3. Action research and reverse thinking for anti-desertification methods
Applying local revegetation techniques based on the ecological knowledge of local farmers in the Sahel of West Africa

Shuichi Oyama

3.1. Introduction

"In November 2001, I observed the men of a Hausa village in Niger spending the afternoon listening to the radio and playing cards for money. When the sun set in the west, they would stop playing cards and return to their homes. They cleaned their livestock yards using rakes and collected the waste. The waste was then carried to their own farmland. The annual millet and cowpea crops had already been harvested and cows, goats, and sheep were left to graze the harvested fields, where they would eat the stems and leaves of the crops. One man put the waste onto an ox cart his 12-year-old boy was driving. Another man placed the waste into an 80 cm diameter iron pan and carried it on his head. The waste included compostable organic matter as well as not compostable plastic and metals. The heat of the sun was still strong in the evening and they were dripping with sweat. Women were also involved in carrying waste from the homesteads to the fields. They wrapped the waste in cloth and carried it on their heads."

This diary entry in the fieldnote-like description of a common scene in a small village in southern Niger stands at the beginning of a puzzle with which this paper deals. At first, I watched such situations without understanding that the waste, and non-compostable waste, was used by local people to fertilize and enrich their soils. This fact I came to understand only when I did participatory observation combined with experiments and helped them to carry the waste to the farmland, where it was placed on the ground. This experience in a Hausa village inspired my research activities and led to my quest for a better understanding of environmental restoration based on the ecological knowledge of Hausa farmers, who use non-organic waste to fertilize their land. How is this possible? How did it impact my collaborative research? And how does it challenge natural science discourse on land restoration in the Sahel by focusing on local ecological knowledge? These are questions explored in this article.

3.2. Desertification in the Sahel region

In the Sahel region, on the southern edge of the Sahara Desert, desertification is a serious problem. It occurs through a combination of natural (irregular rainfall, drought and poor soil fertility) and anthropogenic factors (overcultivation, over-grazing and firewood collection). The rapid increase in the human population of the Sahel is also considered to be a fundamental high-pressure driving force for land and desertification. According to the United Nations Convention to Combat Desertification (UNCCD) in 1994, the definition of desertification is land degradation. Many researchers have reported that unsustainable cultivation, over-grazing, firewood collection and urbanization are the major causes of desertification (e.g. Ayantunde et al. 2000, Dregne 1986, Gonzalez 2001, Mortimore and Turner 2005, Tschakert 2007). In recent years, both farmers and herders have experienced hunger and poverty caused by desertification in the Sahel region. This has fuelled armed conflicts. There is a downward spiral of desertification, hunger and poverty, armed conflict and terrorism occurring throughout the region.

In the Republic of Niger, President Mamadou Tandja made a commitment in the beginning of the century to tackle desertification. Government policy has promoted afforestation, water basin management and erosion prevention. According to government reports, during the three years from 2000 to 2002, an area of 381 $km^2$was afforested, sand dune fixation has occurred over 40 km^2, and erosion prevention measures have been extended over 384 km^2.

The Great Green Wall for the Sahara and the Sahel Initiative is now being implemented across the Sahel region, with more than eight billion dollars promised in support from the European Union, World Bank, Food and Agriculture Organization (FAO), UNCCD, Global Environmental Facility and other organizations. There are some 20 countries involved in the initiative, including Benin, Burkina Faso, Chad, Djibouti, Eritrea, Ethiopia, Ghana, Mali, Mauritania, Niger, Nigeria, Senegal, Somalia, Sudan and Gambia. The scale of the project is enormous, with the aim of creating a 15 km wide green belt extending 8,000 km across the continent. In Senegal, 11.4 million trees have already been planted on 25,000 hectares of land as part of the initiative.

There is a need to evaluate the effectiveness of this enormous project in providing funds to the Sahel countries through international development organizations. The aim of the initiative is to strengthen the coping abilities of the government and individuals, but there have been difficulties in implementing the initiative. In the Sahel, the population density on arable land is high, with little space available for afforestation and re-greening. Trees can be grown on land that is suitable for agriculture, but it is extremely difficult to plant trees on degraded land without soil improvement efforts. Often forests in the Sahel zone are not natural but are planted or fostered by people for centuries, often in the context of high population densities and specific property institutions, rules and regulations regarding ownership, maintenance and use (see Fairhead and Leach 1995, Haller 2003). However, this requires hard work and large inputs based on many gains (shelter, food, timber and non-timber products, ritual sites, etc.). This shows there has been a willingness to create forests, but it is unclear if under the new conditions and under changed property rights over land on fertile ground people are still willing and able to repeat those efforts.

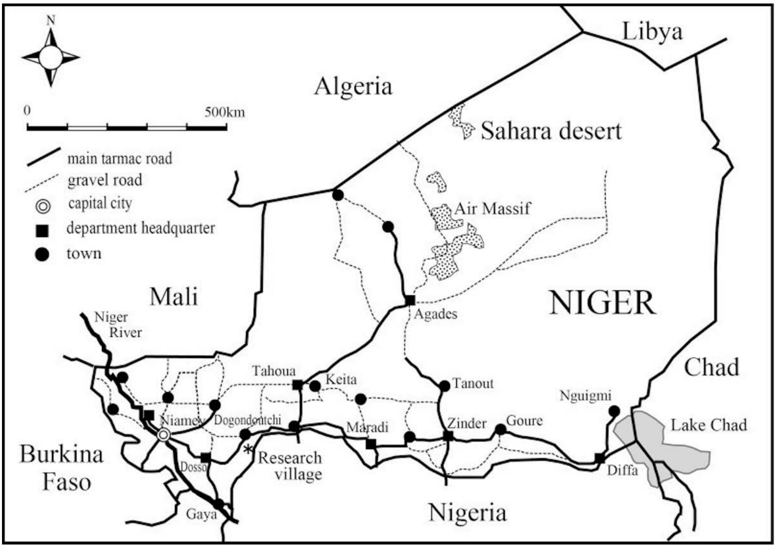
Leisinger et al. (1995) emphasize the importance of communication between local residents and scientists to provide food security and promote rural development in the Sahel. However, the one-sided transfer of knowledge and skills from scientists to local residents is often not desirable and not adequate, as scientists frequently overlook local knowledge and capabilities in contemporary livelihoods and agricultural practices in rural villages. The local people, especially herders, are framed by the large-scale afforestation project as "troublemakers", and pastoral commons are alienated in the form of large-scale land acquisition or land grabbing, including water grabbing and pasture grabbing (Haller et al. 2016). In rural communities of southern Niger, land shortages have made it difficult for farmers to maintain fallow land. Livestock dung is an important resource to improve soil fertility, but farmers can rarely get enough access to the resource. It is imperative before making expensive agricultural interventions that the concerns of local residents about trying to tackle desertification and overcome hunger and poverty are taken into account.

3.3. Approach and research area

My main exploratory research methodology was participatory observation, which is a widely used anthropological research method (see Crang and Cook 2007), combined with field trials. I started my research in Niger in 2000; it continues today.

When I visited Niger for the first time in 2000, I was surprised by the heat and felt it would be difficult to conduct long-term fieldwork. For me, it was impossible to start research in this arid region without drinking large amounts of water. In the surroundings of the Sahara Desert, we also faced security risks related to Tuareg movements. I intended to conduct fieldwork among the Hausa, the largest ethnic group in West Africa, and decided to establish my research area in Dogondoutchi, 270 km east of the capital city, Niamey (Figure 1). I engaged in agriculture with Hausa farmers and grazed livestock with Fulbe herders.

Figure 1: Research area: D village



In 2001, the population in Dogondoutchi Town was 29,200. It takes a full day to travel from Niamey to Dogondoutchi by taxi brousse. My research site was a nearby village, which I call D village. In 2000, there were 280 residents among 41 households in this village, which increased to 65 households with 504 residents over the following ten years. During this period, the annual rate of population increase was extremely high at 6.0 per cent. This rate of increase would lead to the population doubling every 12 years. In 2010, 62 of the households were Hausa farmers, two were Fulbe and one was Tuareg. Both the Fulbe and Tuareg are herders of grazing livestock.

The Hausa are the largest ethnic group in West Africa. Hausa people dwell in an area extending from Filingue, Tahoua and Zinder in central-north Niger to as far south as Kano and Zaria in northern Nigeria.[1] They refer to themselves as *Bahaushe* (singular) or *Hausawa* (plural). Major Hausa communities have formed in northern Ghana and northern Cameroon, and Hausa storeowners and artisans can be found in most of the cities of the Sahel. Most Hausa are Muslims, and it is possible to trace the history of this religion in Hausaland back to the fourteenth century. Islam spread as the Hausa migrated from one part of West Africa to another. In West Africa, Islam is now sometimes considered synonymous with the Hausa people (Adamu 1978). The Hausa kingdom flourished as a centre for intermediary trade in produce from the coastal regions to its south, and for rock salt from the Sahara Desert and goods imported from the Mediterranean (Baier 1980). The Hausa actively pursue commerce in urban areas of West Africa.

D village is one of the nine oldest villages in the Department of Dogondoutchi. Elderly villagers recall that, 60 to 70 years ago, spare land for cultivation remained in the plain land around the village, much of it untouched. Aerial photographs taken by the French colonial government in 1950 confirm this, showing the village surrounded by uncultivated and fallow land (Oyama 2017). Fulbe and Tuareg herders grazed their livestock in the grassland of these lands. As the population grew, however, increasing areas of land were cultivated, and by 2006, all arable land had been cleared for farming and the ownership of each plot in the plain had been established. Communal grazing areas have been limited to the iron-crusted inselbergs and their barren surroundings. The paths to the water pond were secured by the government, but the expanding farmlands made it difficult for herders to connect with the water.

1 Heiss (2015) provides an excellent ethnography on the everyday life in rural Hausa community.

In recent years, land suitable for cultivation has been in short supply, and it has been difficult for villagers to find newly cleared land. Village women have even attempted to cultivate groundnuts and Bambara nuts in the small sand dunes they have found on the inselbergs. Allowing the land to lie fallow is no longer an option, and pearl millet and cowpeas are grown in succession each year. Much of the arable land is already cultivated and land shortages are serious.

Desertification, food shortage, famine and armed conflicts among farmers and herders are problems that the villagers face in their everyday lives. This article details the environmental conditions in the research area and illustrates the local recognition and management of desertification from the viewpoint of the inner community of the village. At the same time, the paper discusses the methods used for land restoration, improvement of food production, and conflict prevention based on local ecological knowledge and institutional arrangements. The article reveals that counter-intuitive explorations and reverse thinking can provide room for manoeuvre in highly complex situations, but the dilemmas of trade-offs between conflict prevention, food production and environmental degradation remain.

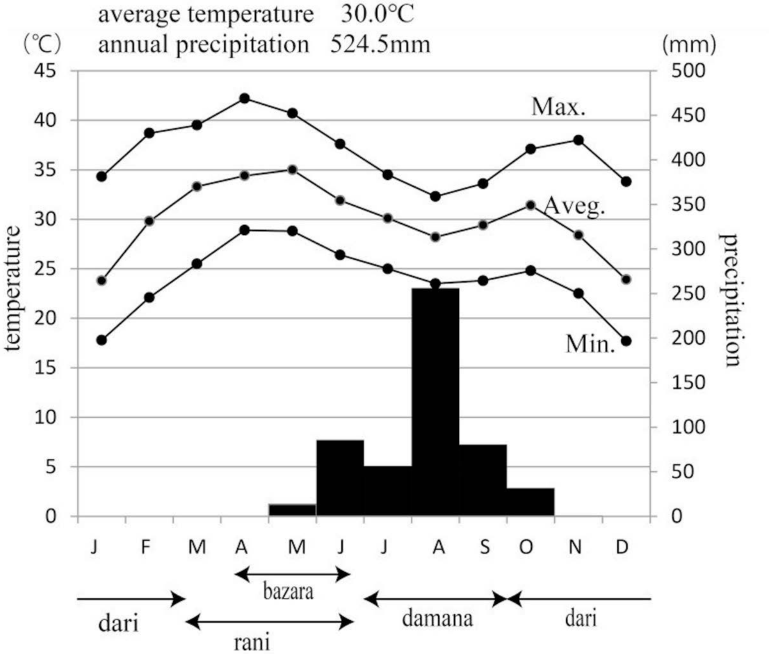
3.4. Agriculture in long-term dry season and short rainy season

3.4.1. Temperature, rainfall and wind

The rainy season in D village is from early June to early October, and is called *damana* in Hausa. The temperature and rainfall in 2010 are shown in Figure 2. The total precipitation in that year was 524.5 mm. The national meteorological station in Dogondoutchi started taking measurements in 1923, and reported an average annual precipitation of 465 mm during the 30 years from 1981 to 2010 from the records of Météorologie Nationale du Niger. The precipitation in 2010 was therefore above the average.

The dry season spans eight months, from October to May. The monthly average maximum temperature usually exceeds 30°C all year round. In 2010, there were 352 days exceeding 30°C out of which 241 days exceeding 35°C. From March to June, the minimum temperature was higher than 25°C during the hot dry season called *rani*. The humid season between May and mid-June is called *bazara*. In the *rani* season, the maximum temperature exceeded 40°C and the minimum temperature around sunrise was still higher than 30°C. For

Figure 2: Temperature and rainfall in D village in 2010 with the seasonal taxonomy according to the Hausa people



local people, too, these temperatures are difficult and they report that they do not sleep well at this time.

Immediately before it rains, a wind stronger than 10 m/s blows and creates windblown sandstorms. In 2011, there were 95 days where wind blasts of stronger than 10 m/s were recorded. This consisted of 35 days during the rainy season from June to September and 60 days during the dry season. The strong winds usually stop after 10 to 30 minutes. In the rainy season, it sometimes starts raining after the strong wind blows, but this does not always happen. The rain clouds and sandstorms originate from the east and south-east. A hot and dry wind called the Harmattan also blows from the east during the dry season. This wind simultaneously induces soil erosion for land degradation and soil accumulation for land restoration in the Sahel.

3.4.2. Agriculture

There are three staple food crops cultivated in D village: millet, sorghum, and maize. Intercropping fields of millet (*Pennisetum glaucum*) and cowpea (*Vigna unguiculata*) are spread around the village. The millet plant stands straight and the cowpea crawls along the ground. Intercropping of the staple food crop and local legume is almost universal throughout tropical Africa and brings benefits to crop production and soil fertility (Richards 1985). The distance between millet plants is 1.2-1.5 m, with cowpea planted in between the millet plants (Figure 3). The villagers also utilize cowpea in cooking their staple food (*tuwo* in Hausa). Because of the shortage of rainfall, they cultivate mainly millet, and only rarely sorghum and maize. Gourd (*Cucumis melo*), watermelon (*Citrullus lanatus*) and okra (*Abelmoschus esculentus*) are also planted on the farmland.

Figure 3: A millet field in southern Niger

The growing period for millet is three to five months. The exact period is dependent on the rainfall conditions and millet variety. There are four varieties of millet: *zongokolo, dogohatsi, bazaumi* and *maiwa,* whose yield from highest to lowest follows that order. According to the villagers, *zongokolo* requires the highest soil fertility. Drought tolerance from strongest to weakest follows the order of *maiwa*, *dogohatsi*, *zongokolo* and *bazaumi*. The variety with the strongest drought tolerance, *maiwa*, is a late maturing variety and has not formed a panicle by the middle of September when the villagers begin to harvest the other varieties. They start harvesting *maiwa* at the beginning of November. The grain of *maiwa* is toxic and the poison has to be removed by soaking the seeds in water. After soaking in water, the grain tastes the same as the other varieties. The use of four varieties creates crop diversity and has enabled the villagers to respond to climate change, but the recent introduction of improved new varieties and chemical fertilizer has led to the extinction of local varieties. This will make local farmers more vulnerable and less resilient to climate changes and drought.

Millet is usually harvested from the middle of September to the end of November. The panicle is cut using a knife. The villagers bundle the harvested panicles together with ropes and store them in a granary or in clay-made storage vessels. Cowpea pods are harvested by all family members, including women and children. Cowpea leaves are collected for use as livestock fodder and stored on the roofs of the houses. Recently a shortage of livestock fodder became a serious problem, and millet stems and leaves have therefore been collected for livestock fodder since 2010.

Men cultivate millet and cowpea in the fields and women plant groundnuts (*Arachis hypogaea*) and Bambara nuts (*Vigna subterranea*) in sand dunes on the inselberg. Women care for small patches of their crops every day during the rainy season. These nuts are important as a household food and also provide cash income for the women. The women also cut trees and collect firewood from the inselberg. The sand dunes are covered with grass, which provides important fodder for the herders' livestock, with most sand dunes cultivated by Hausa women. Deforestation is rapid on the inselberg, and the scattered small patches of nut fields have led to livestock-induced crop damage, resulting in conflicts over land between farmers and herders.

3.4.3. Soil properties and land degradation

The Hausa farmers recognize changes in the soil conditions resulting from continuous millet cultivation (Oyama 2009). For the same general area of land, Figure 4 shows that differences in soil condition and crop production depend on specific locations. The farmers classify the soil conditions into one of three categories: *kasa*, *leso* and *foko*. The Hausa word *kasa* has various meanings, including land in general, country, Hausa land, ground and soil, but here I use its limited meaning of fertile soil. In local conversations, people usually use the phrase *kasa taki* (soil of manure) to refer to fertile soil.

Figure 4: Millet field and stages of degraded soils

There are differences in the soil condition and crop production that depend on specific locations. Left: After a few years of continuous millet cultivation, the fertile soil of *kasa* becomes degraded to *leso*, which appears as white sand in the early stages of land degradation. Right: The solid sedimentary layer, *foko*, is exposed when surface soil is blown away by wind and eroded by rainwater. *Foko* has extremely low plant productivity.

Soil with high organic matter results in high crop productivity. The Hausa call this soil type *kasa*. Compared to the *leso* and *foko* soil types, the *kasa* layer (brownish grey on the Standard Soil Colour Chart), which is 0-3cm and 3-12 cm deep, is weakly acidic and has an abundance of soil nutrients with a rich aggregate structure (see Table 1, Oyama 2012).

This aggregated soil structure is created by termites. Termites use organic matter such as tree branches and leaves as shelter. Their shelters are made of sand held together with saliva and excrement (Lee and Wood 1971). Termites bond the sand grains together with their saliva. Soil aggregates containing air and water promote plant growth. A solid sedimentary clay layer (dull orange), identified as *foko*, accumulates under the *kasa taki* layer. This *kasa* soil type provides favourable growth conditions for millet, with an average stem height of 156 cm recorded on 20 August 2003. The millet crop yielded 1.1 tons/ha in the middle of October 2003.

Table 1: Land and soil classification of Hausa farmers and the soil properties

	pH (H_2O)	Total ($g\ kg^{-1}$) N	C	C/N	E xch.Base cmol(+)/kg Na^+	K	Mg^{2+}	Ca^{2+}	P $Mg\ kg^{-1}$	Soil colour	Sand	Silt (%)	Clay
1. *kasa* (millet yield 1.1 tons/ha)													
0～3cm (*kasa taki*)	6.8	1.20	16.17	13.5	0.06	0.37	2.19	4.36	153	5YR 6/1 (brownish grey)	91.0	1.5	7.5
3～12cm (*kasa gara*)	4.8	0.12	1.28	10.7	0.09	0.24	0.09	0.20	8	5YR 7/4 (dull orange)	84.2	1.5	14.4
12～30cm (*foko*)	4.4	0.08	0.84	10.5	0.02	0.04	0.04	0.09	6	5YR 7/3 (dull orange)	84.6	1.3	14.1
2. *leso* (millet yield 0.1 tons/ha)													
0～9cm (*leso*)	6.1	0.07	0.75	10.7	0.02	0.07	0.09	0.25	7	5YR 8/4 (pale orange)	94.6	1.0	4.4
9～30cm (*foko*)	4.6	0.11	1.18	10.7	0.02	0.1	0.061	0.13	5	5YR 7/4 (dull orange)	90.5	0.6	8.9
3. *foko* (no millet yield)													
0～5cm (*foko*)	4.6	0. 12	1.08	9.0	0.01	0.10	0.12	0.26	13	5YR 6/4 (dull orange)	89.5	2.2	8.3
5～30cm (*foko*)	4.4	0.08	0. 84	10.5	0.01	0.08	0.05	0.14	7	5YR 6/4 (dull orange)	82.0	2.4	15.6

The *kasa* soil type changes into *leso* after a few years of continuous millet cultivation without a manure input. This *leso* soil type shows an early, degraded soil condition that produces low millet yield. The *leso* soil type has a poor aggregate structure and is a pale orange sandy soil that contains little silt and clay. Under the *leso* topsoil, a sedimentary layer of *foko* forms, which appears as dull orange sandy soil. This sandy *leso* soil has high soil porosity and does not disturb the root growth of the crop, but nutrient availability is poor. The average stem height of millet in the fields with *leso* soil was 36 cm on 20 August 2003. The plants failed to form panicles, and the grain yield was only 0.1 tons/ha.

A few years of continuous cultivation without land management leads to wind and water erosion of the topsoil and exposes the solid sedimentary layer. This sedimentary *foko* layer has extremely low plant productivity. Hill (1972) describes this hard and barren ground in his excellent ethnography of the Hausa people in northern Nigeria. The *foko* layer is mainly a quartz sand containing acidic sulphate. The *foko* soil has strong acidity and poor soil nutrition. The clay layer is runny when wet, but hardens after it dries. When the *foko* layer is exposed at the surface, crop growth at the root is significantly hampered due to the soil's single-grain structure and poor chemical constitution. The solid *foko* layer greatly impedes water penetration into the ground. The millet germination rate in this soil is low, and most plants eventually die. All the millet had withered by 20 August 2003, with an average stem height of only 7 cm. The millet grain yield was zero (Oyama 2009).

As Graef and Haigis (2001) note, the soil fertility of farmland is decreasing and further technologies need to be integrated into farming systems to make them sustainable in the Sahel. From the viewpoint of Hausa farmers, land degradation means a transformation of the ground surface from *kasa* to *leso* and then from *leso* to *foko*. According to their explanation of the land degradation process, *kasa* will change to *leso* and then *foko* without land management. In the first step, soil fertility is lost with the change to *leso*. Then the white sand of *leso* is blown away and eroded by rainwater until a solid sedimentary layer of *foko* is finally exposed at the surface.

This land degradation process is caused by water and wind erosion. Surface soil is eroded away and a solid sedimentary layer is exposed to the surface. This process is triggered by anthropogenic factors such as continuous farming, grazing and tree-cutting. Loss of the surface soil creates a barren land surface of sedimentary rocks, which are called *foko* by Hausa farmers. This barren land is the final stage of the land degradation process. The villagers cannot produce millet and cowpea on this land, and natural plants cannot become established.

Initiatives like the Great Green Wall for the Sahara and the Sahel Initiative emerge from such environmental analyses to counteract desertification and to restore land for agricultural production and to sustain livelihoods.

3.5. Local countermeasures against land degradation

The Hausa farmers do not simply accept land degradation. In Hausa society, the importance of *harkuki* (movement) is culturally emphasized. Farmers respond rapidly to the degradation of their farmland. They proudly told me: "We can improve the soil condition of *leso* and *foko* and convert it back to *kasa*." To recover the crop yield, they have adopted the two countermeasures: (1) providing livestock dung to farmland based on an encampment contract with herders in areas of *leso* soil, and (2) providing waste inputs to the degraded *leso* and *foko* soils.

The encampment contract in the Sahel region allows maintenance and improvement of the productivity of millet plots. These institutional arrangements between farmers and livestock herders, called *hulda da makyaya* in Hausa, have been widely practised for generations across semi-arid West Africa (e.g. Baier 1980, Schlecht and Buerkert 2004).

With the arrival of the rainy season, the nomadic Fulbe and Tuareg people move north, crossing the marginal limit of the cultivation zone and grazing their livestock around the edges of the Sahara Desert. The Fulbe people mainly raise cattle, together with goats and sheep, while the Tuareg herders may have camels as well as goats and sheep. Women and children move from one camp to another on donkeys, which are also used to transport household possessions.

In November and December, as the rainy season comes to an end, the herders begin to move their livestock south, passing though farming villages. By this time, the villagers have finished harvesting their millet and cowpea, and the land surrounding the village is covered in post-harvest stubble. The herders try to select a route that will take them through the most productive farmland, and approach villagers - particularly wealthy ones - to discuss encampment contracts.

Once the parties have reached an agreement on terms such as the camp duration and fees, the herder sets up his camp on the contracted land. During the daytime, he lets his animals feed on the post-harvest stubble, leaving them free also to graze on plots other than the one subject to the contract. In the evening, he brings them back to the campsite, where they spend the night. The livestock are not corralled, but the herder keeps livestock on the contracted land. The animals nourish the soil in the vicinity of the camp with significant quantities of manure (Figure 5). The addition of these nutrients is crucial to the outcome of the following season's millet crop (Schlecht and Buerkert 2004, Shinjo et al. 2008, Suzuki et al. 2014). At the end of the contract period, the herder receives payment from the farmer in cash and millet, and leaves the village.

Figure 5: Encampment contracts between farmers and herders

Farmers make encampment contracts with the Fulbe and Tuareg herders. During the night, the herders stay with their livestock on the farmer's farmland. The farmer exclusively receives soil nutrients on the private farmland from the livestock dung. Farmers usually request that herders camp on the sandy *leso* soil, which is nutrient deficient.

The fertilizing effect of the manure from these encampments is encapsulated in the Hausa saying: "Camel five years, goat and sheep three years, cow one year". Cow manure decomposes rapidly, providing nutrients for one year only; goat and sheep manure can last for three years, while camel manure provides five years of fertilization. The Hausa farmers' understanding of the properties of livestock manure is consistent with the scientific findings of Brouwer and Powell (1998). Villagers wishing to enter into contracts with the Tuareg, whose herds include many camels and therefore have the potential to provide highly effective fertilization, are required to pay a high price in cash and millet. Soil nutrients can be added to the degraded farmland through this encampment contract.

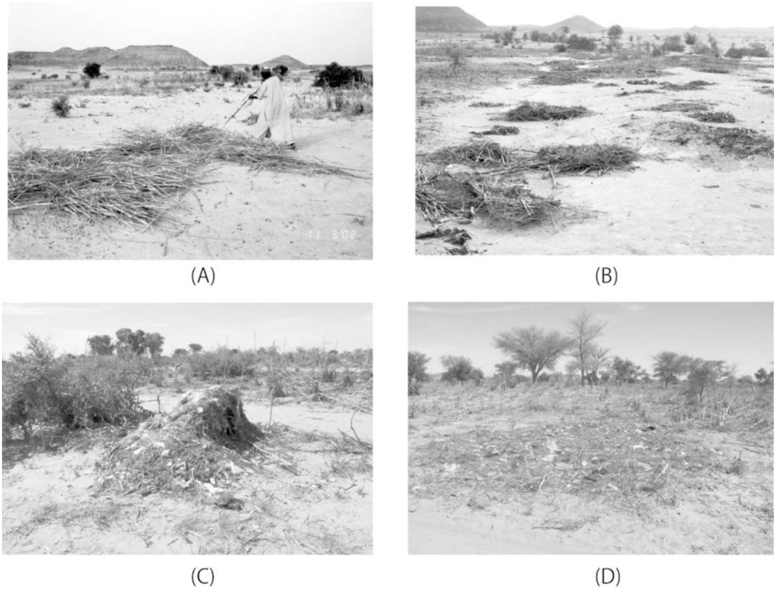
3.5.1. "Waste is manure for our farmland"

Hausa farmers have another countermeasure to restore the degraded farmland. As part of their everyday life, villagers collect waste to fertilize their own farmland (Oyama 2012, Oyama and Mammane 2010). Waste is regarded as manure, called *taki* in Hausa. The famers monitor the soil conditions on their farmland and apply the waste to areas of degraded land (i.e. *leso* and *foko*) as a land management activity (Figure 6). They emphasize the importance of waste inputs and the biological activities of termites for recovering crop productivity. I have conveniently translated the Hausa word *taki* into manure in English, but *taki* means not only organic waste (e.g. the inedible parts of crops, such as plant residues from food processing, and livestock fodder and dung) but also inorganic waste (e.g. worn out clothes, shoes, vinyl sandals, plastic bags, cartons, straw baskets and mats, iron pots and dishes, and used batteries). The villagers claim that non-compostable waste is important for fertilizing the farmland. The farmers transport domestic waste from their homes to their farmland throughout the year. The amount of waste produced varies according to the number of household members and livestock, and the animal species, but the average amount is 10 to 40 kg per day. From a household owning an ox cart, 200 to 400 kg waste is transported to farmland every seven to ten days. Men and women wrap 10 to 15 kg of waste in cloths and carry it to the farmland on their heads every day.

Some farmers living near the town collect urban waste for application to their farmland, with the aim of improving the soil condition. They transport urban waste to the degraded *foko* land by ox cart, tractor or dumping vehicle. Urban waste contains large amounts of soil nutrients such as nitrogen, potassium, phosphate, calcium and magnesium. Sand accounts for at least three quarters of the mass of urban waste and is important for land restoration.[2] This sand is carried by storms immediately before the rainfall and Harmattan during the dry season.

2 According to my weight measurement in February 2018, the urban waste of one tractor was 2826 kg in total. The composition was 2609 kg (92.3%) sand, 189 kg (6.7%) plastic and vinyl bags, 17.4 kg (0.6%) stone, 4.96 kg (0.2%) plastic, 2.48 kg (0.09%) metal, 2.26 kg (0.08%) cloth, 0.68 kg (0.02%) glass fragments and 0.11 kg (0.004%) paper. Even in the urban area, a huge amount of sand is provided by strong wind and sandstorms. The urban dwellers collect the sand and carry it to the dumping site. This sand disturbs the incineration treatment of urban waste in the Sahel.

Figure 6: Waste for fertilizing the farmland



Farmers monitor the soil conditions and apply urban waste as manure to fertilize the degraded farmland. (A) Farmers put millet stems and plant residues onto the degraded land. (B) Sand accumulates around the livestock dung, plant residue and pruned branches. (C) In 2010, farmers started using the urban waste to catch the blown sand. (D) Farmers scattered the waste by fork and promoted termite activities and organic decomposition. The urban waste includes plastic bags, worn out clothes, sandals, baskets, and metal dishes and pots. Farmers claimed that all the materials have functions and good effects for soil improvement and land rehabilitation.

The organic matter provides nutrition for crops and food for termites, so improving the physical condition of the soil. The inorganic matter in worn out clothes, sandals, mats and pots is mixed in with the blown sand in the urban waste and accumulates in the sedimentary layer. The urban waste could be considered a soil dressing applied to the degraded land. Applying urban waste can help to recover the plant productivity of degraded land (Oyama 2012, 2015a, Oyama and Mammane, 2010).

3.5.2. First trial of urban waste-induced land restoration

In a meeting in June 2005, I consulted with the village headman and influential seniors about my plan for a land restoration experiment using urban waste and requested permission to use the degraded land to the east of D village, surrounding an inselberg. All of them approved my request willingly and promptly. At that time, an aged man talked about past activity in this area. He said:

> "The degraded land you want to use was pasture land more than 60 years ago. The ground was covered with grass and a Fulbe herder named Boi lived with his livestock on the grassland. After the trees were cut down for firewood and Boi grazed livestock continuously for many years, the wind blew away the sand and the soil was eroded by rainwater. The erosion exposed the barren rock and plants could no longer grow, leading to the current situation. The ground became unsuitable for grazing livestock and Boi left the village with his son, Madaure."

The ground was "no man's land", with free access to the public. The herders could use the grassland freely and induced the land degradation.

The headman and influential seniors gave me permission to use an area of 2.7 ha. The land was positioned on a gentle slope, and included the pediment around the inselberg. Rainwater flow had washed away the surface soil and the pediment was vulnerable to further water erosion. The sedimentary layer was exposed on the surface and no plants were growing on the barren land. In 2007, it was estimated that between 80 cm and 1 m of soil erosion had occurred by measuring the length of exposed tree roots (Figure 7). The solid, barren ground was classified as degraded land, *foko*, by the farmers. There was no grass and a limited number of trees in the area. We could not find any active termite mounds. Only one old mound was observed in the area; it had been weathered by wind and rainfall (Figure 8).

I rented two bulls and ox carts to carry urban waste from Dogondoutchi to the degraded land. The rental fee was 1,500 CFA francs (3 USD) per journey. It took one and a half hours each way. When we arrived at the town, we collected the waste from a residential area using rakes and loaded the carts with waste using shovels. Under the strong sunshine, I developed blisters on my right hand due to the unfamiliar and strenuous work. At the beginning of June, in the early rainy season, the urban waste was moist and had an unpleasant odour.

Figure 7: Tree roots exposed by wind and water erosion, indicating soil erosion to a depth of at least 80 cm

At first, the residents were perplexed to see us working in the town and transporting waste to the village. I explained the purpose of the experiment to the urban residents and they immediately understood and thanked us for cleaning the residential area and surrounding streets. After loading each ox cart with waste, the carts became heavy and it took more than two hours to reach the site. The two bulls were salivating and struggled to pull the carts.

When we arrived at the experimental site, we dropped the waste from the ox carts and levelled the waste into a round shape. The mass of waste was 400 kg per ox cart. The bull owner complained about the low price for the rental fee and demanded an increase from me. I agreed to increase the fee to 2,500 CFA francs per journey. July is considered the hungry season, when people suffer food shortages. It was also a hungry season for the livestock: we could see the bulls' ribs, and they did not have enough power to pull the ox carts when they were fully loaded with waste. Although I increased the rental price

Figure 8: Weathered termite mound

In this arid land, the most common organisms in the underground environment are termites, but many termite mounds have been abandoned and have subsequently become weathered because the termites cannot get access to wooden material as food following desertification.

to 2,500 CFA francs, we had to reduce the number of journeys made by the bulls to 12.

Some villagers asked to borrow money to purchase household food at that time, but I refused to lend money to avoid later money troubles. I could not reject their requests without being impolite and so, instead, I requested they bring domestic waste to the site for which I paid them a fee. I was able to collect waste 12 times by ox cart, ten times on the back of a donkey, and once carried on a man's head. A total of 5,200 kg of waste was applied to eight locations on the degraded land (Figure 9).

Figure 9: Land restoration experiment using urban waste

3.5.3. Emerging pastureland

I visited the research site in August 2008, which was in the rainy season, two years after we carried the urban waste to the degraded land. I observed a green carpet that had arisen from the urban waste. The green colour was in stark contrast to the surrounding degraded land, which had a uniform brown colour. The son of the village headman was experienced at identifying plant species and counted 75 species at the site (Figure 10). According to my Hausa informants, plastic bags, sandals and metal pots were able to catch the wind-blown sand and so prevented soil erosion. My Fulbe informant explained that most of these plants growing on the urban waste had high levels of nutrition and were favoured fodder for livestock. We collectively believed that urban waste could be used to restore the degraded land. My informants said: "Both urban and domestic waste can be used to create pastureland." Interestingly, the emerging pasture was immediately used by more people in the village.

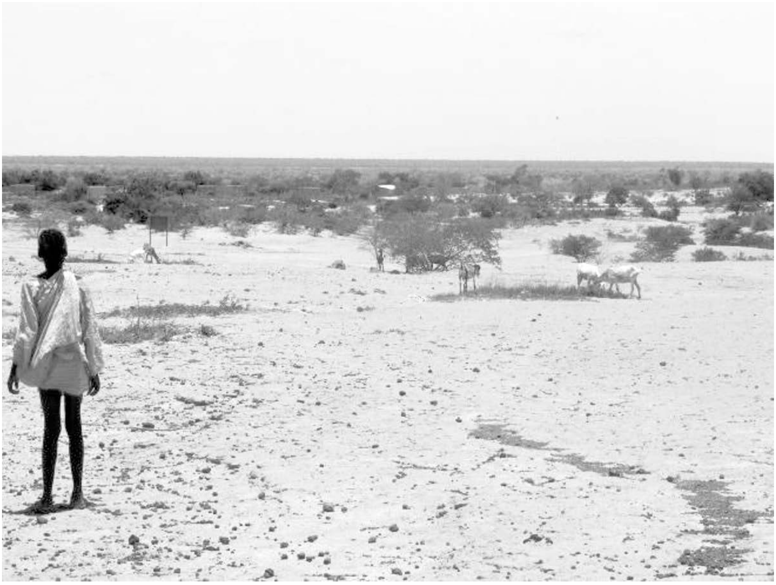
Figure 10: Grassland created from urban waste

I encountered a Tuareg girl in the pastureland created from the urban waste. She grazed ten goats and one sheep for her parents. I knew her parents and they all lived in D village. The time of this encounter was 1:30 pm and the site was in full sun. Despite the heat, she continued to chase and graze the livestock on the pastureland. The girl said to me:

> "If I return home now, there is nobody at home. My mother and father are working on the farmland. I feel good grazing livestock here. When I graze them from the early morning, we can get milk from the sheep and goats in the evening and the milk nourishes us. But Hausa farmers will scold me terribly if I enter their farmland. I am happy to graze here, away from the farmland."

After my conversation with her, I was able to understand more clearly the severe situation faced by Fulbe and Tuareg herders. They needed to secure pastureland to graze their livestock freely without intervention from the farmers (Figure 11). However, free access to pastureland promoted further land degradation. Although I had made a huge effort to transport the urban waste and restore the land, the livestock grazed the pastureland freely and removed the soil nutrients. A few years later, the desertification process would start again, with conversion back to the degraded land referred to as *foko*.

Figure 11: A 12-year-old Tuareg girl grazing goats and sheep on the grassland created from urban waste



3.6. Eight effects of urban waste use for land restoration

It became clear that land restoration from degraded land to pastureland was possible technically. However, I could neither understand the process and mechanism of land restoration nor the necessary amount of waste for land restoration. In November 2008, I consulted the headman and influential seniors again about the possibility of building a large-scale experimental plot. Then I started another trial, as I wanted to assess the effects of using urban waste for land restoration.

With the cooperation of the villagers, we transported urban waste from a residential area of Dogondoutchi for use in a greening experiment on the sedimentary layer. We enclosed the land with fences for 50 m in the east-west direction and 45 m in the north-south direction (Figure 12). The experimental site was located on the pediment, with a gentle slope, and was highly vulnerable to soil erosion. There was no plant growth around the plot and we did not observe any active termite mounds nearby. This area of pediment was the location that the seniors had informed me earlier was degraded pastureland. The termite mounds had been diminished by rain and wind, and tree roots were exposed to a depth of 30 to 70 cm.

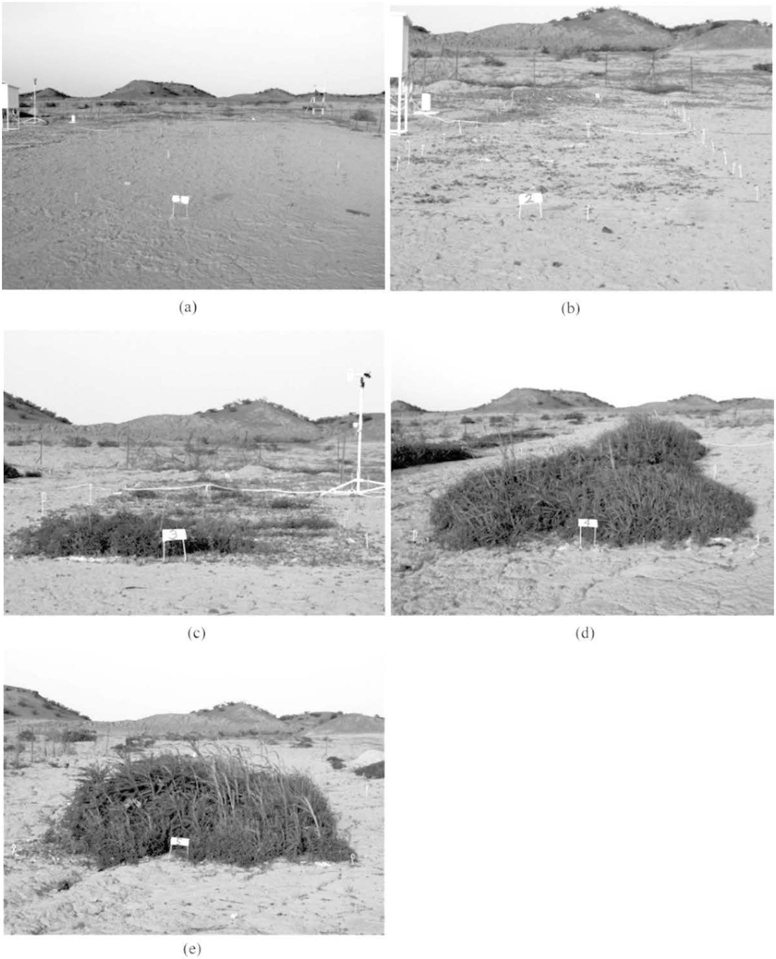
In this 50 × 45 m plot, I made five sub-plots (plots 1 to 5) that extended 4 m in the north-south direction and 30 m in the east-west direction. At 20 m from the east end of the plots, I set two time-domain reflectometry (TDR) sensors for soil moisture at depths of 5 and 20 cm in each plot. These ten sensors measured soil moisture every hour and the data were recorded by a data logger. The temperature, wind direction and speed, and rainfall were also measured and recorded every hour. A technician from the Météorologie Nationale du Niger generously supported my work.

We hired an open Toyota Hilux to carry urban waste from Dogondoutchi town. We measured the weight of the urban waste using a scale (LDS-30H, Shimadzu, Tokyo, Japan; minimum scaling unit was 0.01 kg). Plot 1 was a control and did not contain any urban waste. We placed 5 kg/m^2 (total 600 kg) of urban waste in plot 2; 10 kg/m^2 (1,200 kg) in plot 3; 20 kg/m^2 (2,400 kg) in plot 4; and 45 kg/m^2 (5,400 kg) in plot 5. We placed waste into a flat iron pan and measured the amounts with the help of 15 villagers. One villager levelled the waste on the ground with worn out sandals and said to me, "This trial is very good, and many plants will grow from the urban waste. I will buy this land for sowing millet." He said this to me repeatedly.

The in-situ experiment revealed that urban waste inputs to degraded land improve plant growth through a combination of the eight factors described below (Figure 13). The arenosol soil type[3] is prone to damage from water and

3 The arenosol soil type - one of the typical poor soils in Africa - is also found in Namibia. According to Prudat et al. (2018), local farmers recognize this soil type as *Omufitu* and its suitability for pearl millet is poor. Prudat et al.'s paper integrated the farmers' assessment and technical knowledge in order to develop the practical soil quality assessment.

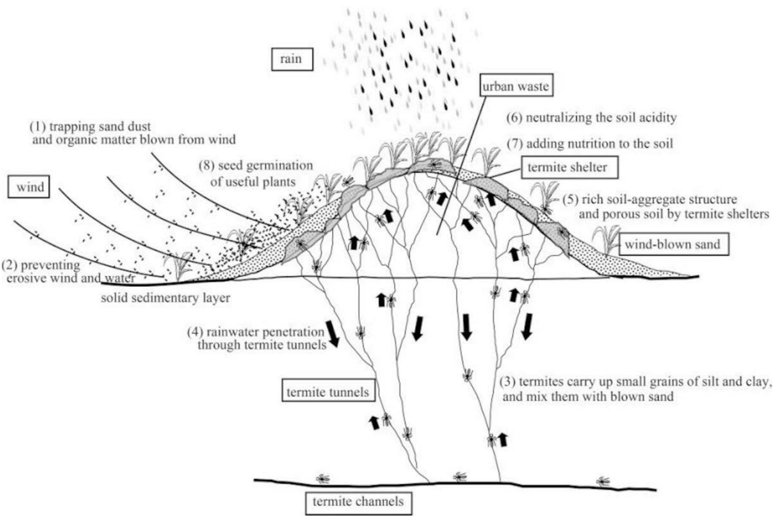
Figure 12: Experimental plots two years after being established (August 2010)



(a) Plot 1: control plot, no waste input. (b) Plot 2: urban waste input 5 kg/m^2. (c) Plot 3: urban waste input 10 kg/m^2. (d) Plot 4: urban waste input 20 kg/m^2. and (e) Plot 5: urban waste input 45 kg/m^2

wind erosion (Bleich and Hammer 1996), but low mounds with a range of elevations superimposed on a flat topography can trap sand and organic matter that is blown by the strong east winds (first effect of Figure 13). This is the same technique that Michels et al. (1995) used to alleviate the effects of wind erosion using millet residue, but crop residues do not usually remain in the field in this region because of livestock grazing and termite decomposition. Local people collect crop residue and take it to their homesteads, where it is eaten by livestock. The Hausa people welcomed the addition of plastic sandals, bags, metal pots and plates in the waste scattered onto their fields: because these items do not easily decompose and are not affected by the termites, they cover the soil and trap windblown sand for longer than organic waste. These wastes prevent erosive wind and water (second effect).

Figure 13 Eight effects of urban waste inputs used for land restoration



I also considered the various effects of elevated termite activity due to the waste input. Most of the waste consisted of millet stalks and leaves, leftover livestock feed and animal excreta. Waste inputs encourage termites to gather. Termite guts and nests contain symbiotic microorganisms such as bacteria, protozoa and fungi that decompose cellulose and lignin, fix nitrogen and produce methane (Benemann 1973, Lee and Wood 1971). These biological activities alter the chemical properties of the soil and, as a result, termite mounds can contribute to high levels of soil fertility (Adepegba and Adegoke 1974, Bagine

1984, Benemann 1973, Pomeroy 1976). As a result of this termite activity, termite shelters develop over the organic matter, these containing concentrated amounts of organic matter. Termites also dig up small grains of clay and silt particles in the soil and mix them with windblown sand (third effect). Termite tunnels also penetrate the sedimentary layer, allowing rainwater to infiltrate easily through the tunnels (fourth effect), and an aggregated soil structure is created as the termites stick grains of sand together with their saliva as they build their mounds. Our observations showed that the aggregated soil structure was porous, allowed plant roots to grow and easily penetrate the soil, and contained oxygen and moisture, both of which are necessary for plant growth (fifth effect).

These factors ameliorate the poor natural nutrient content and strong acidity, as indicated by the low pH of the parched and degraded land. Organic matter, including livestock excreta, contains large amounts of nitrogen, phosphate and potassium, and significantly improves the chemical properties of the soil. Urban waste and excreta are neutral to alkaline, and neutralize the soil acidity (pH 4.5) of the degraded land (sixth effect), as well as adding nutrients to the soil (seventh effect).

Finally, urban waste contains seeds of many edible plant species, including millet, *Hibiscus sabdariffa*, *Balanites aegyptiaca* and many other plants that are suitable as feed for livestock (eighth effect). In Sahel, the seeds of the predominant crop and fodder grass are very small and easily mixed in the urban waste. These germinate naturally with the arrival of the rainy season; in the experimental plots we set up, the seeds germinated and grew thanks to the presence of the moisture and nutrients derived from the waste.

The eight effects described above can be combined to improve soil fertility and plant growth productivity. According to the estimations of the villagers, plant growth in plot 3 was not sufficient, but in plots 4 and 5 growth was sufficient to provide fodder for livestock. In conclusion, the minimum amount of urban waste that should be applied to degraded land to ensure plant growth productivity is 20 kg/m^2, a depth of 3 cm. However, after three years of waste input without further land management, land degradation began again.

3.6.1. Safety issues with urban waste

I have frequently received questions, comments and criticism regarding the toxicity of urban waste following its application in the environment. For example, I have been asked if there are instances where livestock have died after eating plastic bags. The animals, including cattle, sheep, goats, camels and donkeys in the Sahel sometimes did eat plastic bags together with fresh food, but they would never eat plastic bags with spoiled food. The animals have a good sense of smell. We usually allowed the livestock to enter the fenced pastureland after a period of more than three months following the deposition of the urban waste. The livestock never ate plastic bags at that time. Anyway, I was strongly conscious of avoiding the risk of contamination.

I examined the safety of urban waste for land restoration practices and analysed the heavy metal concentration of 100 waste samples in the capital Niamey using energy dispersive x-ray spectrometry (EDX-700HS, Shimadzu). Only five samples had harmful levels of heavy metals (bromine, chrome and lead). These samples were collected from long-term waste dumped at the roadside, in street ditches and in an industrial area (Figure 14). The urban waste disposed of directly from homesteads met the safety requirements of European Union environmental standards. We assume that all urban waste will contaminate the environment, but actual urban waste from Niamey city does not contain high levels of pollutants.

Consequently, we can maintain the safety of urban waste for the land restoration project by avoiding the use of long-term waste dumped at roadsides, in street ditches, in the marginalized greenbelt and in industrial areas. I was able to recognize the safety of urban waste which was dumped immediately from the house yards. According to chemical analysis, urban waste contains beneficial materials such as nitrogen, potassium, phosphate, copper, iron, magnesium, calcium, manganese, sodium and zinc, which are essential for humans and livestock (Oyama 2015b).

3.6.2. Collecting waste from the city administration to resolve the financial deficit problem

After a coup d'état in February 2010, a military regime was established in Niger. Soldiers took over the city administration in Dogondoutchi in an operation that lasted until the election of January 2011. I returned to Niamey in October 2011. The next day, I went to Nouveau Marché with my research partner. We bought a 200 m long fence, wire, an entrance door, paint and a brush for construction of the experimental site. We went to Dogondoutchi City Hall to get a permit to collect urban waste. We met the mayor and explained our three objectives: (1) to collect urban waste and therefore clean the residential area and streets; (2) to restore the degraded land back to pastureland in the

Figure 14: Contaminated urban waste at five sites

Pb-1 to Pb-3: Lead was detected at three sites of street ditch and ash; Cr-1: Chrome was detected in long-term dumped waste; Br-1: Bromine was detected from the road-side.

fenced area using the urban waste; and (3) to prevent conflicts between farmers and herders by allowing the herdsmen to graze their livestock on the pastureland during the harvest season. The mayor understood the aims of our project, but explained that there was a budget shortage due to the military regime. There were 28 civil servants working in Dogondoutchi at the time, and they did not receive a salary under the military regime. The waste disposal trucks were not maintained properly and all of them were out of service. During this period, the city was not collecting waste from the urban area and after the election the conditions did not improve due to a financial deficit. The city was unable to cope with the waste accumulation and dirtiness in the urban area. The mayor therefore thanked us for cleaning the city and using the urban waste for land restoration. We made an agreement with Dogondoutchi City Hall, which was detailed in formal documents.

The mayor introduced me to a tractor owner: he was among the wealthiest merchants in Dogondoutchi, owning a hotel, restaurant, several shops, 200 ha of farmland, several hundred cattle, sheep and goats, and a garden of mango trees and vegetables in a wetland area. He also owned dozens of houses that were rented out, and had seven vehicles, including one Toyota land cruiser, one truck and two tractors. He was engaged in the construction of government buildings, including the city hall, an official residence and water wells.

He considered the introduction from the mayor and provided me with two tractors without rental fees. I paid for the fuel and labour costs for waste transportation. One journey from the town to the experimental site cost 8,000 CFA francs (16 USD). The size of the carriage was 310 cm (length) × 180 cm (width) × 60 cm (height). Six young men used shovels to haul the waste into the carriage. I selected waste that had been recently disposed of in the residential area in order to avoid issues of contamination.

I recorded the initial weight of the transported waste. Before letting the 15 villagers begin to work, I requested that they wear masks. The temperature was higher than 40°C and the masks made it uncomfortable to breathe, but the workers were required to wear the masks all the time because strong wind sometimes blew the waste and dust. The first carriage transported 1.80 tons of urban waste, containing millet straw and stems, and pruned branches. The urban waste in the second and third carriages contained large amounts of sand and weighed 3.31 and 3.27 tons, respectively. The tractor driver considered that urban waste containing large amounts of sand would be suitable for land restoration. We calculated the average weight of urban waste per carriage to be 2.8 tons. Because an ox cart can carry 400 kg, this amount was equivalent to seven ox carts.

According to my previous experiment, at least 20 kg/m^2 of urban waste (i.e. the amount used in plot 4) was necessary for land restoration. We estimated that 50 tons of urban waste would therefore be necessary in a 50 × 50 m plot. This amount was equivalent to 18 tractor loads. To use the same amount as that applied to plot 5 (45 kg/m^2), the amount of urban waste required would be 112.5 tons, which was equivalent to 40 tractor loads (Figure 15).

Figure 15: Building an experimental plot for restoring the land by urban waste

I hired twenty village men in order to support their livelihoods. We dug ditches to prevent rainwater from flowing away from the urban waste. To prevent the wind from blowing away plastic bags, we also carefully placed sand and sedimentary rocks on any loose plastic material.

The urban waste contained a range of items including worn out sandals, clothes for women, trousers for men, pots, plastic shopping bags, vinyl bags used to contain milk and mineral water, and empty boxes of tobacco. The bones and dung of livestock were found in the waste, as well as human excrement. These items were suitable for land restoration inside the fence, but were regarded as contamination outside the fence.

The distance from the experimental fence to the village well was more than 1 km and the water depth in the well was more than 40 m. We therefore did not need to worry about the possibility of ground water contamination, but I decided to dig ten long ditches and 20 half-moon shaped ditches to prevent rainwater from flowing away from the urban waste over the land surface.

3.6.3. Inviting livestock into the fenced pastureland

In September 2012, I came back to the village with three graduate students from my university. I went to observe the experimental site as soon as we arrived at the village. The students followed me to the site. In front of us, green plants had spread across the degraded land (Figure 16). We counted 39 plant species, including seven tree species inside the fenced site. In the first year, the dominant species were crops such as millet, sorghum, watermelon, pumpkin and groundnuts, and fodder species of *Poaceae* and *Leguminosae*. Seeds of these species were present in the urban waste. Baobab tree, *Adansonia digitate*, was present as an ingredient in soups and snacks (Figure 17). People eat the raw fruit of *Piliostigma reticulatum* and the leaves and seeds of *Balanites aegyptiaca*. The leaves of *B. aegyptiaca* taste bitter, but are regarded as the "final" famine food by the villagers: they eat this plant for survival in times of famine. Fruits of the date palm are produced near the Sahara Desert and are transported from Agadez to the Sahel towns in Niger. This is a popular food item among urban dwellers and they dispose of the seeds after consuming the fruit (Figure 18).

Figure 16: Plant survey on the first-year plot

Figure 17: A Fulbe woman collecting baobab leaves on the plot

My Fulbe informant considered there to be sufficient fodder for livestock in the fenced plot in terms of the variety and quantity of plants. I became aware that he was reluctant to allow his livestock to enter the fenced site. I requested that he graze his livestock inside the fenced pastureland, and his son brought 40 cows and 12 sheep to the site. After they approached the site, the livestock stopped at the front of the door and hesitated to enter. In a joint effort, we chased the livestock into the site. When the livestock entered the site, they started to panic and run around. After a while, they calmed down and began to eat the grass (Figure 18).

Another Fulbe herder who lived in a neighbouring village asked me, with some hesitation:

> "I cordially request you to build a fenced site in the same way and carry the urban waste to my village. All of the Fulbe suffer from a shortage of pastureland. We are frightened that the farmers will attack us someday in the near future."

He spoke in Hausa with idiosyncratic pronunciation. Nevertheless, I understood his request and made a promise to build the fenced pastureland.

Figure 18: Livestock eating in the grassland created from the urban waste

3.7. Conflict prevention and livestock-induced land restoration

In the Sahel, the number of armed conflicts between farmers and herders has increased in recent years. According to the Global Terrorism Index 2015 (IEP 2015), there were 1,229 deaths attributed to Fulani (Fulbe) militant attacks in 2014, which was a substantial increase from the 63 deaths recorded in 2013. Fulbe communities have come into dispute with farming communities over resources. Fulbe militants have used machine guns and attacks on villagers to assault and intimidate farmers. To achieve regional stability, it is necessary to avoid armed conflict between the farmers and herders and to stabilize the livelihood of the small number of herders (Turner et al. 2011). Most of these armed conflicts have been caused by livestock-induced crop damage (Oyama 2014).

Livestock-induced crop damage has worsened the relationship between farmers and herders in two ways (Oyama 2014). Firstly, careless herders lose sight of their livestock, which then eat the millet in the farmland, leading to non-intentional livestock-induced crop damage (Figure 19). Secondly, there is intentional livestock-induced crop damage, where herdsmen deliberately enter farmland with their livestock and let them consume crops. The farmers are most concerned about intentional crop damage.

Figure 19: Night grazing

Cattle wake up at 10:00 pm every night and start wandering away from the grazing camp. The herdsmen follow the livestock as they start night grazing. To fatten the livestock, night grazing is an important activity. Most of the herders do not have flashlights. They check the position of livestock using moonlight, but they sometimes lose sight of the animals on dark nights.

Many armed conflicts have occurred between farmers and herders following disputes over livestock-induced crop damage. Farmers sometimes use abusive words to the young herders while the animals are grazing. Some of them jump to the conclusion that the livestock must have entered their fields and consumed their crops. Young herders are angered by the insults and fight back against the farmers. Farmers have also physically attacked herders who were intentionally grazing livestock on their farmland.

Due to the rapid population increase, cash economy and market activities, the area of farmland is expanding and the area of pastureland is decreasing rapidly. There has been a persistent misconception of the nature of pastoral economies, combined with increasing land alienation and fragmentation through government policies and privatization of pasture (Haller et al. 2016).[4] At the local level, the herders are finding it difficult to find suitable pastureland. The herders living in the village lost their livestock and their livelihoods due to repeated droughts during the 1970s and 1980s. They now take care of the farmers' livestock and receive a small caring fee and some cows' milk in return. Young farmers are also suffering from a shortage of farmland. The situation is becoming increasingly difficult for both farmers and herders, and the tensions that have arisen have resulted in armed conflict between them.

I was told by one local resident that, "The farmers and herders in the Sahel are friends during the dry season, but become enemies during the rainy season." The armed conflicts are limited to the rainy and harvesting seasons. During this time, the proximity of livestock to farmland is problematic for the local residents. However, the area of farmland and number of livestock have both increased drastically. It is therefore unavoidable that livestock will come into closer proximity with the farmland.

Moritz (2006) suggested that the proximity of livestock to farmland and the subsequent conflicts could be reduced by decentralizing the regional government and authorizing traditional leadership. In the meantime, the number of deaths due to armed conflicts is increasing. However, as Haller (2002) and Haller et al. (2013) show, what is necessary is to find a way whereby the old institutional design can be revitalized, and not decentralization per se, but local involvement in the co-creation of institutions. In addition, a more effective approach is not to rely solely on local authorities but to create a platform for local institutions creating dialogues between farmers and herders. This platform could reduce the proximity of livestock to farmland under these stressful conditions, but large-scale afforestation without social consideration increases the proximity of livestock to farmland and increases the risk of armed conflicts between farmers and herders.

After my field experiment was repeated, I proposed a solution to restore the degraded land and provide pastureland to the small number of herders. According to this plan, we enclosed an area of at least 50 × 50 m with a fence.

4 Following the independence of the Republic of Niger, the successive governments and central administrations consisted of the educated, political, urban elite with ambitions of modernization, continuing to reduce the political, social and economic power of the chiefs. After ten years of continued cultivation, the use right was transformed into a property right under the Dirori government regime (1960–1974) (Lund 1998).

The size of the enclosed area was determined by the surrounding landforms, such as the inselberg and the seasonal river or *wadi*. We collected urban waste and transported it to the site. At the end of the rainy season, the farmers start harvesting millet on their farmland; during this period, there is extreme tension between farmers and herders. The herders allowed their livestock to enter the fenced plot at night. During the night, the livestock grazed inside the fenced site and the herders avoided the night grazing of crops. During the day, the herders could allow their animals to graze freely both inside and outside the fenced sites.

However, if the livestock consume all of the grass, the soil nutrition will deteriorate, and desertification will result. I requested that the herders keep livestock inside the fenced site during the night for at least two weeks after they had consumed all of the grass. This enabled the animal dung to provide soil nutrition for the following year's plant growth, as well as avoiding livestock-induced crop damage and livestock theft during the night.

In October 2017, when the system had been in operation for six years, my Fulbe informant said to me: "Urban waste could create suitable pastureland. The cows are satisfied with the fodder and they can relax under the shade of trees. This is the first time we have seen this during the day time." To meet his needs for the creation of pastureland, we had repeatedly removed unnecessary grass, trees and branches during the six years. He also emphasized the importance of avoiding livestock-induced crop damage and armed conflicts with farmers. He was no longer worried about cattle movement at night and could sleep very well until sunrise (Figure 20). He invited his Fulbe friends and Tuareg neighbours to graze their livestock inside the fenced pastureland and welcomed Hausa women collecting the edible plants and medicinal herbs. The movement can be regarded as the establishment of commonality among the multi-ethnic residents. This commonality is informal based on face-to-face relationships, and can be created naturally by the generous-hearted mind of the residents.

Some farmers complained to me that I gave too much attention to the herders at the expense of the farmers. The farmers' concerns were that they were poor and did not have enough farmland to sustain their livelihoods. Effectively, the livestock that the herdsmen take care of every day are mostly the property of farmers. The herdsmen own less than 20 per cent of the livestock they manage. In my Fulbe informant's herd of 40 cows, he owns only two cows, the other 38 belonging to farmers. The fence construction provides benefits to all residents, not only for the Fulbe herders but also for the Hausa

Figure 20: Pastureland created from urban waste in September 2017

We repeatedly removed unnecessary trees and grass to make pastureland according to the requirements of the Fulbe herders. By the sixth year, the plot represented optimal pastureland for the herders. There was no plastic waste visible on the ground.

farmers whose livestock are fattened. The project also had the aim of preventing armed conflicts between farmers and herders. Such an explanation proved satisfying for the farmers and they had no further complaints.

3.8. Conclusion: urban waste, new institution and combating desertification

From November 2005 to February 2018, we built 34 sites with a total area of 10.03 ha on which urban waste was used to make pastureland.[5] After receiving requests from Fulbe and Tuareg herders around the research village, I

5 In order to expand activities for land restoration, the author received support from the Mitsui & Co. Environment Fund for three years. I would like to show appreciation for their support.

arranged meetings with a herder client, his family and relatives, the village headman and influential persons of the Hausa people in order to discuss the possibility of site construction. They decided the placement of sites and took me to the planned sites. Then I worked at the site with the villagers, including farmers and herders, males and females, the young and the aged, persons with disabilities and so on. The city mayor issued a letter of permission every year for our activities. I gave the photocopied letters to both of the client herders and the village headmen.

My trial was originally based on the local ecological knowledge of Hausa farmers, carrying urban waste to degraded farmland as part of their everyday life. Around 2005, this knowledge began to expand to other towns in southern Niger. Zarma famers in Niamey now also use urban waste to fertilize their farmland. As I noticed the potential to reduce livestock-induced crop damage and armed conflicts, I began to experiment with the technique and to apply this knowledge in the social context. The beneficiaries are not only herders but also farmers, because the herders take care of the farmers' livestock and the farmers can fatten their livestock on the pastureland created. Moreover, both can avoid paying crop compensation for livestock-induced crop damage. This trial implies a win-win relationship, or at least not a complete win-lose situation - a positive fit to the social-environmental system, indicated by Haller et al. (2013).

I consider my trials, based on local ecological knowledge, as reverse thinking. From the perspective of outsiders, when considering the rural area of the Sahel, we tend to focus on the negative effects of plastic bags and vinyl products, but I was more concerned with the positive effects of combating desertification. Firstly, plastic bags can prevent soil moisture evaporation from the ground under conditions of strong sunshine and high temperature. Secondly, they can catch windblown sand and organic matter and retain it on the degraded land. Thirdly, the plastic bags create a suitable environment for termite colonies. Termites are regarded as harmful insects that damage wooden houses, but they create suitable physical conditions in soil for plant growth, as mentioned by Holt and Lepage (2000). These effects are promoted by the presence of plastic bags.

It is easy for outsiders living in developed countries to criticize the ignorance and mindlessness of farmers with regard to food and environmental safety by applying urban waste to their farm and pastureland. If I had not applied the urban waste to the degraded land in order to create new pastureland, I would not have understood why numerous farmers would continue to collect urban waste from towns and apply it to their farmland. For the farmers living in southern Niger, the urban waste is an important resource for improving soil fertility and restoring their farmland. It is used to prevent land degradation. If we tell them to stop this practice, they will reply, "How can we maintain soil fertility in the face of land degradation?" and "How can we harvest enough millet to sustain our families?"

This practice has to be considered against the large-scale initiatives of the Great Green Wall for the Sahara and the Sahel Initiative, with high investments and overall rather limited effects. It is a small-scale practice that restores degraded land and enables more understanding and the building of sustainable relations between the multi-ethnic and diverse resource users.

Currently, the prevention of desertification, poverty, hunger, armed conflict and terrorism is a serious problem in the Sahel, and there are trade-offs to be considered when highlighting environmental concerns related to the use of urban waste. In recent years, the international community has given much attention to hunger, poverty and terrorism in the Sahel because it is strongly linked to immigration problems in European countries. It is extremely difficult to solve all the problems in the region, but it is my opinion that military operations will not be sufficient to prevent armed conflicts and terrorism. Hunger and poverty are the drivers of armed conflicts and terrorism in the Sahel and, in turn, armed conflicts and terrorism further exacerbate hunger and poverty. Both natural and anthropogenic factors have increasingly combined to generate conflicts over the available resources in the Sahel.

Under these severe conditions, a deadlock has been reached, preventing the situation from being resolved. There is no room for afforestation in the farmland and many afforestation projects have attempted to chase the herders and their livestock away to protect tree seedlings. By combining scientific and local ecological knowledge, we can aim to combat desertification, hunger and poverty, and prevent armed conflicts and terrorism, with the cooperation of the residents, including urban dwellers, rural farmers and herders. Reverse thinking and counter-intuitive approaches combining local and scientific knowledge could provide mitigation effects which create room for potentially better and more sustainable solutions.

Acknowledgements

The author would like to express deep appreciation to Tobias Haller and Claudia Zingerli for offering insightful and stimulating comments on this paper.

This research was carried out with financial support from the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (KAKENHI 17H04506 and 17H02235)

3.9. References

Adamu, M. (1978). The Hausa factor in West African history. Ibadan: Ahmadu Bello University Press.

Adepegba, D. and Adegoke, E. A. (1974). A study of the compressive strength and stabilizing chemicals of termite mounds in Nigeria. Soil Science, 117(3), 175–179.

Ayantunde, A. A., Williams, T. O., Udo, H. M. J., Fernandez-Rivera, S. Hiernaux, P. and van Keulen, H. (2000). Herders' perception, practice, and problems of night grazing in the Sahel: Case studies from Niger. Human Ecology, 28(1), 109–130.

Bagine, R. K. N. (1984). Soil translocation by termites of the genus Odontotemes (Holmgran) (Isoptera: Macrotermitinae) in an arid area of northern Kenya. Oecologia, 64, 263–266.

Baier, S. (1980). An economic history of central Niger: Oxford studies in African affairs. Oxford: Clarendon Press.

Benemann, J. R. (1973). Nitrogen fixation in termites. Science, 181(4095), 164–165.

Bleich, K. E. and Hammer, R. (1996). Soils of Western Niger. In: Buerkert, B., Allison, B. E. and von Oppen, M. (eds.). Wind erosion in Niger: Implications and control measures in a millet based farming system (pp. 23–32). Dordrecht: Kluwer Academic Publishers.

Brouwer, J. and Powell, J. M. (1998). Increasing nutrient use efficiency in West African agriculture: The impact of micro-topography on nutrient leaching from cattle and sheep manure. Agriculture, Ecosystems and Environment, 71, 229–239.

Crang, M. and Cook, I. (2007). Doing ethnographies. Los Angeles: Sage Publications.

Dregne, H. E. (1986). Desertification of arid lands. In: El-Baz, F. and Hassan, H. A. (eds.). Physics of desertification (pp. 4–34). Dordrecht: Springer.

Fairhead, J. and Leach, M. (1995). False forest history, complicit social analysis: Rethinking some West African environmental narratives. World Development, 23(6), 1023–1035.

Gonzalez, P. (2001). Desertification and a shift of forest species in the West African Sahel. Climate Research, 17, 217–228.

Graef, F. and Haigis, J. (2001). Spatial and temporal rainfall variability in the Sahel and its effects on farmer's management strategies. Journal of Arid Environments, 48, 221–231.

Haller, T. (2002). Common property resource management, institutional change and conflicts in African floodplain wetland. The African Anthropologist, 9(1), 25–35.

Haller, T. (2003). Rules which pay are going to stay: Indigenous institutions, sustainable resource use and land tenure among the Ouldeme and Platha, Mandara Mountains, Northern Cameroon. In: Le Meur, P-Y. and Lund, C. (eds.). Everyday governance of land in Africa (pp. 117–134). APAD-Bulletin No 22. London: Lit Verlag.

Haller, T., Fokou, G., Mbeyale, G. and Meroka, P. (2013). How fit turns into misfit and back: Institutional transformations of pastoral commons in African floodplains. Ecology and Society, 18(1), 1–16.

Haller, T., van Dijk, Bollig, M., Greiner, C., Schareika, N. and Gabbert, C. (2016). Conflicts, security and marginalisation: Institutional change of the pastoral commons in a "glocal" world. Revue Scientifique et Technique (International Office of Epizootics), 35(2), 405–416

Heiss, J. P. (2015). Musa: An essay (or experiment) in the anthropology of the individual. Berlin: Duncker and Humbolt.

Hill, P. (1972). Rural Hausa: A village and a setting. Cambridge, UK: Cambridge University Press.

Holt, J. A. and Lepage, M. (2000). Termites and soil properties. In: Abe, Y., Bignell, D. E. and Higashi, T. (eds.). Termites: Evolution, sociality, symbioses, ecology (pp. 389–407). Dordrecht: Kluwer Academic Publishers.

IEP (Institute of Economics and Peace) (2015). Global Terrorism Index 2015. Measuring and understanding the impact of terrorism. IEP Report 36. Sydney, News York, Mexico City: IEP

Lee, K. E. and Wood, T. G. (1971). Termites and soils. London: Academic Press.

Leisinger, K. M., Schmitt, K. and ISNAR. (1995). Survival in the Sahel. The Hague: International Service for National Agricultural Research.

Lund, C. (1998). Law, power and politics in Niger: Land struggles and the rural code. Hamburg: Lit Verlag.

Michels, K., Sivakumar, M. V. K. and Allison, B. E. (1995). Wind erosion control using crop residue II: Effect on millet establishment and yields. Field Crops Research, 40, 111–118.

Moritz, M. (2006). The politics of permanent conflict: Farmer-herder conflicts in northern Cameroon. Canadian Journal of African Studies, 40, 101–126.

Mortimore, M. and Turner, B. (2005). Does the Sahelian smallholder's management of woodland, farm trees, rangeland support the hypothesis of human-induced desertification? Journal of Arid Environments, 63, 567–595.

Oyama, S. (2009). Ecological knowledge of Hausa cultivators for the land degradation process in Sahel, West Africa. Geographical Reports of Tokyo Metropolitan University, 44, 103–112.

Oyama, S. (2012). Land rehabilitation methods based on the refuse input: Local practices of Hausa farmers and application of indigenous knowledge in the Sahelian Niger. Pedologist, 55(3), 466–489.

Oyama, S. (2014). Farmer-herder conflicts, land rehabilitation, and conflict prevention in Sahel region of West Africa. African Study Monographs, 50(supplementary), 103–122.

Oyama, S. (2015a). Land degradation and ecological knowledge-based land rehabilitation: Hausa farmers and Fulbe herders in the Sahel region, West Africa. In: Reuter, T. (ed.). Averting a global environmental collapse: The role of anthropology and local knowledge (pp. 165–185). Cambridge, UK: Cambridge Scholars Publishing.

Oyama, S. (2015b). Tackling the land degradation in Sahel region of West Africa: Trash input for land rehabilitation, food security and conflict prevention. Kyoto: Showado (in Japanese).

Oyama, S. (2017). Hunger, poverty and economic differentiation generated by traditional custom in villages in the Sahel, West Africa. Japanese Journal of Human Geography, 69(1), 27–42.

Oyama, S. and Mammane, I. (2010). Ecological knowledge of Hausa cultivators and in situ experiment of the land rehabilitation in Sahel, West Africa. Geographical Repots of Tokyo Metropolitan University, 45, 31–43.

Pomeroy, D. E. (1976). Some effects of mound-building termites on soils in Uganda. Journal of Soil Science, 27, 377–394.

Prudat, B., Bloemertz, L. and Kuhn, N. (2018). Local soil quality assessment of north-central Namibia: Integrating farmers' and technical knowledge. Soil, 4, 47–62.

Richards, P. (1985). Indigenous agricultural revolution: Ecology and food production in West Africa. London: Unwin Hyman.

Schlecht, E. and Buerkert, A. (2004). Organic inputs and farmers' management strategies in millet fields of western Niger. Geoderma, 121, 271–289.

Shinjo, H., Hayashi, K., Abdoulaye, T. and Kosaki, T. (2008). Management of livestock excreta through corralling practice by sedentary pastoralists in the Sahelian region of West Africa: A case study in southwestern Niger. Tropical Agriculture and Development, 52(4), 97–103.

Suzuki, L., Matsunaga, R., Hayashi, K., Matsumoto, N., Tabo. R., Tobita, S. and Okada, K. (2014). Effects of traditional soil management practices on the nutrient status in Sahelian sandy soils of Niger, West Africa. Geoderma, 223–225, 1–8.

Tschakert, P. (2007). Views from the vulnerable: Understanding climatic and other stressors in the Sahel. Global Environmental Change, 17, 381–396.

Turner, M. D., Ayantunde, A. Patterson, K. P. and Patterson, E. D. (2011). Livelihood transitions and the changing nature of farmer-herder conflict in Sahelian West Africa. Journal of Development Studies, 47(2), 183–206.