14 The arid pastoral and oasis farming system

Key centres for the development of trans-Saharan economies

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Key messages

- Arid pastoral and oasis activity systems are located in the heart of vast arid areas. They combine agroforestry systems intensively managed with highly scarce water resources as well as the management of surrounding Saharan grazing areas of extreme variability and very low productivity.
- Oases are not isolated, insular systems in the middle of desert; they are integrated in trans-Saharan routes and networks which have allowed various commercial exchanges (livestock, agricultural products, salt, etc.) for time immemorial.
- Oases display a large diversity of situations in terms of natural resources, and their social and economic resource management dynamics range from high productivity to decline.
- They are strategic areas where social and economic development should be reinforced in the face of the growing control of the economy by criminal groups observed in the last ten years.
- Trans-Saharan economies should be revived through the enhancement of commercial linkages by promoting security as well as through water and oasis agroecological innovations.
- Development of economic activity specifically geared for the youth and new, more attractive economic production models should be promoted.

Summary

The arid pastoral and oasis farming system represents over 30 per cent of Africa's land area. It extends over seventeen countries in northern, western, eastern and southern Africa. The system features oases that are intensively cultivated using irrigation in desert or highly arid areas, and livestock husbandry on natural vegetation limited to the oases and their surroundings. Traditionally the system was centred on oases north of the Sahara. However, recent socioeconomic changes (economic control by criminal groups, illegal trafficking, insecurity, collapse of trans-Saharan tourism) and climatic trends (temperature rise, late onset of rains, floods) are creating a radically new situation in Sahelian zones as oases become a place for retreat, refuge and security, where inhabitants grow vegetables. The extensive livestock system involves small ruminants (goats) together with camels.

To make the best use of available water, oasis farmers combine several types of crop and animal production, but the level of intensification and productivity varies. Poverty is common and often severe, especially after droughts.

From the simplest to the most complex, all oasis systems are in tenuous balance because they are subject to multiple constraints. Population pressure has caused progressive fragmentation of family plots, which is constraining oasis development, along with the very rigid land tenure systems. Other threats include weak governance, insecurity linked to the control of extremist and criminal groups, the lowering of groundwater tables, and dune encroachment. For these reasons, governments urgently need to assist communities in establishing rules for sound natural resource management and conservation, and to provide financial support to allow access to factors of production such as animal traction, solar-operated water extraction, transport and market infrastructure, improved water points and especially, provide technical support to enable farmers to increase system productivity.

Introduction

The arid pastoral and oasis farming system is composed of oases or water points in desert or arid areas that are intensively cultivated using irrigation and are associated with a pastoral system in the periphery. The system is found in north Africa (Morocco, Algeria, Tunisia, Libya, Egypt), the northern regions of the Sahelian countries (Mauritania, Mali, Niger, Chad, Sudan), eastern Africa (Ethiopia, Eritrea, Djibouti, and Somalia), and parts of southern Africa (Angola, Namibia and South Africa) (Figure 14.1).

The system exists where surface water or shallow groundwater makes the ecosystem favourable to human activity, among large areas that are otherwise either unsuitable for human activities as is the case for the large Ténéré erg, the Djado, Aïr, Tibesti, and Ennedi mountains, or areas that have seasonal grazing resources which could not be sustained without water from the oasis (Assaba mountain range, series of Manga depressions, Tamourt Hodh, el Gharbi and el Chargui in Mauritania). Availability of permanent water in the oasis makes the use of vast surrounding expanses of highly unpredictable grazing lands possible. Agricultural activities are confined to fossil valleys, oases[1] and depressions[2] (where there is available water) (Figure 14.2). For example, the Aïr and Kawar in the Niger Republic, and the Adrar in Mauritania and Mali, are valleys in the desert where the watertable is shallow and where there is running water from the mountains.

The oasis system evolved in conjunction with other systems in surrounding or distant areas. In some countries, surrounding arid pastoral areas are a source of livestock feed for the oasis component of the system. In other regions, exchange relationships and interdependencies are established between oases and pastoral and agropastoral systems. Here, products such as onion, cabbage, garlic, dates and salt from oases are supplied to urban centres further south, and trade in the opposite direction brings manufactured goods, cereals and animals from pastoral areas.

In the north, desert oases have historically been essential, strategic locations in trans-Saharan routes: the most famous are Bilma (Niger), Ouardane (Mauritania), In Salah (Algeria), Taoudeni (Mali), Iférouane, Chinguetti (Mauritania), Kufra, and Murzuk (Libya). Beginning in the tenth century, these caravan roads were regularly used and contributed to a strong cultural and commercial partnership between the two sides of the Sahara. Societies who occupied these oases used them as a base for controlling vast land areas and the trans-Saharan trade (Figure 14.3).

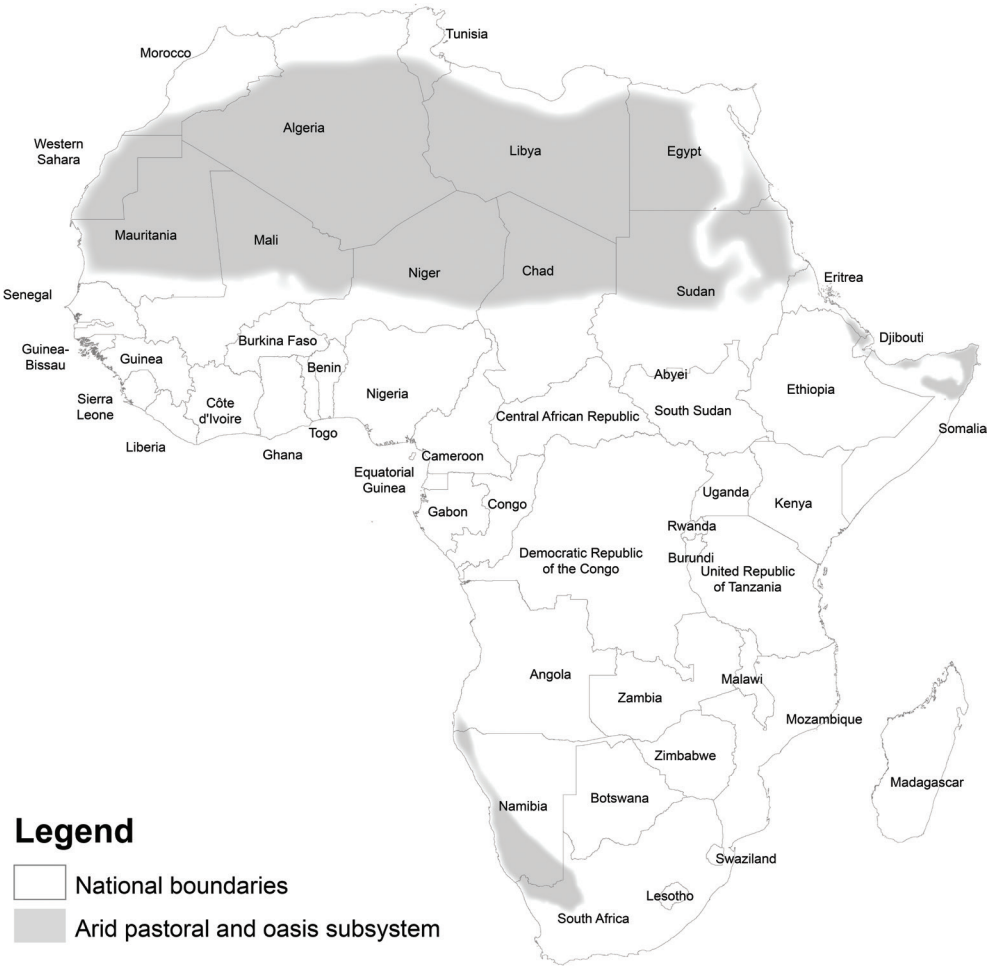

Figure 14.1 Map of the arid pastoral and oasis farming system in Africa.
Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Despite their geographical isolation in vast arid or desert areas, oases are not confined environments, and the economic viability of the system depends on relations with the outside. For several centuries, income from trade caravans and taxation was higher than from oasis production; the oasis farming mainly aimed to contribute to the food needs of the oasis communities and travellers. Thus some oases have known great economic prosperity (oasis of Kawar, Niger). With the development of other means of communication and exchange including maritime transport, oases have lost the economic benefits associated with their relay function on caravan routes. Thus, they have experienced periods of decline.

In southern Africa, the system has the same complementarity between water points (surface or groundwater in shallow aquifers) where irrigation is practised and vast surrounding areas where livestock graze. In Namibia, farming revolves around the availability

Figure 14.2 Cereal cropping in oasis depressions of Goudoumaria, Niger.
Source: Institut de Recherches et d'Applications des Méthodes de développement (IRAM).

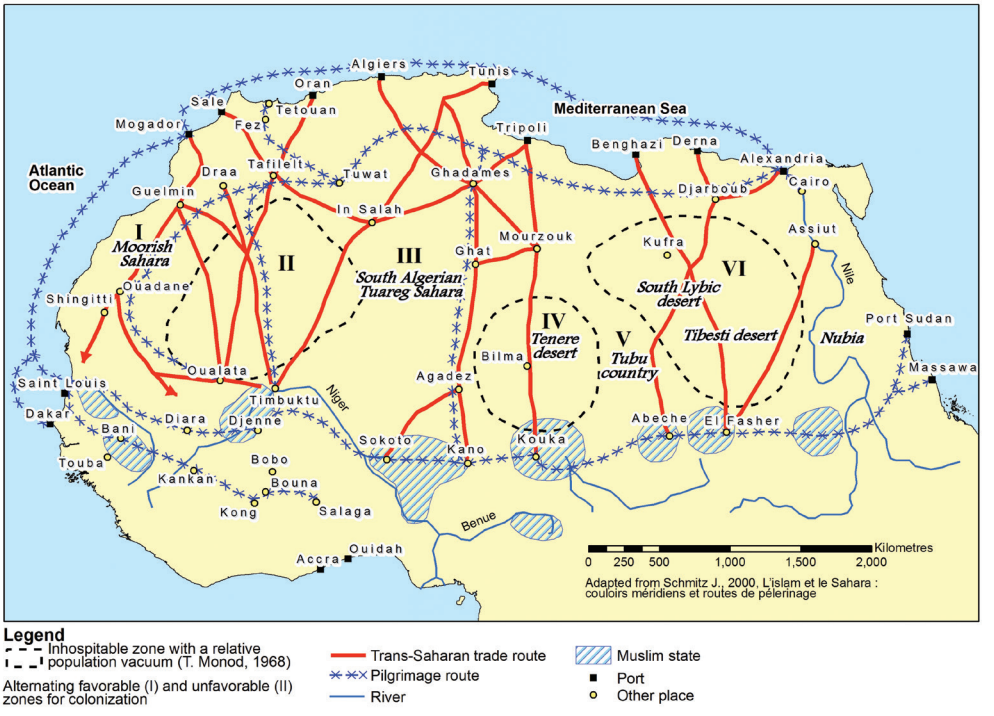

Figure 14.3 Map of trans-Saharan routes and oases.

of water. Homesteads and kraals are located at water sources. Nowadays, these generally include boreholes using windmills or diesel pumps to supply water to reservoirs and drinking troughs. As farm animals need to drink at least once a day, their foraging is restricted to feeding areas within walking distance of water points. Rainfall is insufficient for grass except after sporadic good rains, and sheep and goats depend on browsing the relatively abundant woody and succulent shrub vegetation (Mendelsohn 2006). Before the introduction of permanent farms in the late 1910s, pastoral nomads moved their livestock and homes between seasonal water sources and grazing areas.

Overall description of the farming system and subsystems

This farming system covers about 30 per cent of the continent. However, agricultural activities are confined to spatially limited, suitable environments such as fossil valleys, oases and depressions (Figure 14.2). In 2015, the farming system (north and sub-Saharan Africa) hosted an estimated 67.2 million small ruminants, 13.8 million cattle, 6.9 million camels, 0.1 million pigs and 252 million chickens.

Human population in this farming system, estimated at 16.4 million (Table 14.1), is made up of various ethnic groups. Major groups include Tuareg, Kanuri and Tubu in the Niger Republic; Tubu (Teda and Daza) and Zaghawa in Chad; Moors and Toucolors in Mauritania; Tuareg and Arabs in Mali; Rufa'a, Kababish and Baggara in Sudan; Afar and Dankali in Ethiopia; Somali in Somalia; and Rendille and Sukama in South Africa. Their main activities include agriculture, animal rearing and caravan trading.

The extent of the farming system thus includes the central and irrigated core, as well as areas where cropping, animal husbandry (on vast areas of arid pasture land with mobile herds and herdsmen), salt extraction, trade and communication take place (Godard et al. 1990; Retaille 1986; Riou 1988). The vitality or decline of the system depends on this overall set of activities.

Table 14.1 Basic system data (2015): arid pastoral and oasis farming system

Item	*Data*
Total human population (million)	16.4
Agricultural population (million)	7.6
Total area (million ha)	915
Cultivated area (million ha; % of total area)	0.35; 0.038
Irrigated area (million ha; % of cultivated area)	0.23; 67
Total livestock population (million TLU)	23.3
Major agroecological zone	Tropical warm arid
Length of growing period (average, days; core range, days)	12; 0–30
Access to services	Very low
Distance to 50k market (average, hr; core range, hr)	20.8; 10–10+
Agricultural population density (persons/total area; persons/cultivated area)	0.008; 21.7
Livestock density (TLU/total area; TLU/cultivated area)	0.03; 67.0
Standard farm and herd size (cultivated area/household; TLU/household)	0.3; 17.0
Extreme poverty (% of rural population)*	27

Source: Refer to Table 2.4.

*sub-Saharan Africa only.

Two components of an integrated farming system

The farming system relies on two closely connected components – the oasis component and the arid pastoral component – which cannot exist without one another. Oasis populations own large numbers of livestock due to the surrounding wide stretches of Saharan grazing land, and, in turn, the pastoral component exists due to the ability for livestock to take refuge and drink in oases. This complex and productive agriculture-livestock association is described in Figure 14.4.

Oasis component

Oases are made up of dense vegetation dotted with small intensively cultivated agricultural plots using groundwater from deep or shallow wells. The cultivated area is only 0.35 million ha or 0.04 per cent of the farming system's total area.

Survival of oases' agriculture depends on the mobilization of available water resources. Technically this can be done in various ways. Sahelian facilities are less developed than those observed in north Africa (*khettaras* of southern Morocco, *foggaras* in Algeria (Touat, Gourara and Tidikelt) or Iranian *qanats*). Modes of water collection are specific to the various kinds of oases, basins and wadis, for example shaduf, delou, manual collection, or the use of gourds in inter-dune oasis depressions supplied from a shallow watertable, as found in the region of Diffa, Niger. The use of pumps is spreading rapidly wherever conditions are suitable (e.g. depth of watertable, financial capacity of producers, availability of land and mechanical spare parts).

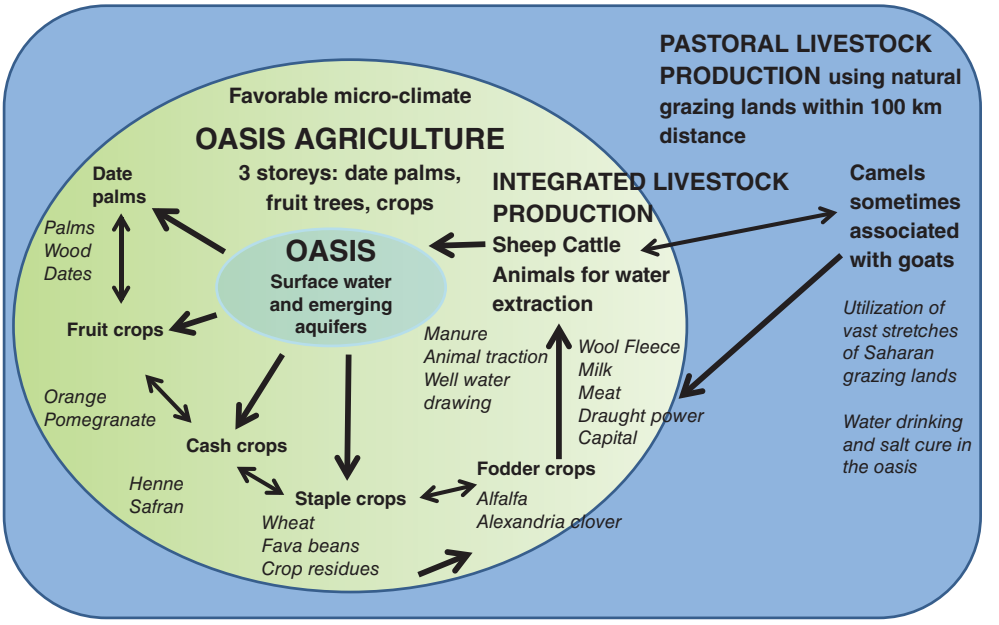

Figure 14.4 Activities and interactions in the arid pastoral and oasis farming system; the three-storey agroforestry system and integrated pastoral system of the Kawar oasis, Niger.

Source: Dollé (1985).

Fine technical control of the water resource is traditionally associated with complex social organization that governs water and land management rights and usage in these highly coveted areas. However, traditional community water management is gradually changing and sometimes declining, particularly in areas north of the Sahara.

Farmer knowledge covers a wide range of experiences accumulated in the field to manage resources. Faced with harsh production environments and survival imperatives, rural populations have developed a range of technological innovations in agriculture, including agroforestry, assisted natural regeneration and soil fertility management practices.

Originally the cultivated core of these ecosystems was mostly made up of natural palm groves. Their management intensity has fluctuated over time according to local social and economic conditions. The local agroforestry system is dominated by the doum palm (*Hyphaene thebaica*) and the date palm (*Phoenix dactylifera*), which are present in all social and economic activities pursued by residents of oases and depressions. The date palm has multiple uses and provides fruits, wood (for building house roofs and door frames), fibre from leaves (for baskets, mats, fans and containers for transporting dates and salt[3] on the back of camels), and dead branches (as garden fences or firewood for cooking). Fruits of the doum palm (the fine dried kernel) are a major product (more than 15 tonnes are harvested annually in the region of Agadez, Niger). Other tree species found in this system include desert date tree (*Balanites aegyptiaca*), jujube (*Ziziphus mauritiana*) and *Acacia nilotica* in Niger, Chad, Mauritania and Sudan. Fruits from these species and their marketing provide substantial income for oasis populations. Some grass species such as *Panicum turgidum, Aristida mutabilis, Cymbopogon* spp. and *Stipagrotis pingens* are also harvested and sold as hay in urban centres, providing further income for farmers.

In more developed systems, the core of the oasis consists of a palm grove under which two vegetation storeys are found when water resources are sufficient, for example, fruit trees (pomegranate, apricot, fig) beneath which are cereals, alfalfa or vegetables (Box 14.1). In major wadi beds or depressions, for example a number of oases organized around a *guelta* and *wadi* (Lagueila in Mauritania, Ounianga-Kebir in the Ennedi in Chad, Oubankort in the Adrar of Ifoghas in Mali), flood recession farming is possible (see Chapter 11 this volume for a description of recession farming). Although very intermittent, this type of farming can contribute significantly to the cereal supply of oasis populations.

The most common cultivated cereal crops are sorghum, wheat, maize, rice and barley in descending order of importance. Fodder crops such as alfalfa (*Medicago sativa*) are also grown. Nevertheless, the most important agricultural crops are vegetables and fruit trees. Fruit tree production is increasing in importance. Species include mandarin, mango, grapefruit, pomegranate, grape, olive and date palm.

The irrigated core of oases is organized in several plots with individually operated water management systems (Figure 14.7). Plots can be isolated from each other in certain types of oases (for instance in the series of small oasis basins in Goudoumaria, Niger) or contiguous within a single, general irrigation system.

Irrigated gardening is the main agricultural activity practised throughout the year. The most important vegetable crops are beans, sugar cane, cassava, yam and sweet potato. Others include onion, tomato, spices, garlic, potatoes, lettuce, eggplant, peppers and cucurbits. Cash crops such as groundnut, cotton and other oilseeds are also produced.

Box 14.1 The Kawar oasis in the heart of the Nigerien Sahara

Halfway between the Ténéré Desert and the mountains south of the Saharan north Djado, there is a string of Kawar oases located at the foot of a cliff extending over 100 km where water from scarce rainfall (12 mm per year) miraculously accumulates. The presence of water results in flourishing date palm plantations and makes commercial extraction of rock salt possible (Figure 14.5). With this water in the desert, Kawar (over 40,000 inhabitants) has for centuries been a crossroad and a strategic stopover for caravans on the main trans-Saharan road linking central Nigeria and Libya via Diffa, Bilma Ngourti and Murzuk (Figure 14.6). The oasis economy is based on trans-Saharan trade, bartering and transport of four water-demanding commodities – date palm, salt, vegetables crops and livestock – which are considered the backbone of oasis society, as well as labour migration. Date palm is the main cash crop, contributing 40–60 per cent of annual household income. Date palms are planted traditionally at a density of 100 trees per hectare (each date palm belongs to a distinct family). The palm is also grown in association with vegetable or forage crops which together have high annual water requirements, estimated at 17,000 m3, provided by extracted groundwater. In addition to dates, export of salt and soda can represent nearly 50 per cent of the income of oasis farms. Kawar's salt production represents 90 per cent of Niger's total national production and is exported nationally and subregionally. The great Azalaï caravan still provides the bulk of a triangular barter system: Bilma salt is carried to Agadez and the Niger River region. The Tubu and Ouled Slimane camel caravans from the Diffa Region (eastern Niger) transport livestock (camels and small ruminants) across the Ténéré to Bilma and Dirkou to exchange for salt and dates. The caravan then goes back to the Kano area, Nigeria – a distance of over 800 km – to exchange these oasis products for cereals that are transported to camps around Dilia on the southern edge of Ténéré. Exchanges are also carried out on tractor trailers.

Vegetable crops (the largest production being alfalfa) are grown on 3 to 10 per cent of the cultivated area and may contribute up to 25 per cent of annual income. Primarily produced for self-consumption (40 per cent), the surplus is sold locally or processed (dry). Residues of vegetable crops are valued for livestock. Management of irrigation water is paramount. The water is drawn from communal wells (15–20 m) or privately owned wells equipped with individual pumps. Collectively managed water is also available from 'water towers' originating from boreholes and springs at the foot of the cliff, which may be located four to five hours upstream from the oasis. Irrigation systems or networks called the 'Californian system' that permit the cultivation of large areas and result in good yields are increasingly used. Market-oriented gardening in the Kawar receives many technical inputs via migrants who go to work for a few years in Libya and return with practical and innovative techniques for oasis farming and fertilizing poor desert soils. About 30–40 tonnes of manure per hectare are needed annually for the production of vegetables. Sale of livestock has an important role for savings and pension.

Figure 14.5 Salt water pool in the oasis of Argui in Kawar, Niger.
Source: IRAM.

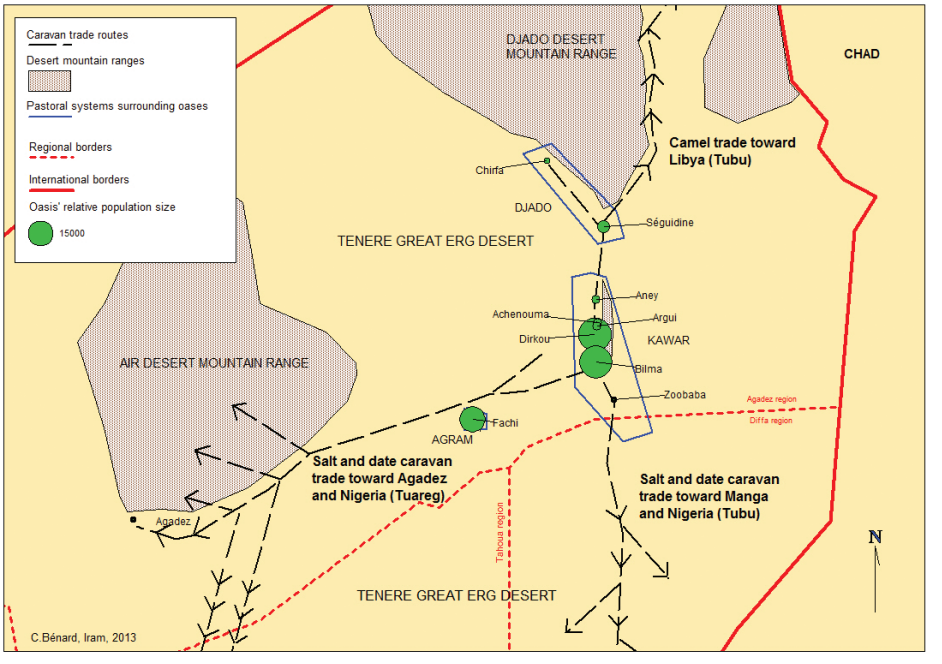

Figure 14.6 Map of oases in Bilma department, Niger.

Figure 14.7 Oasis irrigation system, Niger.
Source: IRAM.

Oases are also important for livestock production. Management is sometimes intensive with crop residues used as fodder supplements for livestock, and manure used as a precious input to vegetable gardening.

The household is the foundation of the community and its economy. Box 14.2 describes a typical household in the oasis component of the system. Women play a vital but often overlooked role in the agricultural oasis farming system. Women specialize in livestock management (unlike the pastoral system) and domestic crafts including manufacturing mats, fans, baskets and other woven artefacts. In some oases, they may have very small plots for vegetable cropping, in particular cucurbits, and engage in salt production. When it comes to marketing the production, men seem to take over. This is usually due to the fact that markets are outside the formal economy of the household, and women are confined to the household, unable to participate in markets.

Mineral salt extraction for human and animal consumption is the most important economic activity in some oases where it provides employment for 90 per cent of the population. The salts are traditionally extracted in a mixed soil paste for animal consumption and crystallized for human consumption.

The oasis component is characterized by technological weaknesses: irrigation equipment is traditional, and water collection and distribution pipes are generally not

covered. Technical support for producers, whether by state technical services, projects or NGOs, is very weak in terms of works maintenance rules, water use, and organization and improvement of cultural techniques.

Box 14.2 A typical household in the oasis component of the farming system

A typical oasis farm household in Niger cultivates around 0.85 ha. Crops usually include onion, tomato, garlic, wheat, maize and dates. Tree products are sold (fruits) or used for animal feed (leaves). Average crop production (for all crops combined) is 10.1 tonnes per year. The herd is composed of 20 small ruminants, 10 camels, 5 to 7 donkeys and 2 head of cattle, with an offtake rate of about 7.5 per cent. The household has six to seven persons, with three or four of these actively farming. The farmer uses organic manure from his own farm. Household income is 60 per cent from the sale of agricultural produce (garden produce, fruits, dates), 20 per cent from livestock products and 20 per cent from other sources. A portion of production is allocated for home consumption, but this depends on the market especially during the lean period or when yields are low. About 49 per cent of households are unable to meet their food requirements. Nutrition is low particularly for one- to five-year-old children in the poorest households. Because of budget constraints or financial needs, poor consumers sell nutritious foods such as milk, eggs and meat and buy cereals, although purchase of cereals is limited by increasing prices. Estimated meat consumption is less than 23 kg/person/year. Energy intake is estimated at 1262 kcal/day, which is below the daily requirement of 2100 kcal. Off-farm income represents a major livelihood source for many households. It consists of remittances and income from migration, or income from work in mines, construction sites and tourism. Women perform all household activities and play a central role in the organization of the household. They have very limited time to engage in income-generating activities and therefore play a minor role in earning household income.

Arid pastoral component

The arid pastoral component of the system is characterized by extensive livestock production taking place on wide expanses of land surrounding oases. It involves small ruminants (goats) associated with camels, the only animals capable of providing transport within Saharan areas. The stocking rate per unit area is extremely low. Animals are fed on plant biomass produced outside oases, which relies on erratic rainfall. For this reason, herders adopt highly responsive and flexible grazing strategies reliant on the natural environment. Camel herds, which do not depend on daily watering, exploit pasturelands which are sometimes very distant from the oasis (e.g. 100 km). Herdsmen carry water for their own needs or drink milk only. Camels' primary food resources for most of the year alternate between ephemerophytic pastures fed by rare rainfall, and winter grazing lands dominated by *Cornulaca monacantha*, which are widely sought after in desert zones.

Given their relatively high population density, oases are a significant source of supply and demand for animal products. Camels are sold as draft animals for oasis agriculture and meat for local markets. Local meat is primarily camel meat; small ruminant meat is rare and very costly. This component represents the largest component of animal production in the overall farming system. Livestock production strategies differ in the oasis and arid pastoral components of the farming system (Box 14.3).

Box 14.3 Livestock management in the oasis and surrounding arid pastoral plateaux in the Kawar oasis

Livestock management in the Kawar oasis is highly intensive and uses animal compounds. Animals that are used for transport (camels and donkeys) – and small ruminants – are raised in the backyard home compounds owned by Kanuri people (vegetable growers and traders). Livestock are the catalyst and cannot be isolated from the rest of the oasis agroecosystem. Their rich diet includes grazed forage from the immediate surroundings of the oasis, cultivated fodder (irrigated alfalfa), groundnut and vegetable crop residues and date palm residues (crushed date stones and damaged dates). Besides providing meat, mostly for home consumption and social and religious ceremonies, the main purpose of raising livestock is for organic matter and fertility transfers. Livestock manure provides a valuable input to vegetable production. Animals are rarely marketed; they are expensive and do not satisfy local demand. (During periods of religious celebrations, livestock are imported from elsewhere in the country.) The Kawar oasis is a complex and intensive system with strong interactions between perennial and annual production, and fertility transfers that are indispensable to plant production in an arid environment (the first dunes are only a few hundred metres from the oasis). This delicate interweaving of various elements helps to preserve system sustainability and sustain life in the desert.

The arid pastoral production component around the Kawar oasis is exclusively based on camels belonging to Tubu herders, for whom pastoralism provides nearly 80 per cent of their income. They use pasture on scarcely and irregularly rainfed dune areas; most pastures are very distant from the oasis, and sometimes as far as 80 km. Animals are left wandering on their own with irregular supervision often limited to ensuring their access to drinking water. This component is characterized by a high level of opportunistic pasture utilization including abandoned or uninhabited palm groves and areas of low rainfall. Camels are watered from oasis wells or more rarely from truck tanks. These camels will be used for renewing draught animals or to supply markets that demand camel meat (Libya and nations of the Arabian Peninsula).

While both components rely on water from the oasis, the integrated oasis livestock component and the extensive arid pastoral component have few interlinkages in terms of livestock food and management. These two system components utilize different vegetation strata and make different use of livestock: draught and export for extensive systems and home consumption for the integrated oasis system.

Source: Christophe Bénard, IRAM.

Subsystems

Four major subsystems of the arid pastoral and oasis farming system are proposed following the classifications outlined by Dollé (1985) and Toutain et al. (1989) based on the dynamics and intensity of oasis management:

- Type A. Gathering oases. Supplementary irrigation of palm plantations becomes increasingly impracticable because of a lack of water or the difficulty in extracting it due to sand accumulation or labour shortage. Oases are being abandoned and only a date-gathering activity persists (Djibouti palm plantations).
- Type B. Pastoral oases. Water resources are available and a significant proportion of palm plantations access shallow groundwater. There is no understorey cropping and management activities are kept to a minimum (pollination and gathering of fruits). The main activity is not palm agriculture, but seasonal transhumant pastoralism. Some family members are left behind with a few animals (Assaba palm plantations, Mauritania).
- Type C. Fallback oases. These are places where farmers who have recently lost their livestock come back to settle. They practise palm agriculture with occasional understorey crops and gradually rebuild their herds (Adrar palm plantations, Algeria).
- Type D. Cultivated oases. Palm plantations here are in good condition, with understorey layers of intensively managed crops making up a proper oasis agroecosystem. The watertable is shallow. Raising livestock is common and byproducts of crops are used (palm plantations of the Draa valley, Morocco).

Trends and drivers of change across the system

The development of oasis agriculture cannot be separated from the history of two older agrarian civilizations: Mesopotamia and Egypt along the Nile (Toutain et al. 1989). During the first millenium BC farming techniques were disseminated along the shores of the Mediterranean and pre-Saharan fringes via major tradeways reaching the Sahel, complemented by caravan routes up to 500 BC through which camels were introduced. Water channelling, irrigation techniques, agricultural practices and crop species spread gradually along caravan routes linking a series of oases. After centuries of selection pressure in the oases, traditional management techniques have led to the development of very well-adapted agricultural plant and animal genetic material. The abolition of slavery, civil peace since the 1960s resulting in infrastructural development such as clinics and schools, the extension of the road network and mechanization have induced important changes. Since World War II, there has been a gradual increase in population and increased trading of agricultural goods. The following paragraphs outline the key trends and drivers affecting the farming system.

Population, food security and poverty

Population in the system grew at a high rate of 2.3 per cent per annum between 2000 and 2015. With 27 per cent of the rural population earning less than US$1.25 a day, the arid pastoral and oasis farming system has the second-lowest incidence of extreme poverty among African farming systems. Markets have the potential to absorb the entire local production from the farming system; however, delivery is a constraint – production areas are far from major urban centres and transport infrastructure is highly constrained. Successive droughts in recent decades have contributed to increased poverty.

When faced with food insecurity, households adopt various strategies: (i) reduction in the number of daily meals, (ii) sale of livestock and household goods, (iii) debt or land mortgage, (iv) migration or involvement in new income-generating activities. In high-risk areas all household members are involved in helping solve the food problem.

Natural resources and climate

Agroecological sustainability is threatened by the degradation of oases' biophysical environment and natural resources. The main threat is reduced water resources. In north African oases and Saharo-Sahelian depressions, successive droughts since the late 1980s have reduced available water and resulted in increased pressure on water and land for cultivation. Contributing to increased water use are the livestock keepers who lost livestock during drought and now cultivate the pastoral periphery of depressions and wadis. Climate change has also affected this system, with a decline in rainfall in upland areas, which has reduced recharge and lowered groundwater levels. A shortage of irrigation water has resulted in reduction of the cultivated area (e.g. Goudoumaria basins).

The other cause of decreasing water resources is overuse of groundwater through uncontrolled proliferation of pumps and wells, even though modern pumping systems are not yet very common in sub-Saharan areas. Water overuse can have several origins:

- adjacent urban development which creates competition for water; this is generally detrimental to the needs of palm plantations
- proliferation of individual, private pumping systems near old palm plantations which allows farmers to free themselves from rules and constraints of collective water use. This can lead to a gradual depletion of water in oases (e.g. Tafilalet, Morocco; Wilaya of Adrar, Algeria; low ground of Goudoumaria, Niger; Wadi Doum, Chad)
- the use of fossil aquifers to create new wells and increased intensification of date palm plantations is also an important ecological risk because deep pumping of water from these aquifers can cause non-renewable resource depletion (e.g. Maghrebian continental intercalary).

Sand accumulation (Figure 14.8) and soil salinization can also contribute to the decline of oases and affect their sustainability. Such processes are observed in the Manga basins in Niger (Ichaou and Guibert 2009), Kanem in Chad and in oases located along the ergs of Chinguetti in Mauritania. Another threat is bayoud's disease, which may destroy palm trees. This fungal disease has spread throughout north Africa and has been a research topic in eastern Niger. Apart from resistant varieties of dates, there is no effective treatment against the disease. Farmers think that this disease is a natural constraint of their environment and that they should live with it.

Energy

Fuelwood represents a major source of renewable energy, but uncontrolled use can lead to unsustainable harvesting. More than 70 per cent of the population in sub-Saharan Africa has no access to electricity. This constraint is particularly severe in rural areas including oasis centres. In Niger, for example, household access to electricity in 2006 was 47 per cent in urban areas and only 0.4 per cent in rural areas (especially in remote areas) (Institut National de la Statistique et Macro International Inc 2007). This is due to a

Figure 14.8 Large Saharan depression threatened by sand accumulation.
Source: IRAM.

combination of several adverse factors: low density and dispersed settlements, remoteness of the network, very low-income populations, lack of profitability of rural electrification projects, lack of technical capacity of private actors, limited investment capacity of national public services, and low access to credit for local, private power producers in rural areas. An effort is being made by multilateral and bilateral donors, national governments and the private sector to improve the situation. Support for energy governance is a priority for international aid for west Africa (e.g. the European Union).

Human capital, gender and agricultural knowledge

The diffusionist, top-down agricultural research approach has led to the development of technologies which are not always adapted to farmers' realities and only rarely take traditional knowledge into consideration. Thus, traditional farming techniques remain the norm, although some new techniques are more water efficient and allow better integration of crops and livestock. The lack of extension (see 'Institutions and policies' subsection below) means that there is little transfer of agricultural knowledge apart from through traditional means. Emigration of youth and their enrolment in trafficking networks and the breakdown in community management of natural resources, in particular water, are leading to reduced knowledge transfer within the farming community. Low public investment in education and health, and the lack of economic integration, also

constrain household capacity to obtain the knowledge needed to improve agricultural and pastoral productivity, develop value-chains, or to earn off-farm income. Women's participation in new enterprises and farming techniques is inhibited by limited access to extension services. Resources and means of transport to remote markets are their biggest challenge. Their need to travel can also be hampered by their role as mothers.

Science and technology

Low capacity to invest in modern farm production techniques and agricultural materials, and households' limited diversity of income sources, explain the use of traditional extensive cultural methods in the farming system. To improve livelihoods, agricultural production needs to be increased and needs protection against physical (e.g. pests) and technical threats. Constraints faced by farms include irrigation water availability and distribution, drainage, salinity and maintenance of water distribution networks. While wells, boreholes and water reservoirs facilitate irrigation, technical support services are very poor in the areas of operation and maintenance (O&M) of irrigation infrastructure, determining collective water use for irrigation (amount to apply, method of application), and collective organization of O&M, water use and improved cultivation techniques.

There are also difficulties related to the lack of local, small-scale processing (postharvest) and preservation of horticultural products. Low allocation of research funds, and remoteness and difficult access, are added constraints in this system.

Markets and trade

Isolation and inadequate public and private investment to coordinate markets are bottlenecks that reduce the system's performance. Nevertheless, there have been remarkable developments in less isolated areas such as the valleys of southern Aïr in Niger. For instance, activities in the Tabelot gardens at the foot of the Aïr Mountains were first supported by NGOs with projects catering for livestock herders who were ruined by the 1973 and 1984 droughts. Driven by markets, irrigated vegetable growing has flourished remarkably since the late 2000s in response to increasing demand in coastal countries for onion (called 'white gold of Aïr') (Penot et al. 2002). Some valleys of the Agadez region, Niger, have taken the place of more classical onion production zones through dynamic planning and development (small-scale irrigation investments, technical advice, loans, etc.) led by local organizations supported by NGOs and technical partners. The same situation is observed in some wadis in Chad, near Abeche, where road development facilitated substantial onion production and trade.

However, a very high level of insecurity, loss of state control and trafficking of illegal goods are crippling development in these areas. The wave of high insecurity since the late 1990s has reinforced isolation by making communication risky and has reduced commodity commercialization. The impact is strongly felt as many households derive most of their income from marketing and particularly transport of products. The gradual closure of trans-Saharan roads since the late 1990s in Mali and Niger has economically stifled agrosilvo-pastoral farming in oases. The 2012 northern Mali conflict is a particularly striking example of how weak state governance and support have contributed to the control of the territory by extremist groups and drug and weapon trafficking networks. This was also the case in northern Niger with the Tuareg rebellions of 1990–1995 and 2007–2009 and northern Chad during the years of the Chad-Libya conflict.

Road transport could be developed in some countries such as Chad, Niger and Mauritania to facilitate communication and trade with other centres. Political will exists as shown by the Trans-Saharan Highway Project. Camels are another means of transport in the desert. Even though slower than vehicles, camels can reach very distant cities (Tamanrasset-Khartoum caravan via N'Djamena) and camel transport is in full expansion. Ecotourism has not yet developed but could contribute to an improved economy in peaceful areas of Mali, Mauritania, Niger, Chad, Sudan and Somalia.

Institutions and policies

Land tenure problems include difficulties in land acquisition and inheritance, and land fragmentation as a result of increasing population and distinct ownership patterns for soil, water and palm trees.

Central governments provide little support to arid pastoral and oasis system areas. These areas are often marginalized and forgotten by decision centres, and the lack of funding to improve production impedes their development. After a dynamic phase during the 1980s to 2000s, research and extension have suffered from financial crisis and the closure of support projects in many countries. In this system, we estimate there is one technical extension agent for 2,000 agriculturally active persons. As extension agents are poorly resourced, the impact of their interventions remains very insufficient relative to support needs. Most agricultural banks in the system's countries (including Mali, Mauritania, Niger) were liquidated during the 1980s in the context of structural adjustment. However, some NGO development projects are granting micro-credit to rural actors. The average African government budget for the agricultural sector in 2010 was 6 per cent, despite 2003 Maputo commitments to achieve 10 per cent by 2008. It is similarly low in Niger and Mali, but with contributions from technical and financial partners in the agricultural sector, total expenditures for the sector reached 22 and 19 per cent in Niger and Mali respectively.

The European Union, the World Bank, the United Nations system, France, Belgium, and other countries and organizations have invested in pastoralism and continue to participate in resource mobilization. Investments in irrigation are supporting small-scale private irrigators through credit or subsidies for development of their operations, as well as new rural development schemes. Government institutions and civil society organizations are supporting communities through establishment and financing of micro-projects and income-generating activities. Credit lines for women, market cooperatives, micro-finance institutions and other support for grass root communities are benefitting risk-prone areas, although their quantitative scale and coverage are low, given the widespread poverty and vulnerability.

Political threats to the arid pastoral and oasis farming system include the current shift of traditional and state governance modes to control by mafia-like and extremist groups following geopolitical interventions of neighbouring and northern countries, which stem from the Libyan and Syrian crises that are largely controlled by international politics. One cannot overemphasize the need to re-establish security and rule of law to help this system exit the destructive spiral in which it is currently engulfed.

System and subsystem performance

It is very difficult to characterize performance of these systems because of their diversity and the range of products. Performance also depends on subsystem type as defined in

Dollé's typology of gathering and survival oases (see 'Subsystems' above). Examples of fully developed oasis agroecosystems with palm plantations in equilibrium showing three cropping storeys (palm trees, fruit trees, understorey of irrigated cereal and cash crops) are numerous yet isolated. Most palm plantations in Mauritania do not meet this description. In Djibouti, most palm plantations are used for gathering. According to Toutain et al. (1989), performance of Moroccan palm groves of the Draa valley, Gheris and Ferkla is the highest in this system. This higher productivity is thought to be due to the association of intensified cropping and sedentary livestock (mainly sheep and some cattle or goats), with livestock production providing high levels of animal manure (25 t/ha/year). In the sheep production system, the D'Mane breed (Dollé 1982) also has an exceptional reproductive capacity (two lambings per year and many lambs per lambing) making it an ideal breed for a fully integrated intensified oasis farming system.

Average area per farmer in oases in Niger is 0.85 ha. The average oasis production per farmer (all crops cultivated) is estimated to be about 10 tonnes, with about 21 per cent consumed by the household (Pini and Tarchiani 2007a). In the Djado valley in Niger, oasis production is based on two other activities: date collection and salt extraction. Date production is very important and can reach 5,000 tonnes per year in some oases (50.9 ha/oasis) (Pini and Tarchiani 2007b). Dates are a much appreciated food and are bartered by nomads living in these desert areas to obtain cereals.

The declining yield of major oasis crops in past years is due to a range of factors, including the dominance of small traditional family farms (0.3 ha per household of 5.5 persons); limited use of modern inputs compared to needs; and limited access to land, research, extension, agricultural technical support, credit and mechanization. System performance is also reduced due to insufficient water and lack of access to technology and agricultural inputs. It is clear that in this situation, living conditions of local people are bound to deteriorate rapidly. This could be alleviated with improved rural productivity or development of the labour market outside of the agricultural sector.

The following directly or indirectly constrain productivity increases:

- remoteness that reduces opportunities for commercial use of salt and dates
- low technological level preventing increases in production and processing
- insufficient basic infrastructure as well as a lack of producer organizations
- increasing insecurity and economic suffocation of these areas resulting from a lack of government presence and control by extremist groups and traffickers.

Promising system management and restoration technologies

To control declining groundwater resource associated with generalized sand accumulation, the introduction and dissemination of more efficient technologies for water drainage as well as sand accumulation control are needed.

More than twenty years of struggle to control sand deposition in basins have led to several successful experiments, with the following general, qualitative lessons (Ichaou and Guibert 2009). Positive results can be observed after three to four years of dune stabilization work using several techniques: wattles based on *Leptadenia pyrotechnica* or doum palm fronds, manure from small ruminants allowing rapid herbaceous plant cover, and planting woody trees such as *Prosopis chilensis* and *Acacia senegal*. Impacts of such sand control systems managed by oasis farmer organizations have been: mobile dune soil becomes more stable, pioneer vegetation reappears during the following rainy season and accumulated

organic matter enhances soil physical properties. Herbaceous vegetation cover brings the various elements together making life possible, leading to a new equilibrium. Seedlings are weak but moisture in the profile of the stabilized dune ensures easier root development. This is the case for *P. chilensis*, which grows to a spectacular size in only three to four years.

Implementing a concerted strategy jointly with local desertification control organizations certainly does not stop this phenomenon, but it facilitates displacement of the sand drop zone from areas that are deemed very sensitive towards less risky locations. Because they cause damage to natural resources, deforestation (logging) and bushfires should be controlled. In addition, sand dune control should be done in a gradual, incremental manner starting with the most fragile areas and moving towards locations where a preventive strategy is more suitable. In the medium term (five to ten years), the first selective harvests (a few stems) should be planned in order to motivate local people.

Strategic priorities for the system

From the simplest to the most complex, these arid pastoral and oasis systems are in delicate balance because of the numerous constraints they face. These include:

- population pressure resulting in a progressive fragmentation of family plots, which is incompatible with oasis development
- rigid land tenure inherited from past management systems, which impedes value-addition of unmanaged lands
- competition for water resources between traditional and mechanized water use systems with the latter leading to high water consumption, a decline in groundwater levels and a lack of system sustainability
- expansion of diseases such as bayoud that have destroyed half of Moroccan palm groves (Toutain et al. 1989) and now extend to sub-Saharan oases
- lack of trans-Saharan and sub-regional project planning for trade and development
- changes in social groups and production-oriented relations between oases and their national and international surroundings
- worrisome religious extremists and mafia-like traffickers that can take control of local economies.

These old and new constraints act to weaken the arid pastoral and oasis systems developed by local farming societies in oases over past centuries. There is an urgent need to help maintain these systems in balance; save, rehabilitate and extend existing oases; and put emphasis on implementing a series of major initiatives for the sustainable development of these systems.

Poverty escape pathways

The banditry, armed movements, criminal economy (e.g. migrants, cigarettes, drugs, arms) and utter physical insecurity of people and goods present in most arid pastoral and oasis systems of northern Mali, northern Niger and eastern Mauritania precludes the development of intensification, diversification and other strategies to escape poverty. Until security and rule of law are reinstated, exit from agriculture to join such trafficking networks may, unfortunately, be the prevailing strategy for agropastoral farmers in the present system.

Poverty escape strategies for the poor have remained relatively unchanged since 2000 (Table 14.2). Spatial expansion of agriculture in this system is constrained. However, provided security of roads is ensured to supply Saharan urban centres and promote livestock trade, the intensification and diversification pathways can be pursued by households who can afford basic crop and livestock technical support services from the government. Less resource-constrained farmers will tend to invest in intensifying herd management and increasing stocking rates (e.g. purchased feed, mobile cisterns making the grazing of temporary inaccessible pastures possible during droughts). However, without rule of law, large herds may be controlled by armed groups and allied dignitaries who are able to arm themselves to protect their activities and keep military control of scarce watering points for livestock.

Non-agricultural income is generally from aid granted by government authorities or remittances from urban-based migrant or civil servant relatives. Armed groups are also using tactics to enrol young men into their trafficking activities. In addition to trans-Saharan trade, tourism had developed significantly in the Saharan regions of Niger, Mali and Mauritania, but progress is limited by the current insecurity.

Key priorities for the arid pastoral and oasis farming system are outlined in the following discussion and summarized later in Table 14.3. Thereafter, Table 14.4 also presents intervention strategies for a selection of arid pastoral and oasis farming system sites and their specific characteristics.

Population, hunger and poverty

Reduction of rural poverty is not limited to increasing agrosilvo-pastoral production and off-farm income. A fundamental condition for sustainable growth and socioeconomic development is also improved (qualitative and quantitative) access by farmers to goods and services (road and transport infrastructure, technical support services, education, health) whose supply is normally a public responsibility. Strong political will is required to make the investments needed to reduce the challenges of remoteness and isolation of oasis agro-ecosystems and increase the opportunities for their economic development.

Vulnerability to food scarcity can be reduced by anticipating and locally managing food crises, for example by storing resources or diversifying activities. Usually crises have resulted from a combination of complex phenomena, such as the increase in world prices for basic foodstuffs, a break in traditional solidarity among people, simultaneous deregulation of markets in different geographical areas, and late or inappropriate government reaction.

Table 14.2 Relative importance of household livelihood improvement strategies*

Livelihood improvement strategy	*Extremely poor (2000)*	*Extremely poor (2015)*	*Less poor (2015)*	*Total population (2015)*
% of total ag pop	–	27	73	100
Intensification	0	0.5	5	4
Diversification	1	1	2	1.5
Increased farm size	0	0	3	2
Off-farm income	3	3.5	0	1
Exit from agriculture	6	5	0	1.5

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.
* for the sub-Saharan component of the arid pastoral and oasis farming system.

Natural resources and climate

Sound technical and social management of water resources is critical for adequate oasis function. However, shortage of water resources, obsolete water management rules, abandonment of community resource management and the uncontrolled proliferation of private pumping systems threaten the sustainability of some oases. Recent change that permits private initiatives at the expense of collective ones has undermined social control of water resources and excluded some people from acquiring water access rights.

Better control of water pumping and pumping systems must be ensured. In most countries where oases occur, water pumping is controlled by laws and regulations to avoid overuse of the resource, but these are frequently violated. While law enforcement and administration need to be consolidated, local development experiences have shown that strengthening social control of water resources has much more impact on sustainable management of this resource (Ostrom 1990). Such social control has allowed the survival of oases for past centuries. Regaining a greater equity in water resource access is a prerequisite for mobilizing oasis populations towards this reconstruction (Jouve et al. 2005).

Economically unsustainable individual initiatives threaten the sustainability of some oases. The emergence of new management institutions must be facilitated so that sustainable management of resources and infrastructure can be collectively agreed and adapted to local conditions (Deygout et al. 2012; Jouve 2012). These institutions could be the new territorial governments (rural communes) set up in the context of political decentralization and democratization. However, their wide operational zone is often an obstacle to effective participation and results in very high operational costs. Therefore management structures should be anchored at the level of local oases and allow local people, especially women, to determine their own development. Examples of local, decentralized, common property resource management have been developed in Mauritania and can provide lessons in appropriate models of organizational and legal frameworks (Bonnet 2012). The proliferation of interventions by oasis-based NGOs, often initiated by highly trained individuals of local origin, shows that civil society participation is a major asset for building sustainable development policy for oases.

Significant investment is required to restore and create water management infrastructure that is more efficient and adapted to the physical environment and local management capacity. The restoration of irrigation networks, and development of micro-irrigation and mutual arrangements for operating pumping systems to support small private gardens in the periphery of old palm plantations, should be encouraged. Wadi development infrastructure can also promote groundwater recharge and leverage the significant efforts required for the establishment of a palm plantation. From this point of view, the management experiences with various water capacity thresholds developed in Chad and Niger are to be promoted (Banzhaf et al. 2012; Bender 2007).

Pastoral water management must also be integrated into the water management strategy, given the economic and agroecological roles played by animals and their products. This includes pastoral wells, water reservoirs in rangelands and secure pastoral access to wadis managed for oasis farming.

Local people's initiatives to promote woodland regeneration and control sand accumulation need to be supported. Shifting dunes that are responsible for sand accumulation in oases can be stabilized using mechanical and biological means (see second paragraph in 'Promising system management and restoration technologies' in 'System and subsystem performance' section earlier).

Energy

Access to energy is essential for sustainable development, health, social welfare, peace and security, and the fight against poverty. As in other farming systems, it is important to reduce reliance on wood energy and fossil fuel imports, and to promote electrification and gas energy through subsidy and education programmes. Renewable energy can also be a solution to the energy deficit: solar energy has a huge potential for this system and should become a major component of energy production by the 2040s in Saharan zones. Similarly, thermal energy must be explored and used. But poorly adapted policies and regulations are the main cause of the inability to exploit the enormous potential of renewable energy. The key to tapping the energy potential of sub-Saharan countries lies in opening energy markets to private sector investment. With political commitment, countries of the arid pastoral and oasis farming system could transform their remote villages, triggering a cycle of economic growth and stimulate technological innovation in critical sectors such as agriculture, livestock and food security.

Agricultural knowledge and human capital

The availability of information for smallholder farmers is critical to both the intensification and diversification of arid pastoral and oasis farming system. Both traditional and modern knowledge is necessary in the design of new ecological intensification models and increased agrosilvo-pastoral production in the various layers of oasis agricultural systems.

Apart from water, livestock is also a key element of the sustainability of arid pastoral and oasis farming system. They provide essential organic matter for soil fertility and are key economic pillars in integrated farming practices and the trans-Saharan livestock trade that oases make possible. Support to oasis farmers should focus on the improvement of integrated systems: food, productivity, value addition of manure, reducing drought effects on livestock, land management to ensure access to water, and protection against cattle theft.

The challenge for agricultural research in this farming system is to develop new models of oasis agriculture based on sustainable management of natural resources, to ensure harmonious development. This new agriculture should aim to deliver not only increased quantities produced but also ecological services rendered, the rational use of water and investment in farmer training and empowerment. The innovative character of such production systems should also help enhance the image of agricultural activity among oasis communities, including the youth who need to invest in oasis development.

The increasing isolation and the weakening of Sahelian public services to the farming system must be overcome – through improved transport, education and other services to improve human capacity. Also, the current institutional landscape includes a multitude of organizations that need to be more systematically identified and involved in development strategies to help oasis communities successfully adapt to new technological, economic and social realities. The restructuring and improved organization of stakeholders will be a decisive factor in the rejuvenation and sustainable development of oases and surrounding territories.

Basic needs of women and their families will be better met when their contribution and responsibilities are recognized, when they obtain property rights, better access to services and markets, a voice in decision-making about resources and products, and more control over income. For this purpose, a better understanding of constraints and opportunities for

the economic participation of women is needed. Priority should be given to how women can get access to services, information, education and training. Because they have been less exposed to education programmes than men in the past, both the format and content of training and information dissemination need to be targeted to women's specific needs. Putting active means, resources, technologies and inputs in the hands of women will have important consequences for addressing hunger and creating wealth in the arid pastoral and oasis farming system.

Science and technology

Maintaining high levels of productivity requires a continuous supply of organic matter – this is provided through livestock in oases, which is why mixed crop-livestock management practices are essential for the survival of oases. Research on appropriate agronomic, technical, hydraulic and economic techniques and innovations should be mobilized to assist oasis farmers and herders who manage these systems. Emphasis on variety improvement for higher yields and lower water use requirements is also needed. Infrastructure and means of preservation and processing of harvested products must be developed in order to avoid losses and realize economies of scale to achieve favourable prices on national and international markets.

Increased frequency of droughts is predicted with climate change, and improved herd resilience is an area for improvement. The use of crop residues could be significantly enhanced through grinding and nitrogen addition, as demonstrated in Nigerien research. During crises, emergency systems for supplying fodder to livestock that are managed collectively by governments or international aid tend to be heavy and untimely. In order to enhance pastoral resilience, structural livestock feed supply chains should be established. These allow higher herd stocking rates while preventing high losses during extreme weather events (Bonnet and Guibert 2012).

Almost all arable land in oasis agriculture is used, yielding a diversity of produce. Therefore, there are two main oasis development options:

1 intensification through more efficient technical support and easy access to means of production (inputs, improved seeds, technical equipment)
2 improving the quality of products and value addition. This can be done not only by promoting improved varieties and those appreciated by consumers but also by improving products' visual aspects and packaging.

However, in response to international food crises and demographic pressure, governments must also step up their support for the development of oasis zones by restoring and extending existing perimeters and increasing mobilization of available water using new proven technologies. This calls for an integrated water resource management approach that ensures both optimal and sustainable water collection, and product value-addition over time. Specific needs for water extraction, irrigation and drainage techniques adapted to oasis environments need to be planned for in relation to the growing demand and markets of Saharan urban centres.

Markets, value chains and trade

The 2012 northern Mali conflict is evidence that governments should prioritize interventions to reduce isolation of these areas and open them up through new roads to

allow marketing of agricultural production and to supply local populations with primary necessities. This opening up of the region must not only be economic but also social and political.

Once water management is improved, the regeneration of degraded palm plantations can be undertaken through the replanting of palm trees, favouring bayoud-resistant varieties and improved maintenance of palm plantations (Jouve et al. 2005). After their restoration, the economic viability of oases depends on their level of agricultural production. Given severe constraints faced by oasis systems (isolation, land and water fragmentation, high evapotranspiration), the challenge is to use a production strategy that promotes the comparative advantages and opportunities of oases. Countries such as Tunisia and Algeria have been able to enhance the production of quality dates with the 'Deglet Nour' variety and to develop their exports. But sustainable production cannot be based on monoculture of a single date variety. The wide range of fruit trees that can grow under palm trees, including apricot, fig, olive, peach, pomegranate and orange, is also an economic opportunity that deserves to be better utilized. For high altitude oases these new fruit crops are economically more promising than palm.

A condition for enhancing the value of these crops is to promote producer organizations and the acquisition of knowledge and experience for value-addition through sorting, storage and preservation, packaging, and even marketing and branding as is attempted in southern Morocco with the support of the United Nations Development Programme. A primary step to achieve these improvements is to promote the establishment of well-structured producer organizations with the aim of improving the presentation of products on the market, particularly for dates or other specific products (saffron, henna) and therefore increasing revenue and supporting more active, local economic development (Vandecandelaere 2012).

Livestock trade in the Sahel, notably the camel and small ruminant export sectors, can be supported or revitalized through improved health controls that ensure export of healthy livestock. It can also be strengthened through infrastructure development that facilitates the reception and exchange of cattle convoys on foot or by truck: development of livestock markets, creation or rehabilitation of pastoral water points, tracking markers along routes in dangerous desert zones, and engineering of crossings or fragile road sectors and crossings of wadis.

Policies and institutions

Survival of oases is largely dependent on income sources other than from agricultural products. Income from remittances sometimes takes over what used to be generated by the caravan trade. This income has so far been used mainly to meet the needs of family members who remained in the oases. But when back in their countries for retirement or as a result of the economic crisis in northern countries, some migrants invest in economic sectors such as trade, transport, agriculture and tourism. This trend should be encouraged.

The public attraction to oases due to their architectural heritage, beautiful scenery and the hospitality of local people is favourable to tourism development. Activities that have developed in Saharan zones of northern Mauritania, Burkina Faso, Mali and Niger provide relevant examples. When security conditions are met, this opportunity should be enhanced while ensuring that income generated can benefit the largest number of families and that tourism does not lead to altered quality of sites and human relations. Following the major wave of insecurity in the western Sahel, activities which used to thrive in the

Aïr and Nigerien Ténéré regions as well as northern Mali and Mauritania have shifted towards the Ennedi and Tibesti regions in Chad.

Apart from major commercial palm plantations mostly observed north of the Sahara, traditional oases are struggling to maintain economic viability on their own despite remittance and tourism income. As is the case for hardship areas in Europe, their future also depends on national and international solidarity. This solidarity has begun to emerge in Maghreb countries through the development of public policies favouring the creation of offices and infrastructure in oasis zones. At the international level, FAO has already recognized oases as a component of world heritage through the Globally Important Indigenous Agricultural Heritage Systems (GIAHS).

Lastly, despite their low population density, northern Sahelian desert areas are strategically critical in political and economic terms due to their abundant mining resources. They are thus entitled to public services that are well adapted and equally effective as in other parts of the country. Recent administrative decentralization must be supported with financial and human resources that permit a true recognition and legitimacy of communities in these very distinctive territories, and set up a democratic and responsible management of infrastructure and public services.

Conclusion

The arid pastoral and oasis farming system is a centre of human activity within vast Saharan, north Sahelian and southern African land expanses. They represent important geographic sites for community survival and strategic locations on trans-Saharan trade routes for the exchange of Sahelian, Saharan and north African products.

In this hyper-arid environment, oases and Saharan depressions offer access to water that sustains life and integrated agrosilvo-pastoral systems producing dates, vegetables, other products and often salt. These activity centres are not necessarily autarkic and self-reliant. Beyond production, they function to enable exchange and trade networks through major trans-Saharan routes. The wide diversity of situations derive from ecological dynamics linked to water resources as well as socioeconomic characteristics of regional trade routes which may sometimes escape the control of states and local communities.

Local agricultural production systems are certainly very limited in size compared to pastoral and agropastoral areas further south, yet the arid pastoral and oasis farming system allows for the utilization of vast expanses of semi-desert or desert land. In addition their networking has contributed to making very important trans-Saharan trade possible for centuries.

Threats to these systems should be a major concern of policymakers, given the isolation and implosion they may experience due to development of narcotics trafficking and Islamist terrorism. Other threats are related to the fragile natural environment (dune encroachment, salinization, groundwater depletion), and also to economic changes (trade, political orientations, interventions or abandonment of roads) and government weaknesses that manifest in the lack of utilities, rule of law, political control and appropriate policies for sustainable development.

For communities in these Saharan, north Sahelian and southern African regions, the challenges of sustainable development are numerous and substantial: increased agricultural production adapted to markets, protection and sustainable management of water resources, soil fertility and pastures, protection against degradation of fragile environments, improving infrastructure and linking agricultural intensification with market development.

Table 14.3 Summary of strategic interventions for the arid pastoral and oasis farming system

Drivers of farming system evolution	*Intervention*	*Implementers*	*Implications for farming system structure and function*
Population, hunger and poverty	Invest in improved infrastructure and increased access to services (transport, family planning, health, education, agricultural extension)	Ministries; World Food Programme; NGOs	Increased opportunities for development, wider access to off-farm income; better coordinated services to farmers
Natural resources and climate	Decentralization; empowerment of local organizations in sustainable resource management; equitable and social water management; governance of natural resource use	Ministries; NGOs, projects; communities; farmers' organizations	Increased productivity and resilience
Human capital, gender and agricultural knowledge	Improve communication infrastructure (local radios) and farmer access to agricultural knowledge; increase women's access to services, information, education and training; strengthen organization of stakeholders	Ministries; NGOs; WFP; research institutions and training	More knowledgeable farm managers; use of appropriate technologies; enhanced contribution of women to food security; enhanced community representation and capacity for local development
Energy	Improve access to energy services; open energy markets to private sector; promote renewable energy	NGOs; ministries; other organizations	Reduced poverty; economic growth; stimulation of technological innovation in agriculture, livestock and food security
Science and technology	Promote integrated market-oriented production systems; involve private sector; support labour-reducing and soil fertility management innovations; establish structural livestock feed supply chains	Farmer groups; ministries; projects	Higher profitability of new technologies and more integrated farming systems; increased pastoral resilience
Markets and trade	Promote system linkages with international markets; open markets through road construction; support market information including ICT and credit; better access to services and markets	Agribusiness; NGOs; private organizations	Wider choice and better informed production and marketing decisions therefore increased eco-efficiency
Institutions and policies	Strengthen public services; establish innovative development models and projects at regional and trans-Saharan scale; reduce barriers to cross-border agricultural trade; land tenure; farmer training; micro-credit	Ministries; NGOs; World Bank	Increased regional cooperation in development planning; lower cost and wider choice in inputs; increased farm gate prices; sustainable land management

Table 14.4 Intervention strategies according to the characteristics of selected arid pastoral and oasis sites

Site	*Physical environment and resources*	*Settlement history*	*Dominant livelihood system*	*Major system threat*	*Project experience to date in system management*	*Priority intervention strategies*
Manga oasis basins in Niger (Goudoumaria)	Ancient dune erg with surface water table from the Chad Lake basin	Manga society historically occupied basins	Doum and date palm plantations, vegetable gardening (cabbage, banana, onion, maize, cassava, etc.); pastoralism in the oasis periphery, gum arabic and salt extraction	Sand accumulation, invasive dunes leading to the abandonment of oasis depressions; rise of saline conditions; landlocked position; low product sales linked to low commercialization capacity; permanent emigration; deterioration of public infrastructure	Dune repair work; value chain strengthening for supply and marketing; infrastructure, wells, roads	Support for local integrated management, desertification control and value chain organization; public investment in water management, health, school education and reduced isolation through road construction
Kawar Oasis (Bilma, Dirkou) in Niger	Fossil wadis of Bilma with ancient palm grove	Saharan societies; with Kanuris and Tubus	Date palm plantations, salt; important market for livestock, salt and dates on caravan route	Persisting isolation and insecurity which slows the sale of agricultural production; drying up of valleys and water salinization	Aïr and Ténéré resource co-management project	Opening up of the region; irrigation infrastructure restoration following recent floods; strengthening of public security in the region; support for NGOs, Tran-Saharan Road Project, Great Green Wall Project

Fira wadi in the Ouaddaï in Chad	Ouaddaï wadi with significant runoff and sand accumulation	Farmer-herder ethnic groups	Development of flood recession sorghum (bere bere), vegetable crops (onion, tomato, etc.)	Persisting local isolation; local organization constraints for waterworks maintenance, including flood management/ irrigation dikes damaged by intense floods in 2010 and 2012	Support for and networking of local producer organizations; management of flood thresholds, rock bunds, individual pump facilities	Support for local organizations and networks; improvement of roads linking villages to the regional capital; land management that better integrates mobile pastoralism; funding system for waterworks' maintenance
Assaïta oasis in Ethiopia	Oasis on the banks on the Awash river which splits into several parts before flowing into neighbouring lakes; these irrigate the only arable lands in this hostile environment	Afar communities of the Awash valley	Agropastoral system where the agricultural component complements and enhances transhumant livestock production; this diversified system promotes higher food security and desertification control; new industrial farms run by the state or private investors have cropped the fertile pasturelands of the Awash valley	The Afar people have lost their best dry-season grazing lands; thousands of hectares carelessly put into cultivation by industrial farms (with no drainage and untimely irrigation that raises aquifer levels) have or are becoming saline, and will thus become unfit for agriculture, thereby threatening food security of local populations	Given constraints of the traditional Afar pastoral system, current work aims for oasis development while benefitting the communities of Afar livestock keepers (with a focus on date palm introduction)	Development of the system needs to support diversification, higher food security and desertification control; it should also facilitate development of socioeconomic structures that contribute to integrated rural development

(continued)

Table 14.4 (continued)

Site	*Physical environment and resources*	*Settlement history*	*Dominant livelihood system*	*Major system threat*	*Project experience to date in system management*	*Priority intervention strategies*
Djibouti oases	Oases in 80 sites located along wadis	Afar groups in the North and Centre; Issa groups in the South	There are several types of oasis gardens: 1) altitude gardens with vegetables and fruit trees; 2) continental gardens with vegetables and sheep fattening; 3) dairy gardens with fodder and livestock; and 4) specialized ornamental and aromatic gardens; the northern part of the country specializes in fruit tree growing in the mountains and fodder production along the coast, while the south is more multipurpose	Small herders who have become vulnerable as a result of the desertification of pasturelands find refuge along alluvial valleys and impoverished civil servants succeed in generating sufficient income to maintain agropastoral activities by using cheap labour	Participatory planning of surface water retention works, agropastoral well and borehole infrastructure, grazing zone exclosures, income generating activities and community capacity strengthening	Oasis development is one of the national objectives; this strengthens the livestock sector (through fodder production) and contributes to vegetable production; another objective is to secure the livestock sector by expanding the collection of runoff water for herds, irrigation and regeneration of grazing lands
Adrar oasis in Mauritania	Adrar region is a plain flanked by plateaux cliffs; plateaux are intersected by valleys which sometimes form deep gorges where oases are found	Agropastoral Moorish groups including marabout tribes (Smacides) and their believers (Telanides) as well as Baratines; pastoral societies (Hassan groups and in the northern limits of Adrar, the Ouled Delim, Regueibats of Tell and Sahel and Gouacem)	Well-maintained and irrigated oases with date palms and rare cropping	Fallback oases for herders who have lost livestock due to the 1973 and 1984 droughts	Support for agricultural management and development	Conservation, mobilization and utilization of natural resources: water, water management facilities and equipment ; control of sand accumulation; socioeconomic infrastructure and services: opening-up of region, health services; economic agricultural production: control of livestock encroachment in palm plantations, manage palm diseases, marketing support

But sustainable development primarily depends on the security of local people and goods locally produced with high levels of know-how (Plateforme Pastorale Tchadienne 2013). Maintenance of security and development of these sparse, arid systems are possible from a technical point of view, if one considers various experiments on the northern and southern shores of the Sahara. But this presupposes that concerned governments invest in the socioeconomic development, education and health of these territories and truly recognize responsibilities for managing these systems and the resources they can generate.

Given their remoteness in desert areas, decentralization of decision-making power to local oasis communities is necessary. Their sustainable development therefore rests upon strengthening farmer capacity as well as improving and linking marketing systems to new regional channels.

As was the case historically, the development of Saharan systems still relies on the trade routes to which they are linked (four geographical meridians of the Saharan world described by Monod (1968)). Not all of the main trans-Saharan routes have become grey and uncontrolled areas like northern Mali (Choplin and Pliez 2013). The western Moorish meridian going from Morocco to Senegal through Mauritania is experiencing a true revival because of the coastal road infrastructural development that took place through agreements between national governments to facilitate and secure exchanges. Only a regional political will by Saharan states to break geographical isolation, add value in the utilization of renewable natural and mining resources, and ensure security can promote real economic development in these areas. In this context oases can become indispensable centres and relays for modern trans-Saharan economies.

Glossary

Foggaras: long, underground structures to supply water to some oases from the mountains or plateau. This ancient technique has emerged in Iran under the name 'Qanat'.

Guelta: is a word of Arabic origin which means temporary water bodies or perennial flow without apparent source (from a spring); ponds found in the beds of wadis, often surrounded by mountains. They can be found in situations protected from sun in the mountains, as in the Ennedi and the Adrar des Iforas in Mali.

Khettara: is a drain designed to transport groundwater from the mountains to agricultural land. It usually begins near a well in the foothills of the mountains where underground water is available but cultivable soil is not. The water moves by gravity from this place through a tunnel to an oasis.

Wadi or Oued: is an Arabic term traditionally referring to a valley. In some cases, it may refer to an ephemeral riverbed that contains water only during times of heavy rain, or simply an intermittent stream.

Notes

1 Oases are intensively cultivated areas with access to water in desert or arid environments that are generally characterized by a large deficit between precipitations and evaporation linked to high temperatures and frequent dry winds (Lacoste 1987).
2 Oasis depressions are specific geomorphological units of spatially limited area (up to a few hectares) found in inter-dune depressions with clayish soils where oases are found.
3 salt that comes to the soil surface through capillary action. It is collected, at least partially separated from its muddy base, evaporated, and transported in long blocks on camel back.

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