha containing 20-23 mg N/g amounts to 30 kg N/ha, which is indeed 2-3 fold the amount of N applied in microdosing. However, experimental on-farm data provided solid evidence that natural N inputs, such as from associative N_2-fixation (e.g. by free living bacteria like *Azospirillum*) play a major role in field-grown millet and that N leaching can be substantially reduced by P application enhancing early millet shoot and root growth (Hafner *et al.*, 1993a; Hafner *et al.*, 1993b). All available data therefore suggest that rather than introducing N-deficiency or even contributing to soil organic matter decay as vaguely claimed by Breman (2012), microdosing in Sahelian millet and possibly also in sorghum is – at least at the low to medium yield levels – a highly attractive option for small-scale farmers to sustainably enhance grain yields as well as the amounts of crop residues available for carbon and nutrient recycling (Buerkert *et al.*, 2000) and multiple other uses (Lamers and Feil, 1993). The chain of mechanisms underlying this yield increase are well understood, even if recently explored varietal differences in root parameters and P use efficiencies of millet and sorghum (Brück *et al.*, 2003; Beggi *et al.*, unpublished data) are still to be exploited: higher early P availability enhances root and shoot growth of seedlings, particularly in combination with ammonium-N (Strasser and Werner, 1995; Lima *et al.*, 2010), increases mycorrhizal infection, and strengthens plants' early resistance to abrasive storms and burial of seedlings (Michels *et al.*, 1995; Bagayoko *et al.*, 2000) as well as to early season drought. This underlines the particular nature of microdosing, a cost-effective mode of precision agriculture that has recently also been successfully farmer-tested by ICRISAT applying only maize (*Zea mays* L.), sorghum and millet in Zimbabwe applying only 10-17 kg N/ha (Twomlow *et al.*, 2010). The micro-dosing practice as such matches the traditional coping strategies of Sudano-Sahelian farmers with their mixture of subsistence and marketing goals for staples.

"Moutons de case" – Fattening small ruminants for specific occasions

Sheep fattening is an economically interesting activity across Sudano-Sahelian West Africa, especially shortly before the Islamic holiday Eid-al-Kabir (Ayantunde *et al.*, 2008). This low-risk strategy is often particularly promoted to women because of the i) low investment needed for housing (animals are mostly kept in the courtyard, sometimes confined under a thatched hangar); ii) little capital required to buy a few young male animals; iii) short-term nature of the activity (2-3 months of intensive feeding, depending on breed, age/weight and health/condition of the animals); iv) secure outlet market and high prices (especially if sheep are sold shortly before religious festivals); and v) broad social acceptance of the activity (Ayantunde *et al.*, 2008). Yet, the regular supply of the required amounts of roughage feeds (millet and sorghum stover, bush hay), of protein-rich forages (haulms of cowpea and groundnut), cotton (*Gossypium hirsutum* L.) seed expeller, and energy supplements (such as meals or brans of millet and rice *Oryza sativa* L. or chips of cassava *Manihot esculenta* Crantz.) is costly and not always feasible. Rural farmers may select young rams from their own flocks or cheaply buy animals from neighbours; they can produce some or all of the required feeds and thus face only moderate input costs. However, since they mostly have to sell their fattened sheep to middlemen who transport the animals to urban centres, rural farmers reap a lower profit than urban sheep keepers who can sell their animals directly to consumers. On the other hand, the latter producers face higher feed costs year-round. Due to seasonal feed scarcity in the rural setting and high feed prices in the peri-/urban environment, many farmers temporarily underfeed their animals, hence growth rates of fattening sheep often remain below the animals' genetic potential (Ayantunde *et al.*, 2008). Altogether, these factors may lead to only modest net returns of the fattening operation (Ayantunde *et al.*, 2007), especially when compared to (peri-/urban) vegetable farming (Graefe *et al.*, 2008). Yet, in official as well as farmer-managed credit schemes, sheep fattening operations often rank among the most attractive sectors of investment (Tabo *et al.*, 2009).

Urban and periurban agriculture: intensification, innovation, and marketing

At an annual population increase of 3% and a current urbanization rate of about 20%, an important proportion of the population of Sudano-Sahelian West Africa will live in cities by the year 2020 (FAO, 2003). The rapid development of urban and periurban agriculture (UPA) that accompanies this process is perhaps the most striking evidence of how innovative and ready to invest small-scale farmers can be, if profits from investments in land use systems are unaffected by unpredictable risks such as rainfall variability and speculative market prices such as for millet. Typically, UPA are high input/high output systems largely oriented towards the production of vegetables, fruits and flowers, sometimes also medicinal plants, as well as cow milk, eggs, and poultry and sheep meat (Cofie *et al.*, 2003; Drechsel *et al.*, 2005; Diogo *et al.*, 2010a; Dossa *et al.*, 2011). Irrigation of crops with fresh or waste water of usually no or little cost, but sometimes doubtful quality (Binns *et al.*, 2003; Diogo *et al.*, 2010a; Abdu *et al.*, 2011) allows to eliminate the effects of dry spells during the rainy season and enables year-round cropping of short-cycled, often quickly perishable crops. Although they generally lack secure tenure – as most land on which UPA is practiced is either temporarily rented or semi-legally occupied – peri-/urban farmers judiciously maintain the productivity of their small irrigated gardens and are well aware of short and medium term productivity changes of their plots. They rather over- than under-fertilize their crops with both organic and inorganic fertilizers to enhance the visual appearance of the produce and to shorten cropping cycles. Compared to the soils of rural cereal fields, UPA plots are typically much higher in pH, Corg, available P and N (*figure 4*), which is only partly due to differences in the soils' origin but largely reflect differences in management through year-round addition of organic matter in the form of compost, crop residues or manure, and of mineral fertilizers and nutrient-loaded waste water (Diogo *et al.*, 2010a; Predotova *et al.*, 2010; Lompo *et al.*, 2012, Sangaré *et al.*, 2012). Similarly, an oversupply of feed (that is, of energy and especially protein), can often be observed in the peri-/urban holdings of dairy cattle and small ruminants, especially sheep, which are specifically fattened for religious holidays and ceremonies (Diogo *et al.*, 2010b; Amadou, 2012). In all cases so far studied in West Africa, extension services do not play a significant role in farmers' willingness to adopt innovations related to UPA (Rischkowsky *et al.*, 2006; Dossa *et al.*, 2011). Due to short distances and good road and market infrastructure in cities and their immediate peripheries, direct product marketing is common, and middlemen only play a minor role. The risk-poor engagement in peri-/urban vegetable farming and livestock husbandry allows poor rural migrants, uneducated city dwellers and other marginalized individuals alongside with retired government employees and investors to secure a regular income. This may exceed the average household income six-fold (Drechsel *et al.*, 2006; Graefe *et al.*, 2008; Diogo *et al.*, 2011) and triggers self-reinforcing development and further adoption of innovations. Given the yet increasing population in West Africa and the continued migration to urban centers, the role of UPA as a job and income provider will continue to grow in the foreseeable future. While the concomitantly increasing demand for food, land and water resources in cities and their peripheries will lead to conflicts, it offers at the same time multiple opportunities. Particularly post-harvest processing and transformation of raw agricultural commodities into safe high quality products remains to be further developed along market-oriented agricultural value chains.

0-0.2 m	pH_{KCl}	P_{Bray} (mg/kg)	C_{org} (%)	CEC ($cmol_c$/kg)	pH_{KCl}	P_{Bray} (mg/kg)	C_{org} (%)	CEC ($cmol_c$/kg)
	4.4	3	0.23	1.10	6.1	41	0.27	2.92
					6.7	41	0.96	9.57
	Arenosol Sadoré (Niger)				Fluvisol on river bench Niamey (Niger)			

Figure 4. Typical Arenosol (left) for millet cultivation in rural subsistence agriculture and two Fluvisols (right) used for urban agriculture in Niger (particularly note the dark surface layer rich in organic carbon).

Conclusion

Based on our review of some very successful agricultural practices that emerged in Sudano-Sahelian West Africa during the past 30 years, we conclude that innovations with low or moderate entrance fees ('charette' use, onion production, fertilizer microdosing) are especially promising for rural areas, when they enhance farm income without enhancing production risks. On the other hand, strategies that require higher investments in production inputs (feed to fatten sheep or produce cow milk; irrigation water, fertilizers and pesticides to grow high value vegetables) are only adopted if production risks are low due to reliable access to key inputs (such as irrigation water), secure markets (high demand for fattened sheep at religious holidays, for vegetables/fruits by urban middle class customers) and high product prices (especially in the peri-/urban setting). While the adoption of 'rural' innovations was, and still is, supported by government extension and NGOs, 'peri-/urban' strategies are often spontaneously adopted by farmers themselves.

Yet, especially for peri-/urban production systems a move from mere production of raw commodities (crude vegetables and fruits, raw milk and meat) towards safe post-harvest conservation and transformation of produce into high value foodstuffs (such as fruit baskets, dried mixed vegetable soups, a wide range of dairy and meat products) may further enhance the incomes of those involved at a low risk of failure.

References

Abdoulaye T, Sanders JH, 2005. Stages and determinants of fertilizer use in semiarid African agriculture: the Niger experience. *Agricultural Economics* 32 : 167-79.

Abdu N, Agbenin J, Buerkert A, 2011. Phytoavailability, human risk assessment and transfer characteristics of cadmium and zinc contamination from urban gardens in Kano, Nigeria. *Journal of the Science of Food and Agriculture* 91 : 2722-30.

Agwe J, Morris M, Fernandes E, 2007. *Africa's growing soil fertility crisis: what role for fertilizer?* Agricultural and Rural Development Notes 21. Washington (DC) : The Word Bank.

Amadou H, 2012. Effect of management strategies on the performance of ruminant livestock production systems and the safety of plant and animal products in the city of Sikasso, Mali. PhD thesis, University of Kassel, Germany. Available at: http://nbn-resolving.de/urn:nbn:de:hebis:34-2012050241150.

Ayantunde AA, Delfosse P, Fernández-Rivera S, Gerard B, Dan-Gomma A, 2007. Supplementation with groundnut haulms for sheep fattening in the West African Sahel. *Tropical Animal Health and Production* 39 : 207-16.

Ayantunde AA, Fernández-Rivera S, Dan-Gomma A, 2008. Sheep fattening with groundnut haulms and millet bran in the West African Sahel. *Revue d'Élevage et de Médecine Vétérinaire des Pays Tropicaux* 61 : 215-20.

Bagayoko M, George E, Römheld V, Buerkert A, 2000. Effects of mycorrhizae and phosphorus on growth and nutrient uptake of millet, cowpea and sorghum on a West African soil. *Journal of Agricultural Science* 135 : 399-407.

Bagayoko M, Maman N, Palé S, Sirifi S, Taonda SJB, Traore S, Mason SC, 2011. Microdose and N and P fertilizer application rates for pearl millet in West Africa. *African Journal of Agricultural Research* 6 : 1141-50.

Bationo A, Mokwunye AU, 1991. The role of manure and crop residues in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa. *Fertilizer Research* 29 : 117-25.

Bationo A, Chien SH, Henao J, Christianson BC, Mokwunye AU, 1990. Agronomic evaluation of two unacidulated and partially acidulated phosphate rocks indigenous to Niger. *Soil Science Society of America Journal* 54 : 1772-7.

Bationo A, Christianson BC, Baethgen WE, Mokwunye AU, 1992. A farm-level evaluation of nitrogen and phosphorus fertilizer use and planting density for pearl millet production in Niger. *Fertilizer Research* 31 : 175-84.

Bationo A, Christianson BC, Klaij MC, 1993. The effect of crop residue and fertiliser use on pearl millet yields in Niger. *Fertilizer Research* 34 : 251-8.

Bationo A, Kihara J, Vanlauwe B, Waswa B, Kimetu J, 2006. Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems* 94 : 13-25.

Bationo A, Lompo F, Koala S, 1998. Research on nutrient flows and balances in West Africa: state-of-the art. *Agriculture, Ecosystems and Environment* 71 : 19-35.

Binns JA, Maconachie RA, Tanko AI, 2003. Water, land and health in urban and peri-urban food production: the case of Kano, Nigeria. *Land Degradation and Development* 14 : 431-44.

Breman H, de Wit CT, 1983. Rangeland productivity and exploitation in the Sahel. *Science* 221 : 1341-7.

Breman H, 2012. *Micro-Dosing Fertilizers for improved Food Security and Resilience in the Sahel & the Horn of Africa*. Report to the Dutch Development Cooperation. The Hague (The Netherlands) (unpublished report).

Brück H, Sattelmacher B, Payne WA, 2003. Varietal differences in shoot and rooting parameters of pearl millet on sandy soils in Niger. *Plant and Soil* 251 : 175-85.

Buerkert A, 1995. Effects of crop residues, phosphorus, and spatial soil variability on yield and nutrient uptake of pearl millet (Pennisetum glaucum L.) in Southwest Niger. PhD Thesis. University of Hohenheim, Verlag U.E. Grauer, Beuren-Stuttgart, Germany.

Buerkert A, Bationo A, Dossa K, 2000. Mechanisms of residue mulch induced cereal growth increases in West Africa. *Soil Science Society of America Journal* 64 : 346-58.

Buerkert A, Haake C, Ruckwied M, Marschner H, 1998. Phosphorus application affects the nutritional quality of millet grain in the Sahel. *Field Crops Research* 57 : 223-35.

Buerkert A, Hiernaux P, 1998. Nutrients in the West African Sudano-Sahelian zone: losses, transfers and role of external inputs. *Journal of Plant Nutrition and Soil Science* 161 : 365-83.

Buerkert A, Lamers JPA, 1999. Soil erosion and deposition effects on surface characteristics and pearl millet growth in the West African Sahel. *Plant and Soil* 215 : 239-53.

Cofie OO, van Veenhuizen R, Drechsel P, 2003. *Contribution of urban and peri-urban agriculture to food security in sub-Saharan Africa*. Africa Session of 3rd WWF, Kyoto, Japan. Available at http://www.ruaf.org/sites/default/files/contribution_ua_food_security.pdf

Diogo RVA, Buerkert A, Schlecht E, 2010a. Horizontal nutrient fluxes and food safety in urban and peri-urban vegetable and millet cultivation of Niamey, Niger. *Nutrient Cycling in Agroecosystems* 87 : 81-102.

Diogo RVA, Buerkert A, Schlecht E, 2010b. Resource use efficiency in urban and peri-urban livestock enterprises of Niamey, Niger. *Animal* 4 : 1725-38.

Diogo RVA, Buerkert A, Schlecht E, 2011. Economic benefit of gardeners and retailers from cultivating and marketing of vegetables in Niamey, Niger. *Outlook on Agriculture* 40 : 71-8.

Dossa LH, Buerkert A, Schlecht E, 2011. Cross-location analysis of the impact of households' socioeconomic status on their participation in urban and peri-urban agriculture in West Africa. *Human Ecology* 39 : 569-81.

Drechsel P, Quansah C, Penning De Vries F, 2005. Stimulation of urban and peri-urban agriculture in West Africa: characteristics, challenges, need for action. In: Smith OB, ed. *Urban agriculture in West Africa. Contributing to food security and urban sanitation*. Ottawa (Canada) ; Wageningen (The Netherlands): International Development Research Centre (IDRC), Technical Centre for Agricultural and Rural Cooperation. (ACP-EU).

Drechsel P, Graefe S, Sonou M, Cofie OO, 2006. *Informal irrigation in urban West Africa: An overview*. IWMI Research Report 102. Available at: http://www.iwmi.cgiar.org/publications/iwmi_research_reports/pdf/pub102/rr102.pdf

FAO, 2001. *Soil fertility management in support of food security in sub-Saharan Africa*. Rome: FAO.

FAO, 2003. FAO Statistical Databases. http://www.fao.org.

Faye A, Fall A, Tiffen M, Mortimore M, Nelson J. 2001. *Région de Diourbel (Sénégal): Synthesis*. Drylands Research Working Paper No. 23. Crewkerne (UK): Drylands Research.

FCMN-Niyya. http://www.ipsnews.net/2012/04/niger-onion-producers-in-tears-over-market-glut/Last accessed on 3 April 2013.

Friesen DK, 1991. Fate and efficiency of sulphur fertiliser applied to food crops in West Africa. *Fertilizer Research* 29 : 35-44.

Graefe S, Schlecht E, Buerkert A, 2008. Opportunities and challenges of urban and peri-urban agriculture in Niamey, Niger. *Outlook on Agriculture* 37 : 47-56.

Hafner H, Ndunguru BJ, Bationo A, Marschner H, 1992. Effect of nitrogen, phosphorus and molybdenum application on growth and symbiotic N_2 fixation of groundnut in an acid sandy soil in Niger. *Fertilizer Research* 31 : 69-77.

Hafner H, Bley J, Bationo A, Martin P, Marschner H, 1993. Long-term nitrogen balance for pearl millet (*Pennisetum glaucum* L.) in an acid sandy soil of Niger. *Journal of Plant Nutrition and Soil Science* 156 : 169-76.

Hafner H, George E, Bationo A, Marschner H, 1993. Effect of crop residues on root growth and nutrient acquisition of pearl millet in an acid sandy soil in Niger. *Plant and Soil* 150 : 117-27.

Halm AT, Dartey K, 1991. Efficient fertilizer use for increased crop production: The Ghana experience. In : Mokwunye AU, (ed). *Alleviating soil fertility constraints to increased crop production in West Africa*. Dordrecht (The Netherlands): Kluwer Academic Publishers.

Herrmann L, Bleich KE, Stahr K, 1993. Veränderung eines landwirtschaftlich genutzten Standortes in Niger/Westafrika durch Staubeintrag. *Mitteilungen der Deutschen Bodenkundlichen Gesellschaft* 72 : 927-30.

Hiernaux P, Diarra L, Maïga A, 1990. Dynamique de la Végétation Sahélienne après la Sécheresse. Working document 001/90. Bamako (Mali): Centre International pour l'Élevage en Afrique/ILCA.

Hoogmoed WB, Klaij MC, 1990. Soil management for crop production in the West African Sahel. I. Soil and climate parameters. *Soil and Tillage Research* 16 : 85-103.

Kaboré PD, Reij C, 2004. *The emergence and spreading of an improved traditional soil and water conservation practice in Burkina Faso*. Environment and Production Technology Division Discussion Paper 114. Washington (DC): International Food Policy Research Institute.

Jallah JK, Mulbah CK, Kiazolu JS, Frank K, Morris MZ, 1991. Efficient fertilizer use for increased crop production: The Liberia experience. *Fertilizer Research* 29 : 55-64.

Lamers JPA, Feil P, 1993. The many uses of millet residues. *ILEA Newsletter* 9 : 15.

Leihner DE, Buerkert A, Banzhaf J, Serafini PG, 1993. Soil tillage and windbreak effects on millet and cowpea: II. Dry matter and grain yield. *Agronomy Journal* 85 : 400-5.

Lima JE, Kojima S, Takahashi H, von Wiren N, 2010. Ammonium triggers lateral root branching in *Arabidopsis* in an ammonium-transporter 1;3-dependent manner. *The Plant Cell* 22 : 3621-33.

Lompo DJP, Sangaré SAK, Compaoré E, Sedogo MP, Predotova M, Schlecht E, *et al.,* 2012. Gaseous emissions of nitrogen and carbon from urban vegetable gardens of Bobo Dioulasso, Burkina Faso. *Journal of Plant Nutrition and Soil Science* 175 : 846-53.

Maduakor HO, 1991. Efficient fertilizer use for increased crop production: The humid Nigeria experience. *Fertilizer Research* 29 : 65-79.

McClellan GH, Notholt AJG, 1986. Phosphate deposits of tropical sub-Saharan Africa. In : Mokwunye AU, Vlek PLG, eds. *Management of nitrogen and phosphorus fertilizers of sub-Saharan Africa*. Dordrecht (The Netherlands): Martinus Nijhoff.

Michels K, Lamers JPA, Buerkert A, 1998. Effects of windbreak species and mulching on wind erosion and millet yield in the Sahel. *Experimental Agriculture* 34 : 449-64.

Michels K, Sivakumar MVK, Allison BE, 1995. Wind erosion control using crop residue: II. Effects on millet establishment and yield. *Field Crops Research* 40 : 111-8.

Mortimore MJ, Adams WA, 2001. Farmer adaptation, change and 'crisis' in the Sahel. *Global Environmental Change* 11 : 49-57.

Mortimore M, Tiffen M, Boubacar Y, Nelson J, 2001. *Synthesis of long-term change in Maradi Department 1960-2000*. Drylands Research Working Paper 39. Crewkerne (UK): Drylands Research.

Mortimore M, Turner B, 2005. Does the Sahelian smallholders' management of woodland, farm trees, and rangeland support the hypothesis of human-induced desertification? *Journal of Arid Environments* 63 : 567-95.

Muehlig-Versen B, Buerkert A, Bationo A, Roemheld V, 2003. Phosphorus placement on acid Arenosols of the Sahel. *Experimental Agriculture* 39 : 307-25.

Norman WR, 1997. Indigenous community-managed irrigation in Sahelian West Africa. *Agriculture, Ecosystems and Environment* 61 : 83-95.

Ouedraogo A, Sawadogo H, 2001. Three models of extension by farmer innovators in Burkina Faso. In : Reij C, Wayers-Bayer A, eds. *Farmer innovation in Africa: A source of inspiration for agricultural development*. London: Earthscan.

Palé S, Mason SC, Taonda SJB, 2009. Water and fertilizer influence on yield of grain sorghum varieties produced in Burkina Faso. *South African Journal of Plant and Soil* 26 : 91-7.

Payne WA, Williams JH, Maï Moussa KA, Stern RD, 1998. Crop diversification in the Sahel through use of environmental changes near *Faidherbia albida* (Del.) A. Chev. *Crop Science* 38 : 1585-91.

Pender J, Abdoulaye T, Ndjeunga J, Gerard B, Kato E, 2008. *Impacts of inventory credit, input supply shops, and fertilizer microdosing in the drylands of Niger*. International Food Policy Research Institute (IFPRI), Series No. 763 Washington (DC): IFPRI.

Penning de Vries FWT, van Keulen H, 1982. La production actuelle et l'action de l'azote et du phosphore. In : Penning de Vries FWT, Djitèye MA, eds. *La productivité des pâturages sahéliens*. Wageningen (The Netherlands): Centre for Agricultural Publishing and Documentation.

Pieri C, 1989. *Fertilité des terres de savanes*. Paris: Cirad-Irat; ministère de la Coopération.

Predotova M, Gebauer J, Schlecht E, Buerkert A, 2010. Emissions of ammonia, nitrous oxide and carbon dioxide from urban gardens in Niamey, Niger. *Field Crops Research* 115 : 1-8.

Rebafka FP, Bationo A, Marschner H, 1993. Phosphorus seed coating increases P uptake, early growth and yield of pearl millet (*Pennisetum glaucum* L. R. Br.) grown on an acid sandy soil in Niger, West Africa. *Fertilizer Research* 35 : 151-60.

Rebafka FP, Ndunguru BJ, Marschner H, 1993. Crop residue application increases nitrogen fixation and dry matter production in groundnut (*Arachis hypogaea* L.) grown on an acid sandy soil in Niger, West Africa. *Plant and Soil* 150 : 213-22.

Rebafka FP, Hebel A, Bationo A, Stahr K, Marschner H, 1994. Short- and long-term effects of crop residues and of phosphorus fertilization on pearl millet yield on an acid sandy soil in Niger, West Africa. *Field Crops Research* 36 : 113-24.

Reij C, Tappan G, Belemvire A, 2005. Changing land management practices and vegetation in the Central Plateau of Burkina Faso (1968-2002). *Journal of Arid Environments* 63 : 642-59.

Rischkowsky B, Bednarz K, Jahn G, 2006. Peri-urban sheep production in West Africa: Do smallholders benefit from proximity of the urban centres? *Small Ruminant Research* 66 : 22-31.

Sangaré SK, Compaore E, Buerkert A, Vanclooster M, Sedogo MP, Bielders CL, 2012. Field-scale analysis of water and nutrient use efficiency for vegetable production in a West African urban agricultural system. *Nutrient Cycling in Agroecosystems* 92 : 207-24.

Sivakumar MVK, Maidoukia A, Stern RD, 1993. Agroclimatology of West Africa: Niger. *ICRISAT Information Bulletin* no. 5 (International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India).

Strasser B, Werner W, 1995. EinfluÞ von Form und Plazierung der N- und P-Düngung auf Wurzelentwicklung, Phosphat-Aufnahme und Wachstum von Sonnenblumen (*Helianthus annuus*) und Zuckerhirsen (*Sorghum bicolor*). *Journal of Agronomy Crop Science* 175 : 157-65.

Tappan G, McGahuey M, 2007. Tracking environmental dynamics and agricultural intensification in southern Mali. *Agricultural Systems* 94 : 38-51.

Tabo R, Bationo A, Amadou B, Marchal D, Lompo F, Gandah M, *et al.,* 2011. Scaling-up and-out fertilizer microdosing and "warrantage" or inventory credit system to improve food security and farmers' income in West Africa. In : Bationo A, Okeyo J, Waswa BS, Mapfumo P, Maina F, Kihara J, eds. *Innovations as keys to the Green Revolution in Africa*. Dordrecht (The Netherlands): Springer.

Tabo R, Bationo A, Sawadogo-Kabore S, Hassane O, Amadou B, Siebou P, *et al.*, 2009. Institutional innovation: the potential of the "warrantage" system to underpin the Green Revolution in Africa. In: Humphreys E, Bayot RS, eds. *Increasing the productivity and sustainability of rainfed cropping systems of poor smallholder farmers*. Proceedings of the CGIAR Challenge Program on Water and Food, International Workshop on Rainfed Cropping Systems, Tamale, Ghana, 22-25 September 2008.

Twomlow SJ, Rohrbach DD, Dimes J, Rusike J, Mupangwa W, Ncube B, *et al.,* 2010. Microdosing as a pathway to Africa's Green Revolution: evidence from broad-scale on-farm trials. *Nutrient Cycling in Agroecosystems* 88 : 3-15.

Uyovbisere EO, Lombim G, 1991. Efficient fertiliser use for increased crop production: The sub-humid Nigeria experience. *Fertilizer Research* 29 : 81-94.

Vitale JD, Sanders JH, 2005. New markets and technological change for the traditional cereals in semiarid Sub-Saharan Africa: the Malian case. *Agricultural Economics* 32 : 111-29.