22 Inland Valleys: Africa's Future Food Baskets

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Introduction

Inland-valley ecosystems are expected to play a crucial role in boosting Africa's rice production. They are defined as the upper parts of river drainage systems, comprising the whole upland–lowland continuum (Windmeijer and Andriesse, 1993), from the rainfed uplands (*pluvial*) to rainfed, flooded and intensified lowlands in the valley bottom (*fluxial*), with the hydromorphic fringes (*phreatic*) as the (sloping) transition zone between them (Fig. 22.1).

The morphology of inland valleys can vary as a result of climate, geology and geomorphology. There are many shapes of inland valleys, but the three most frequently observed morphology types are: (i) rectilinear, broad valleys with gentle (<3%) and straight slopes; (ii) concave, relatively narrow valleys with concave side slopes (3–8%); and (iii) convex, with moderately steep convex side slopes and flat narrow (20–400 m) valley bottoms (Fig. 22.2). Raunet (1985) and Windmeijer and Andriesse (1993) report that in West Africa, rectilinear inland valleys (Fig. 22.3a) are located in areas with mean annual precipitation of 800–1100 mm as observed in the Sudan savannah to Guinea savannah zones; concave inland valleys (Fig. 22.3b) are associated with the Guinea savannah zone with intermediate rainfall regimes ranging from 1100 mm to 1400 mm per year, while convex inland valleys (Fig. 22.3c) are formed under the high-rainfall regimes of 1400 mm and above, typical of the equatorial forest zone.

With an estimated land area of 190 Mha,[1] inland valleys are common landscapes serving a multitude of ecosystem functions in many parts of Africa. In general, wetland environments and particularly valley bottoms – commonly referred to as *bas-fonds*, *fadamas* and *inland swamps* in West Africa; *mbuga* in East Africa, and *vleis*, *dambos*, *mapani*, *matoro*, *inuta* or *amaxhaphozi* in Southern Africa (Acres *et al*., 1985) – generally have high agricultural production potential (Andriesse *et al*., 1994), although the only major crop that can be grown under the temporary flooded conditions in these ecosystems is rice (e.g. Andriesse and Fresco, 1991). The development of inland valleys for rice production can be accomplished with relatively small-scale technologies that require moderate investments (Roberts, 1988). Thus, inland valleys are strategically important for realizing Africa's rice promise (e.g. Sakurai, 2006; e.g. Balasubramanian *et al*., 2007).

Wetlands, including inland valleys, are particularly important assets for the rural poor as they can fulfil many crucial services

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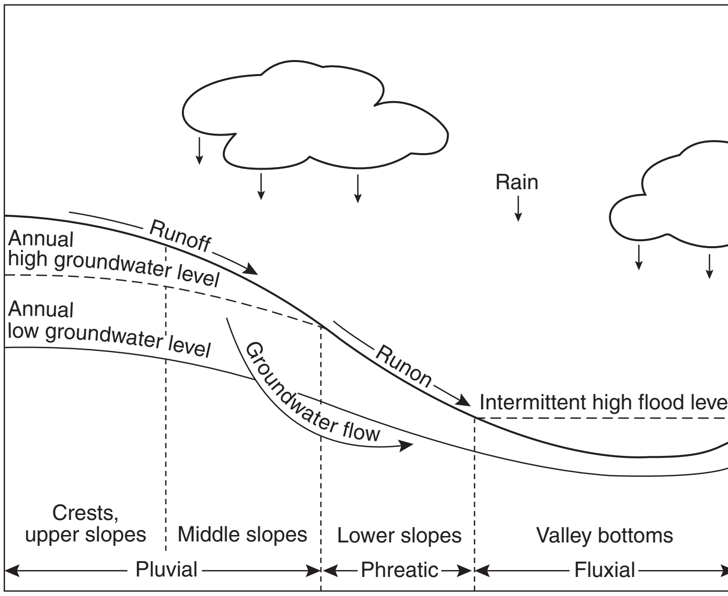

Fig. 22.1. Schematic landscape presentation of rice production environments along the upland–lowland continuum, and their hydrological regimes. (Adapted from Windmeijer and Andriesse, 1993.)

(Turner *et al.*, 2000). Apart from agricultural production, these ecosystems supply local communities with hunting, fishing, forest and forage resources (e.g. Roberts, 1988; Scoones, 1991; Adams, 1993) and they are local hot spots for biodiversity (Chapman *et al.*, 2001). As different inland-valley ecosystem functions may conflict with agricultural objectives, and because there are large area-specific differences in development suitability and risks, indiscriminate development should be avoided (McCartney and Houghton-Carr, 2009). Agricultural developments implemented without proper impact assessments can affect local livelihoods and environments negatively (e.g. Whitlow, 1983), as other functions, like biodiversity and water buffering, are inevitably lost, at least to a certain extent. Benefiting sustainably from the potential of inland valleys therefore requires aligning food production with biodiversity, soil and water conservation such that local rural livelihoods, and hence regional objectives of reducing poverty, are achieved while inherent ecosystem services of local and regional importance are safeguarded. This chapter focuses on how inland valleys can be efficiently and sustainably used to boost Africa's rice production.

Inland Valley Development Opportunities and Challenges

Ecological and economic importance

Inland valleys are not obvious ecosystems for agricultural production, and traditionally they have not often been used for agriculture in Africa (Adams, 1993; Verhoeven and Setter, 2010). This is partly because inland-valley bottoms are difficult to manage and they are also often associated with water-borne diseases such as bilharzia (schistosomiasis – *Schistosoma haematobium* and *S. mansoni*), river blindness (onchocerciasis – vector: *Onchocerca volvulus*, cause: *Wolbachia pipientis*), sleeping sickness (trypanosomiasis – *Trypanosoma brucei gambiense* or *T. brucei rhodesiense*) and malaria (e.g. *Plasmodium falciparum*, *P. malariae* and *P. ovale*) (Gbakima, 1994; Yapi *et al.*, 2005). Moreover, inland-valley exploitation is often complicated by unfavourable land-tenure arrangements (e.g. Fu *et al.*, 2010; Oladele *et al.*, 2010) or prohibitive customary beliefs. Despite such challenges, inland valleys have increasingly been put under production by several generations in areas where they exist. Global changes, such as population growth and

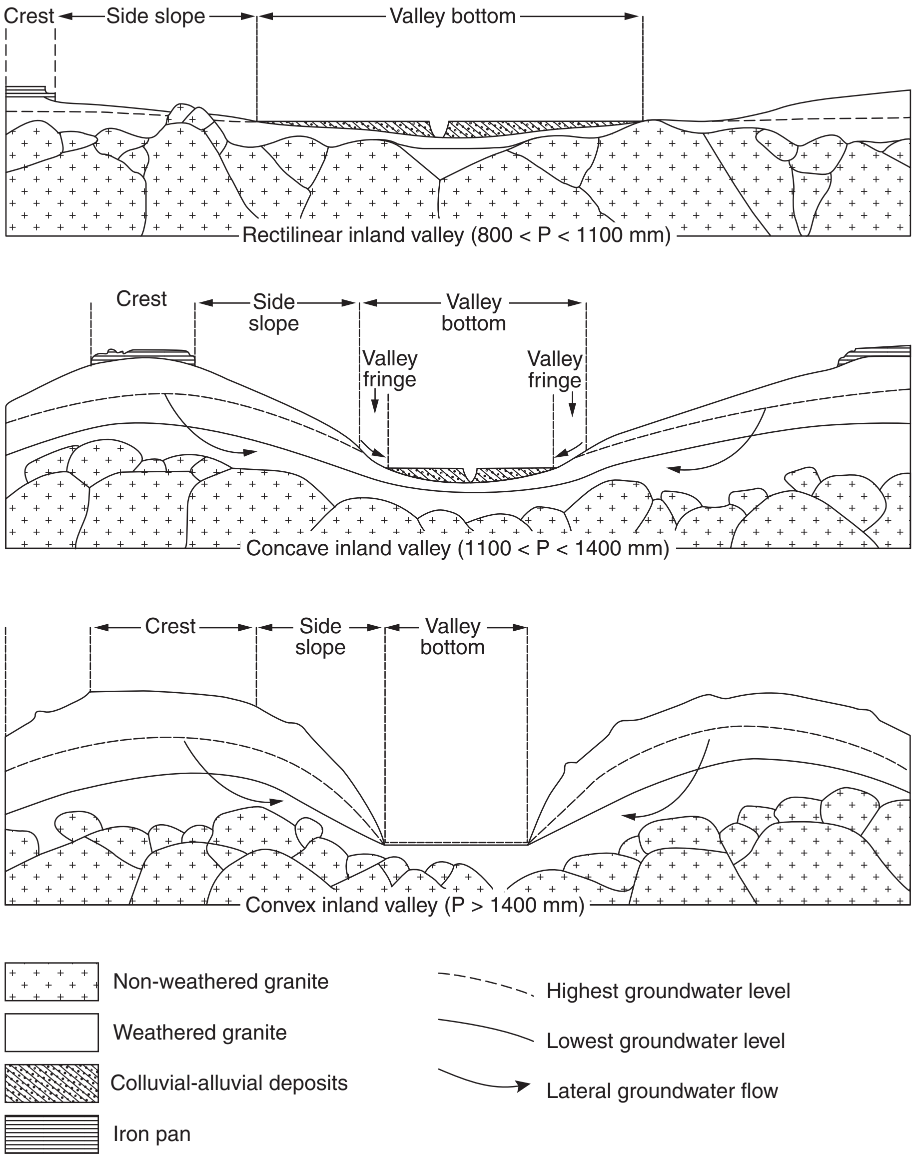

Fig. 22.2. The three most common inland-valley morphology types in West Africa, developed on granite–gneiss complexes under different rainfall regimes. (From Windmeijer and Andriesse, 1993, with permission from Alterra (Wageningen UR); adapted from Raunet, 1985.)

climate change, provide new incentives for inland-valley development. Valley bottoms and hydromorphic fringes generally have higher water availability and soil-fertility levels compared to the degraded upland soils (e.g. Andriesse *et al.*, 1994; van der Heyden and New, 2003), even though soil fertility can still be sub-optimal. A secure harvest from a wetland-produced crop becomes of invaluable importance in dry and unreliable agricultural environments (e.g. Scoones, 1991; Sakané *et al.*, 2011). Therefore, inland valleys are expected to become increasingly important in terms of food security in sub-Saharan Africa. However, climate change also poses a hydrological and therefore ecological threat to inland valleys. Ecological functioning

(a) (b) (c)

Fig. 22.3. Three inland-valley types: rectilinear inland valley Mwanza, north-east Tanzania (a), concave inland valley near Banfora, south-west Burkina Faso (b) and convex inland valley near Umuahia, south-east Nigeria (c). (Photos: J. Rodenburg.)

of inland valleys is sensitive to changes in water supply, and preventing degradation of these ecosystems requires adaptive management strategies (Erwin, 2009).

Inland-valley development also has an economic driver. About 10 million tonnes (Mt) of milled rice, approximately 40% of the annual regional consumption, is imported into Africa (mainly from Asian countries) each year, worth about US$5 billion (Seck *et al*., 2010, 2012). Regional production has, however, increased steeply since the early 2000s due to a declining availability of global rice stocks for export, and consequently an increase in regional farm-gate prices from an estimated average $285 per tonne in 1999 to $564/t in 2009 (based on available data from 20 rice-producing countries in sub-Saharan Africa; FAO, 2010). These significant price changes have encouraged many small-scale farmers to take up rice production. Increased inland-valley use for rice (and vegetable) production can, for instance, be observed around large urban centres as a result of increasing population density and the attraction of the urban market (e.g. Erenstein, 2006; Erenstein *et al*., 2006; Sakurai, 2006).

Inland valley development: water management

Developing inland valleys for effective rice-based production systems (i.e. cropping systems with rice as the dominant crop in association with other staple crops or vegetables) primarily means establishing water management structures – for example, to control flooding, optimize irrigation and conserve water for late-season use. As inland valleys in Africa are socio-economically and biophysically diverse and complex (Sakané *et al.*, 2011), the development of these landscapes for crop production requires a flexible and careful approach (e.g. Andriesse *et al.*, 1994). Every inland valley is unique in terms of its biophysical characteristics and there is no 'off-the-shelf' technology with a broad and indiscriminate application range. Therefore, technologies for inland valleys need to be locally adapted to be effective. Local morphology, hydrology and climate, for instance, will determine the depth, duration and frequency of flooding of the valley bottom, which in turn will determine the suitability of the valley bottom for rice-based production.

These physical conditions need to be considered in the design of the most effective water management system. There are five main systems: (i) the traditional random-basin system; (ii) the central-drain system; (iii) the interceptor-canal system; (iv) the head-bund system; and (v) the contour-bund system (Oosterbaan *et al.*, 1987). In the traditional random-basin system, the inland valley (the lower parts of the slope and the valley bottom) is partitioned into rectangular plots by small bunds. Farmers regulate the water level within these plots by opening the bunds. In the central-drain system, the valley-bottom drainage is improved by a central drainage canal. The remainder of the inland valley can still be divided by small bunds as in the traditional system. The interceptor-canal system has two interception canals along the valley fringes parallel to the central stream. Water from the central stream is carried to these interceptor canals by contour drains. Rice fields are flooded from the interceptor canals and these canals protect the rice fields from uncontrollable floods or runoff from the uplands and can ensure irrigation during short droughts. The head-bund system comprises head bunds that are built across the stream to create small reservoirs or ponds that can provide the rice fields with water through contour canals. In the contour-bund system, the valley bottom is divided by contour bunds across the stream. Within the space between two bunds (the rice field) the land can be levelled. Water from the stream is blocked by the contour bund and distributed over the field. Each contour bund has an outlet or spillway to enable water to flow from one field to another. To improve drainage of the lower fields, interceptor canals can be dug along the valley slopes (Windmeijer and Andriesse, 1993; Windmeijer *et al.*, 2002). The *sawah* systems in Madagascar represent a perfected example of a contour-bund system (Fig. 22.4 a and b).

Besides biophysical conditions, socio-economic and institutional factors should also be considered when inland valleys are to be developed. Like the biophysical environment, the socio-economic context in inland valleys is also diverse and often complex. Land tenure arrangements, for instance, vary between locations (e.g. Fu *et al.*, 2010), and within and between countries, ranging from ownership by families or individuals through single villages to whole states; state-owned tenure may discourage investment. Farmers working in the inland valleys do not often possess the required rights over the land and therefore do not always benefit from inland-valley development investments. Land-tenure arrangements also often have gender implications. Land is mostly owned by men but cultivated by women, particularly when the value of the land is low (e.g. low soil fertility, rainfed). After development, when the value of the land is raised, men may claim their rights again. Such social realities should be considered when inland-valley development projects are designed with the aim of benefiting the poor and empowering disadvantaged groups like women.

The Pegnasso inland valley, near Sikasso (south-east Mali), was developed in 1994 by Agence Française de Développement (AFD). The project deliberately opted for a partial development rather than a complete development to avoid land redistribution among farmers. The logic was that large investments would increase the land value and cause conflicts between men and women. Women who had used the land prior to the development would then risk being denied access to it, and would not benefit from the project. The partial development proposed and implemented consisted of the construction of a modest water-retention structure (Fig. 22.5a) and one central water inlet and irrigation canal to redirect water to the neighbouring farmers' plots. The plots were surrounded by simple bunds for within-plot water management. These modest improvements enabled farmers to make better use of the available water for a prolonged period of time and thereby increased rice productivity. Since rice production is mainly the responsibility of women, the project succeeded in its twin goals of benefiting the community while strengthening the position of women.

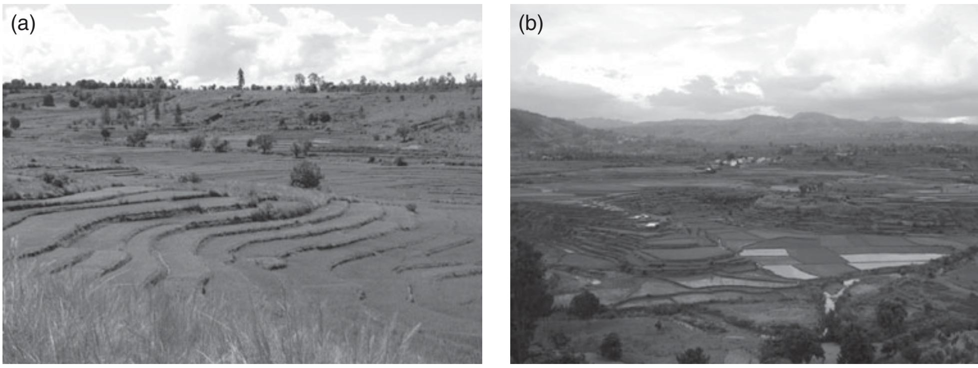

Fig. 22.4. Perfect examples of the contour-bund system: the *sawah* systems of Madagascar. (Photos: J. Rodenburg.)

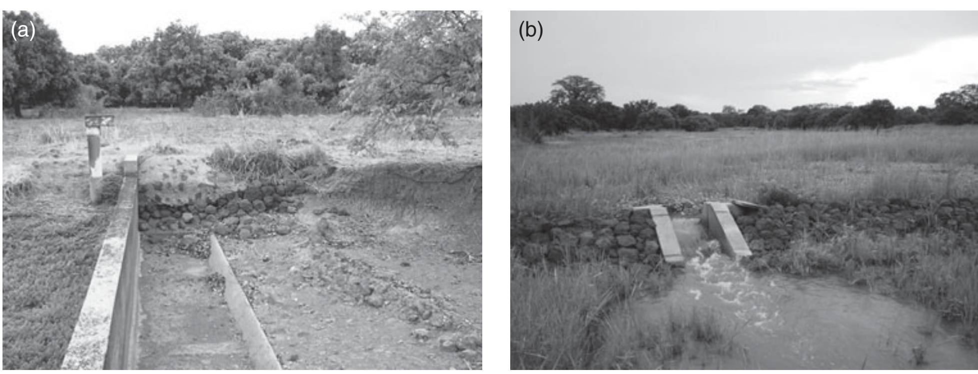

Fig. 22.5. Water-retention structure of the Pegnasso inland valley, southern Mali (a) and laterite-rock bunds with inlet at the Blétou inland valley, southern Burkina Faso (b). (Photos: J. Rodenburg.)

In the Blétou valley, near Blédougou (southwest Burkina Faso), rice production was limited by the lack of water retention. Water was only available during and shortly after a rainfall event, and quickly drained to lower parts of the larger catchment area. Droughts were the main production constraint and yields were erratic and low (less than 1 t/ha). A project funded by the Common Fund for Commodities (CFC) was implemented between 2006 and 2009 with the aim of improving the water availability in the part of the inland valley with the highest production potential. A contour-bund system consisting of small water-retention bunds along the contour lines, covered with impermeable cloth and laterite rocks, was installed (Fig. 22.5b). A community-participatory development approach was used, whereby plots would be distributed among farmers according to their participation in the construction of these water-management structures. The active participation of farmers in the construction reduced the costs of the investment and, more importantly, provided a basis for ownership by the community. The farmers participating in the bund construction (e.g. collection of laterite rocks) were predominantly female (104 women out of a total of 121 farmers) and they were indeed rewarded when the plots were partitioned upon completion of the inland-valley development. The plots were assigned in a participatory manner with group consensus, respecting individual time investments and disregarding gender or age.

Many water-management infrastructures built in the 1970s have been abandoned. Such failures are thought to have resulted from the lack of local community participation during the selection, design and planning of the developments (e.g. Dries, 1991; Maconachie, 2008), or because traditional local land-tenure arrangements were overlooked (Brautigam, 1992). In the 1960s and 1970s, many irrigation-scheme developments in West Africa were funded by public investment corporations and development projects. The Benin–China Cooperation, for instance, developed a total of 1400 ha of inland valleys and flood plains into medium-sized (25–150 ha) irrigation schemes by equipping them with water-retention structures, irrigation and drainage canals, inlets and outlets, cofferdams and small bridges. Most of these irrigation schemes are under-utilized or abandoned. Examples of abandoned schemes can be found in Bamè and Zommon in Zagnanado (Ouémé valley, Benin), where broken and silted water management structures are common (Fig. 22.6 a, b and c). One exception is the nearby irrigation scheme of Koussin-Lélé, where farmers grow rice on 106 ha of developed land using gravity irrigation. A comparison between this scheme and the schemes of Bamè and Zonmon (33 ha and 84 ha, respectively) showed that careful selection of the valley and local stakeholder participation in planning, design, implementation and use of the developments are prerequisites for successful development efforts (Djagba *et al*., 2013).

Production constraints

Estimated actual rice yields in inland valleys across Africa (1.4 t/ha according to Rodenburg and Demont, 2009) are much lower than the attainable yield in these production systems (>6 t/ha). The top ten production constraints in inland valleys, based on a survey among rainfed lowland rice experts in eight countries in West Africa, include biophysical (e.g. weed competition, lack of water control, poor soil

Fig. 22.6. Broken and silted water management infrastructures at Zommon, Benin. (Photos: J. Rodenburg (a and b); P. Kiepe (c).)

fertility) and socio-economic and institutional factors (e.g. land tenure and lack of inputs, labour and credit), and human health problems (Thiombiano *et al.*, 1996; Fig. 22.7). Overarching biophysical production constraints in the ecosystem (from hydromorphic fringes to intensified lowlands) are weeds, pests and diseases, nitrogen and phosphorus deficiencies, and iron toxicity (Table 22.1).

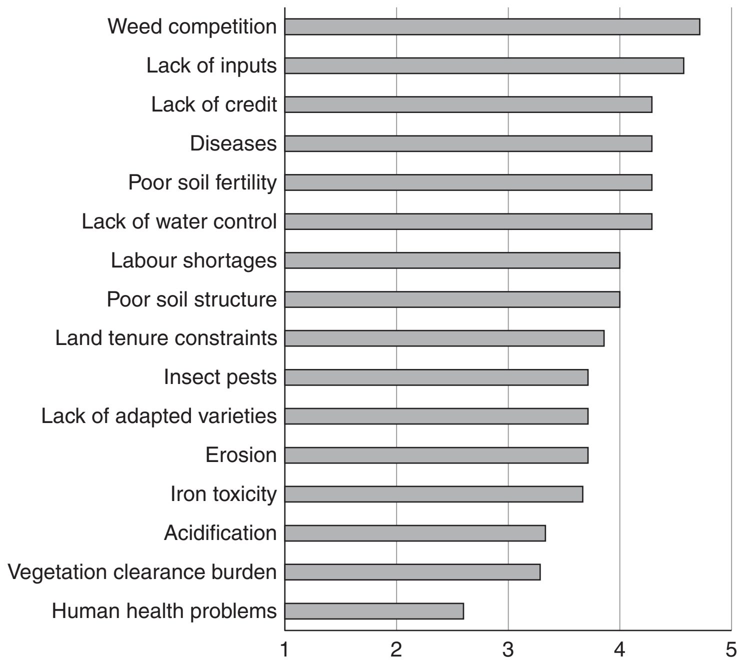

Fig. 22.7. Ranking of constraints[a] to the use of inland valleys for rice production as perceived by rainfed-lowland rice experts from eight countries in West Africa in 1993. (Adapted from Thiombiano *et al.*, 1996.)
[a]Rating of constraints on a scale of 1 (not important) to 5 (very important).

Table 22.1. Rice-growing ecosystem characterization (water supply, agroecological zone, and main biophysical production constraints). (Data from Andriesse *et al.*, 1994; Thiombiano *et al.*, 1996; Kiepe, 2006; Wopereis *et al.*, 2007.)

Ecosystem	Upland	Hydromorphic fringes	Lowland	Intensified lowland	Irrigated lowland
Main water supply	Rainfall	Rainfall + water table	Rainfall + water table + unregulated floods	Regulated floods	Full irrigation
Agroecological zones	Guinea savannah to humid forest	Guinea savannah to humid forest	Sudan savannah to humid forest	Sudan savannah to humid forest	Sahel to humid forest
Main biophysical production constraints	Drought, weeds, pests and diseases, P and N deficiencies, soil erosion, soil acidity	Drought, weeds, pests and diseases, P and N deficiencies, soil erosion, soil acidity, iron toxicity	Drought/flooding, weeds, pests and diseases, P and N deficiencies, iron toxicity	Drought/flooding, weeds, pests and diseases, P and N deficiencies, iron toxicity	Weeds, pests and diseases, salinity/alkalinity, P and N deficiencies, iron toxicity

Weed competition is a major constraint. Dominant weeds in inland-valley rice are grasses like *Echinochloa colona*, *E. crus-pavonis*, *Oryza longistaminata*, *O. barthii*, *Ischaemum rugosum* and *Leersia hexandra* and sedges such as *Fimbristylis littoralis*, *Bolboschoenus maritimus*, *Kyllinga pumila*, *Cyperus difformis* and *C. iria*. Frequently encountered broad-leaved weeds in inland valleys are *Sphenoclea zeylanica*, *Ludwigia abyssinica*, *Heteranthera callifolia* and *Ipomoea aquatica* (Rodenburg and Johnson, 2009; Rodenburg and Johnson, Chapter 16, this volume). Another emerging problem in inland valleys across Africa, particularly the ones with poor water control, is the parasitic weed *Rhamphicarpa fistulosa* (Rodenburg *et al*., 2010). This facultative parasitic weed, from the same family as the better known *Striga* spp., can grow independently like any of the other weeds mentioned, but in the vicinity of a suitable host plant like rice, it can develop into a parasite by establishing underground root-to-root connections, extracting host-derived carbohydrates and nutrients (Ouédraogo *et al*., 1999). Parasitic infection causes crop yield losses in infested fields in excess of 60%, and fields are sometimes abandoned by farmers because of high infestations (Rodenburg *et al*., 2011).

Other important biotic production constraints to rice in inland valleys are insect pests such as African rice gall midge, stem borers and rice bugs (see Nwilene *et al*., Chapter 18, this volume), and diseases such as *Rice yellow mottle virus*, leaf blast, bacterial leaf blight and brownspot (see Séré *et al*., Chapter 17, this volume); rats and birds can also cause significant yield losses (Balasubramanian *et al*., 2007). African rice gall midge is common in West and East Africa. It damages rice tillers, and each 1% of damage is estimated to result in 2% of yield loss – final yield losses can reach 65% (Nacro *et al*., 1996). *Rice yellow mottle virus*, endemic to Africa, is transmitted by beetles (order Coleoptera, family Chrysomelidae, e.g. *Chaetocnema pulla*, *Sesselia pusilla*, *Trichispa sericea* and *Dicladispa viridicyanea*) and can lead to total yield losses (ranging from 5% to 100% depending on agro-climatic zone) in rainfed lowland rice in Africa (Kouassi *et al*., 2005).

Soil fertility in inland valleys is often far from optimal for sustainable and profitable crop production. While soil fertility varies across agroecological zones (Issaka *et al*., 1997), soil sampling in inland valleys across West Africa revealed low to very low levels of nitrogen, available phosphorus, pH, CEC and total carbon (Issaka *et al*., 1996), deficiencies in micronutrients like sulfur and zinc (Buri *et al*., 2000; Abe *et al*., 2010) and poor clay mineralogy (Abe *et al*., 2006). A problem commonly associated with low soil fertility in inland valleys is iron toxicity (Becker and Asch, 2005; Audebert and Fofana, 2009), a complex nutrient disorder caused by excessive iron in the soil solution under specific but typical waterlogged conditions of inland valleys (Narteh and Sahrawat, 1999). A plant growing under such conditions takes up more soluble iron (Fe^{2+}) than it needs, resulting in iron accumulation in the leaves beyond the critical level, shown by reddish-brown or yellow coloration (leaf 'bronzing') and high leaf mortality, which in turn negatively impacts crop yield (e.g. Becker and Asch, 2005). Direct and indirect effects of iron toxicity can lead to 40–45% rice yield reductions in lowlands, depending on the extent of the problem, water, soil and crop management (e.g. cultivar choice), and the availability of other soil nutrients (Audebert and Fofana, 2009).

Ecosystem functions of inland valleys

Inland valleys deliver a range of associated ecosystem functions (Adams, 1993). Inland valleys are important for local flood and erosion control, water storage, nutrient retention, stabilization of the micro-climate, as well as for recreation and tourism and for retrieving water, clay and sand for crafts and construction. While the main crop is often rice, inland valleys and their fringes are used to grow a variety of other crops (e.g. maize, vegetables, fruit trees), and are also often used for cattle grazing (Fig. 22.8) – particularly during the dry season when the water table recedes below the soil surface of the valley bottoms, but with sufficient residual moisture to support crop growth. Furthermore, these environments provide important forest, wildlife and fisheries resources, and contribute to biological diversity as well as local cultural heritage (Dugan, 1990; Adams, 1993). The water resources available in inland valleys are often used by rural communities to fulfil a variety of daily household needs (Fig. 22.9 a and b). Besides the water resources, biological diversity

Fig. 22.8. Multiple uses of inland valleys: rice production is often combined with fruit trees (background) and small-scale vegetable and maize production and free-browsing cattle (foreground). Buganda, near Mwanza, north-west Tanzania. (Photo: J. Rodenburg.)

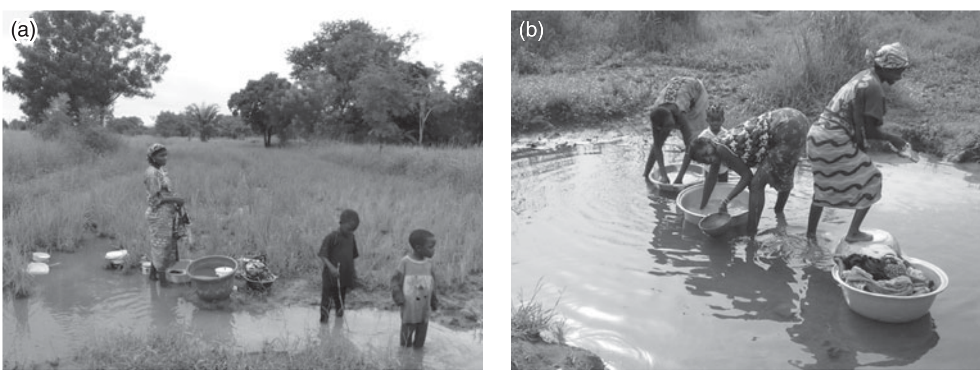

Fig. 22.9. Using local inland-valley water resources for daily household needs in Benin (a) and Burkina Faso (b). (Photos: J. Rodenburg.)

of inland valleys is probably among the most important functions for the local communities: inland valleys are important locations for the collection of non-agricultural plant resources, and local communities have considerable knowledge of the useful plant species, their use, abundance and collection places (Rodenburg *et al.*, 2012).

Because of their multifunctional character, inland valleys are attractive for exploitation and therefore vulnerable to degradation. The economic opportunities of inland valleys have been widely recognized and investments have been made to make these areas more accessible and profitable. Indiscriminate development of these vulnerable environments, however, will lead to degradation of the natural resources they harbour, and thereby jeopardize their unique and diverse ecosystem functions (e.g. Dixon and Wood, 2003). For a long time, the important functions of wetlands such as inland valleys for local communities have often been ignored in policy planning (Silvius *et al.*, 2000). Understanding the use and management of ecosystem functions by local communities is the first necessary step in generating recommendations for their sustainable use (Rodenburg *et al.*, 2012).

Different ecosystem services do not always conflict. For instance, while local community members in Togo and Benin perceive that agriculture is an important cause of a decline in plant biodiversity, agricultural fields were also considered as one of the most important locations for finding useful non-cultivated plants (Rodenburg *et al.*, 2012). Farmers recognize the useful weed species during weeding and leave them untouched or keep them apart after uprooting (see references in Rodenburg and Johnson, 2009). Useful species (predominantly trees) are also often maintained during field clearing (e.g. Leach, 1991; Madge, 1995; Kristensen and Lykke, 2003). In fact, this is a common strategy to cope with declining forests

(Shepherd, 1992). Other strategies, observed by Rodenburg *et al.* (2012) around inland valleys in Togo and Benin, include the establishment of a community garden with (about 300) useful species and the conservation of a small community forest. These observations show that local communities that depend on natural resources in and around inland valleys are able to exploit these landscapes synergistically, balancing agricultural production with biodiversity conservation, use and management. However, aligning the multiple interests in inland-valley resources requires participation of local communities in any development or conservation initiative, as they depend entirely on these natural resources. As primary stakeholders, their knowledge and needs should be taken into account when the objective is to achieve sustainable land use in inland valleys.

Turning Inland Valleys into Africa's Food Baskets

The Inland Valley Community of practice

The Consortium for the Sustainable Use of Inland Valley Agro-Ecosystems in Sub-Saharan Africa (Inland Valley Consortium, IVC), convened by the Africa Rice Center (AfricaRice) and composed of ten West African national agricultural research systems (NARS) and a number of international (IITA, ILRI, IWMI, FAO and CORAF/ WECARD[2]) and advanced research institutes (CIRAD,[3] Wageningen University), was founded in 1993 with the objective to develop, in a concerted and coordinated manner, technologies and operational support systems for intensified but sustainable use of inland valleys in sub-Saharan Africa. IVC uses a multidisciplinary scientific approach aiming at: (i) determining the agroecosystem potential of inland valleys, based on an integrated characterization and classification; (ii) identifying means to achieve this potential by targeting research activities, by developing technological innovations and by transferring them to the plots, landscapes and watersheds; and (iii) capitalizing on available resources such as inland-valley ecosystems, inland-valley developments and local knowledge and innovations. IVC projects since the early 2000s have focused on rehabilitation of abandoned or sub-optimal functioning inland-valley systems; participatory valuation of inland-valley ecosystem goods and services; sustainable productivity improvement for rice, targeting water and weed management; exploring possibilities for the integration of rice–fish and rice–vegetable production; and enhancing the productivity and competitiveness of inland-valley lowlands through sustainable intensification and diversification and product value chain development, while conserving land and water resources. In 2011, IVC became the Inland Valley Community of practice, which better reflects its new *modus operandi*.

A strategy for sustainable inland valley selection, development and use

Based on almost 20 years of experience under the umbrella of IVC, complemented by insights gained from other initiatives, a strategy for inland-valley selection, development and use can be outlined. While regional food security is an important goal, and inland-valley development could be an effective way to achieve this, the selection, development and exploitation of these environments should be approached with care. Not all inland valleys are necessarily suitable for crop production (e.g. Kotze, 2011; Sakané *et al.*, 2011). If only 9.1% of all inland valleys in Africa were set aside for rice production (i.e. 17.30 Mha) and average rice productivity could be raised by 1 t/ha (from 1.4 to 2.4 t/ha, which is feasible according to Becker and Johnson, 2001), this would produce 41.5 Mt of paddy, about the same as the current sum of total rice production and imports in Africa.[4] Hence, only a fraction of the total inland-valley area should suffice to produce enough rice to feed the entire continent and the remainder should be safeguarded for other purposes such as pastoralism, biodiversity and wildlife sanctuaries, and natural (excess) water buffers. This strategy would, however, require systematic approaches and methodologies for: (i) selecting the 'best-bet' (most suitable and low-risk) inland valleys for agricultural development to avoid investment failures or unnecessary destruction of wetlands; (ii) land-use planning within the inland valley;

(iii) designing and implementing the 'best-fit' water management development infrastructure; and (iv) optimizing crop management practices for increased crop productivity.

Inland valley selection and land-use planning

Potential inland valleys (for agricultural development) can be identified with GIS (geographic information system) and remote-sensing tools (e.g. Thenkabail and Nolte, 1996; Gumma *et al.*, 2009; Chabi *et al.*, 2010). The necessary on-the-ground evaluation and confirmation ('ground truthing') can be done at the semi-detailed level using the Integrated Transect Method (ITM) proposed by van Duivenbooden *et al.* (1996). Based on geo-morphological, hydrological, soil and land-use characteristics, different inland-valley types can be distinguished, which will be helpful in identifying their (potential) 'best-bet' use (e.g. Andriesse *et al.*, 1994; Sakané *et al.*, 2011). Alongside these biophysical and agronomic assessments, socio-economic variables, such as market access and population densities, are important for feasibility studies to assess which valleys can be developed for agriculture (e.g. Narteh *et al.*, 2007). The 'best-bet' inland valleys for rice-based production systems should score high on (agricultural) production and marketing potential and low on environmental and social risks, and preferably also low on other ecosystem functions such as biodiversity. Hence, a thorough assessment of the valley's economic value for local communities, including direct, indirect and non-use benefits is required (Scoones, 1991). In addition, local stakeholders should play a role in the land-use planning within a selected inland valley. So-called multi-stakeholder platforms (MSP) could be created to reach consensus on economic, social and environmental gains and risks, and to identify hot spots for specific ecosystem services within the inland valley under consideration.

Inland valley development

After selection and land-use planning, the actual development can start, consisting mainly of clearing of vegetation and establishment of water management structures to increase water control. As mentioned above, various physical factors, such as the size of the catchment area, the valley morphology and soil texture (determining hydrological behaviour), need to be considered for the design of the most suitable water management system. This requires a thorough diagnostic study on the spatial and dynamic water movements within the valley (Wopereis *et al.*, 2007) and in-depth discussions with the farming community to ensure full buy-in of the community and that land tenure issues are identified and solved beforehand. Discussions on the land- and water-development options that could be put in place should also consider consequences in terms of water availability for downstream users.

To aid in deciding what water control infrastructure to develop, the diagnostic interactive tool called DIARPA (*diagnostic rapide de pré-aménagement*) may be used (Lidon *et al.*, 1998). This rapid hydraulic diagnosis method works as a decision tree and helps to assess the 'best-bet' type of intervention at a given location and a given level of investment, to optimize agricultural production with limited hydraulic risks. Explanatory indicators for water dynamics are categorized under topographic, pedological and hydrological indicators and have been selected, characterized and validated for use as an index for the selection of the best interventions (Table 22.2).

The proper functioning, management and maintenance of the water control requires the actual users (farmers) to understand the basic principles. They should be involved in the development of water control infrastructure as much as possible to enable them to acquire ownership. As in the case of the Blétou valley (south-west Burkina Faso) (see 'Inland valley development: water management' above), information on the extent of participation in the development work provided by an individual stakeholder can be used to guide plot partitioning once the inland-valley development is finalized, and the personal time investments at these stages will also ensure user commitment to future management and maintenance of the development structures, and thereby benefit the sustainability of the inland-valley production system. After completion of the water management structures, a performance assessment, similar to the one suggested by Dembele *et al.* (2011), should be carried out on a seasonal basis to enable farmers to make necessary adjustments and thereby further improve water productivity.

Table 22.2. DIARPA indicators and their threshold values for each type of intervention. (Adapted from Legoupil *et al*., 1998.)

	Type of intervention					
Indicator	Contour bunding	Contour bunding with spill over	Water-retention dykes without seepage barrier	Water-retention dykes with seepage barrier	Diversion barrier to diffuse flow	Diversion barrier for the re-infiltration and restocking of the water table
Pedological						
Permeability (m/s)	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
Impermeable layer depth	NI	NI	NI	<2 m	NI	NI
Topographic						
Average longitudinal slope of the valley	<1%	<1%	<0. 5%	<0. 5%	<1%	<1%
Flow axis	No flow axis	NI	Noticeable flow axis	Noticeable flow axis	Narrow flow axis	Narrow flow axis
Hydrological						
Peak flow by metre of valley-bottom width	3×10^{-3} m^3/s	25×10^{-3} m^3/s	0. 25–0. 6 m^3/s	0. 25–0. 6 m^3/s	50×10^{-3} m^3/s	50×10^{-3} m^3/s
Depth of the valley-bottom groundwater flow at the start of the dry season	NI	NI	NI	NI	NI	<2 m

NI, not important.

The first steps towards improved water management in inland valleys in Africa will entail the construction of main and secondary drainage pathways and identification, bunding and levelling of individual fields with minimal soil disturbance. Slightly sloping valleys will be divided into relatively large bunded fields, whereas valleys with steep slopes will be divided into smaller, 'terraced', bunded fields. Worou *et al*. (2013) provide guidelines for the development of such 'partial water control' structures that can be constructed entirely by the farming community. Farmers involved in the Japan-funded SAWAH-IV project implemented by AfricaRice and partners in Benin and Togo obtain very good results in inland valley settings, introducing such relatively simple, low-cost water management structures (drainage canal development, bunding, levelling) that can be constructed and maintained entirely by farmers themselves. Use of power tillers is not essential at the first stage for land development and rice cultivation, but their introduction can substantially speed up land development once farmers are familiar with the technique. Similar observations were reported in Ghana by JICA staff (K. Saito, Cotonou, Benin, 2013, personal communication).

The introduction of such very simple water management structures will already lead to substantial yield gains (1–2 t/ha), especially if accompanied with good crop management practices (see below).

Locally adjusted production strategies

Local constraints need to be tackled in order to benefit from the inherent production potential of the inland valley.

Relevant modules of the *Curriculum for Participatory Learning and Action Research (PLAR) for Integrated Rice Management (IRM)* can be used to raise rice productivity. PLAR-IRM was developed by AfricaRice, based on the insight that a locally adapted and integrated approach is required to increase rice productivity in inland-valley production systems in Africa (Wopereis and Defoer, 2007). It is essentially a farmer-participatory, step-wise approach to put inland valleys under rice production using good agricultural practices (Defoer *et al.*, 2004; Wopereis *et al.*, 2007; see also Defoer and Wopereis, Chapter 31, this volume).

Following improved water management, key factors for raising productivity in inland valleys are weed and soil-fertility management (Wopereis and Defoer, 2007) and to a lesser extent pest and disease control (Table 22.1). However, the order of importance of production constraints needs to be assessed locally for each inland valley. Data collected during the detailed characterizations should be helpful in this respect (e.g. Sakané *et al.*, 2011). The PLAR-IRM curriculum also provides a useful method to identify key production constraints, as well as locally researchable issues. PLAR-IRM further stimulates farmer experimentation in order to test 'what works best' under the given local (biophysical and socio-economic) conditions, using an integrated management approach. The available modules of the PLAR curriculum provide guidelines for such approaches.

Through integrated water, soil-fertility and weed management in inland valleys, rice yields can be increased considerably. Bunding, puddling (if possible) and levelling, for instance, facilitate water management and decrease weed competition – as many weed species are not well adapted to permanently flooded conditions (e.g. Kent and Johnson, 2001) – and generally increase nutrient-use efficiencies, especially in well-drained fields. These relatively simple technologies have been shown to increase rice yields by 40%, and reduce weed infestation by 25% across agroecological zones (Becker and Johnson, 2001; Toure *et al.*, 2009). Yield improvements can then be achieved by using improved rice cultivars. For instance, some NERICA cultivars (New Rice for Africa) adapted to lowland conditions have an inherent high weed competitiveness (Rodenburg *et al.*, 2009) and high yield potential (Sié *et al.*, 2008).

Concluding Remarks

Inland valleys are the future food baskets of Africa and play a pivotal role in realizing the region's rice promise. Based on nearly 20 years of experience with work carried out by IVC, a locally adapted, step-wise and bottom-up approach for site selection, land-use planning, water-management design and implementation, and crop management is proposed for the sustainable exploitation of the inland-valley potential. This approach includes: (i) the selection of 'best-bet' inland valleys using multi-scale characterizations based on climate and geomorphological data and using GIS and remote-sensing tools followed by semi-detailed and detailed typologies using ITM and socio-economic assessments; (ii) a stakeholder-participatory land-use planning within the inland valley, based on the earlier characterizations and using MSPs; (iii) participatory inland-valley development (e.g. clearing, levelling and construction of water management structures) following relevant modules of the PLAR curriculum and the pre-development diagnostic tool DIARPA, followed by regular performance assessments of the water-control system; and (iv) improving rice productivity and resource-use efficiency through farmer-participatory identification of local production constraints and adapting management practices following the principles of IRM using PLAR.

It is essential to use systematic analysis approaches for the selection of 'best-bet' inland valleys for rice-based production systems, as only a fraction of the available inland valleys in Africa would need to be put under production in order to achieve regional self-sufficiency in rice. The remaining inland valleys could then be safeguarded to fulfil other ecosystem services. However, for this strategy to be effective, conservation regulations and monitoring and evaluation mechanisms need to be established to help protect those inland valleys that are either too vulnerable (to, e.g., soil and water degradation or social conflicts) or too valuable (because of other ecosystem functions such as biodiversity) to be subjected to agricultural development. Selection of 'best-bet' production valleys should be based on both biophysical and socio-economic criteria and be broadly supported by the local communities depending on them. The same approach is proposed for the identification of locations within the inland valley that should be used for crop production and those that should continue to fulfil other ecosystem functions. This again requires involvement of local stakeholders.

Following these steps, the next challenge is the actual development. The right choice of water-management system is of vital importance and depends largely on the valley morphology and the local soil and hydrological characteristics. Development and implementation of such water management systems and the agricultural production practices following such development should not negatively impact the water quality and availability downstream. For the actual crop production, high-yielding and stress-resistant lowland rice cultivars and locally adapted and integrated crop management practices are required. Postharvest facilities for drying, threshing, milling, storage and transport should also be included in inland-valley development plans.

Full local stakeholder participation in all stages, from decision making to development and implementation, should result in consensus on the selection and land-use plans of inland valleys, the implementation of broadly supported interventions, and flexible, locally adaptable and acceptable solutions to the numerous technical, socio-economic and institutional constraints encountered by resource-poor farmers working in the inland-valley systems of Africa. This should create a solid basis for the required sustainable use of inland valleys and for turning these valuable resources into Africa's food baskets.

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Notes

[1] Based on FAO and national databases, in particular FAO TERRASTAT (2003).
[2] IITA, International Institute of Tropical Agriculture; ILRI, International Livestock Research Institute; IWMI, International Water Management Institute; FAO, Food and Agriculture Organization of the United Nations; CORAF/WECARD, West and Central African Council for Agricultural Research and Development.
[3] CIRAD, Centre de coopération internationale en recherche agronomique pour le développement.
[4] 10 Mt of milled rice was imported into Africa in 2010, this translates in to 16.7 Mt of paddy (using a conservative paddy–milled rice conversion rate of 60%); in the same year an estimated 24.7 Mt of paddy was produced in Africa (FAO, 2012), the sum is 41.4 Mt of paddy.

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