Land Rehabilitation Methods Based on the Refuse Input: Local Practices of Hausa Farmers and Application of Indigenous Knowledge in the Sahelian Niger

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Abstract

In developing methods and land care system in Sahel of Sahel of West Africa, the Hausa farming practice of scattering refuse over the degraded land for improving soil productivity holds promise. When the fields become degraded, the Hausa scatter livestock manure as well as household refuse and sometimes urban refuse over their land. The organic matter improves the soil quality. The author carried out an *in situ* experiment, using multiple plots scattered with varying amounts of urban refuse over three years, to quantify the soil improvement effect of the refuse scattering practice, which increased termite activity in the soil as well. According to the plant growth observation, the critical amount of urban refuse was at least 20kg/m^2, approximately 2 cm thick on the ground, for land rehabilitation. The results revealed that the Hausa practice was able to regenerate grassland and to prevent soil erosion and exposure of the sedimentary layer. After two years from refuse input, the plant growth began to deteriorate. In order to maintain plant productivity recovered using urban refuse, it is necessary for continuous input of refuse to compensate for nutrition depletion from the plant remove and soil erosion.

1. Introduction

Land degradation, or desertification, has brought about crop failure, food shortage, malnutrition of the people, let alone financial hardship to the Sahelian nations. The Sahel Drought of 1972-1974 and the resultant resource crisis were understood by international academe as having 5 dimensions: drought, poor food supply, inadequate livestock management, environmental degradation, and overdrawn household coping capabilities (Mortimore and Adams 2001).

In the Sahel countries, numerous projects were undertaken to conserve the land, protect the natural resources, achieve development, and alleviate poverty. One of the major project concepts was the greenbelt, which is a strip of tree plantation ring-fencing the urban areas to protect cities from sand encroachment and erosion. In 1965, the Republic of Niger put up a 2,500 ha greenbelt around the capital, Niamey, consisting of local and introduced species. Mali, Mauritania, Senegal, and Burkina Faso, have also initiated greenbelt projects. The projects had 5 aims: (1) protect land against sand encroachment, (2) fight against erosion and improve crop production, (3) produce firewood and reduce pressure on existing natural forests, (4) develop and manage the natural forests, and (5) supply fodder for pastoral production (Sahara and Sahel Observatory 2008).

At the second EU-Africa Summit in 2007, the European Union (EU) and the African states agreed to implement a large-scale green wall project, the “Great Green Wall Initiative of the Sahara and the Sahel,” across the vast Sahara. The project activities started in Algeria, Burkina Faso, Chad, Djibouti, Egypt, Ethiopia, Mali, Mauritania, Niger, Nigeria, Senegal, Sudan, and Gambia,

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to push back desertification and to help agriculture and livelihoods in the region. In September 2011, the EU and Food and Agriculture Organization of the United Nations (FAO) decided to endorse 1.75 million euro to this project to adopt a more ecologically appropriate and socioeconomically sustainable, holistic approach, more effective and directly benefiting the local land and water users through identification and up-scaling of the best land management practices (Europafrica.net 2011).

The main subsistence activities of the Sahel region are cultivation and grazing. The main crops are maize (*Zea mays*) and cassava (*Mahnichot exculenta*) in the south, sorghum (*Sorghum bicolor*) in the center, and pearl millet (*Penisetum glaucum*) in the north. Rain falls only on the periphery of the Sahara and agriculture is limited. Raising animals is predominant, and the pastoral peoples continue to move with their livestock. The nomadic Fulbe (Fulani) people mostly keep cattle, and the Tuareg people keep camels and goats. Historically, the settled cultivators have built socioeconomic relationships for maintaining subsistence with the nomads in the Sahel region (Baier 1980; Oyama 2002). The farmers provide pearl millet and sorghum, cotton clothing, wooden and iron goods to the pastoral peoples in exchange for products from domestic animals. The pastoral peoples contract with the cultivators to set up camps in the fields of their farming partners for several weeks to months. The livestock graze around the camp and stay in the camp during nighttime. The cultivators provide substantial meals, and pay rewards after the contract periods. The domestic animals provide excreta, and the cultivators see improvements in the soil fertility in their fields (Harris 1999; Shinjo *et al*. 2008).

The Sahel area has seen high population growth. Senegal has an increase of 2.4% per year, Mali has 3.3%, Burkina Faso has 2.8%, and Niger, 3.7% (United Nations 2010). With such growth, the population is calculated to double in 31 years in Senegal, 23 years in Mali, 27 years in Burkina Faso, and 20 years in Niger. The expansion in cultivation and livestock grazing given the high population growth is excacerbating the environmental pressure on land and imperilling the soil. Against such desertification, international countermeasures started in the 1970s, whose core policy was planting trees. However, the process and effect are underperforming, and several droughts since have precipitated even larger desertification and numerous corollary problems that affect the dry, semidry, and subhumid areas worldwide (Kadomura 1988; 2001). Without soil improvement, revegetation of the already degraded land is limited in its effectiveness.

Rapid population increase, low technology in agriculture, and overgrazing are considered to be causing land degradation in the Sahel area (Ayatunde 2000; Mortimore and Turner 2005; Tschakert 2007). The farmers in Niger claim that the proportion of cultivated fields to fallow fields increased from the mid 1980s to the present. The actual fallow periods are too short to allow for sufficient soil fertility recovery, and the farmers are aware of this problem (Wezel and Haigis 2002). Gritzner (1988) made 7 proposals against the environmental degradation: (1) wadi (seasonal drainage) head planting, (2) dune stabilization and tree restoration of the regional forest, (3) establishment of shelter belts and modern energy systems for the urban areas, (4) rehabilitation of peri-urban areas, (5) conservation of endangered species and biological diversity reservoirs, (6) diversion of surplus river water into regional depressions, and (7) improved natural forest management.

Although the settlers of the Sahel area, both farmers and nomads, are regarded as contributors to desertification, there has been little research that examines the people's recognition and the indigenous countermeasures against land degradation. The adaptive capacity of the residents has been underestimated in the past, and makes it difficult to assess their measures. Recent research has shown that the awareness of the local residents as to land degradation was consistent with the scientific soil information (Hayashi *et al*. 2000a, 2000b; Warren *et al*. 2003; Oyama 2009). This article identifies the indigenous soil knowledge, daily practices and countermeasures of the Hausa farmers against land degradation, and to examine the plant recovery effects of urban refuse input practice with an *in situ* experiment to develop further land rehabilitation methods and land care system.

2. Research Area

The research area was Dogondoutchi region, Department of Dosso, Republic of Niger (Fig. 1). The

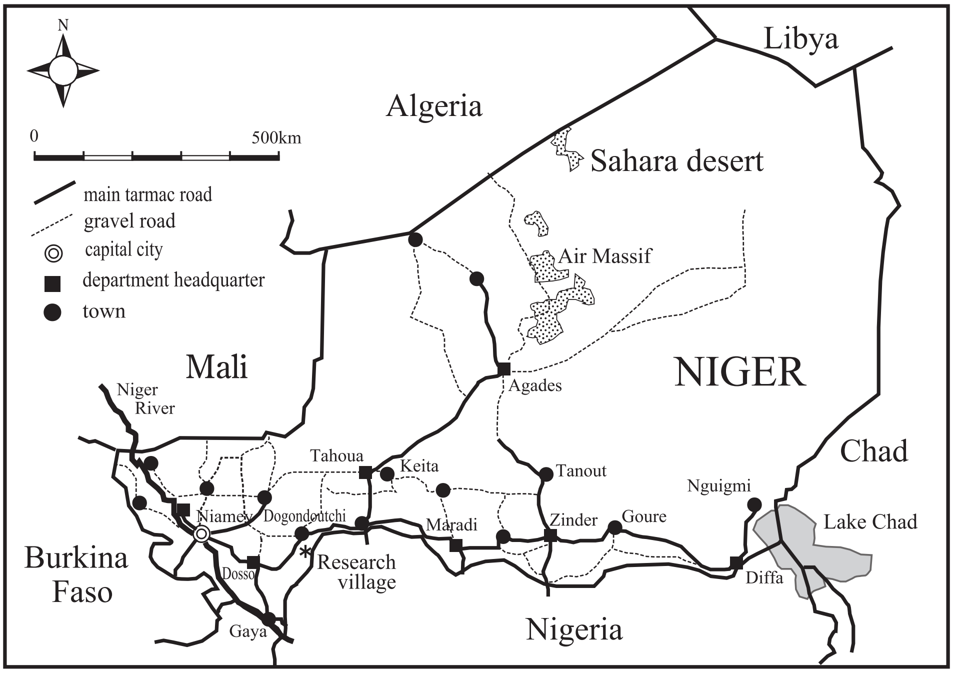

Fig. 1. Research area of southern central Niger

altitude of the village is 240 m. The population of the village is 310 persons, with 60 households in 2010. The villagers are Hausa cultivators, except for a household each of pastoral Fulbe and Tuareg people. Both Fulbe and Tuareg households simultaneously cultivated millet and grazed livestock. The Hausa also maintained their livelihood with millet farming and attendant grazing.

The author measured rainfall (using Climatec Inc., CTK-15PC), temperature (Vaisala, HMP45A, at 1.5m high), and wind (Young, CYG-5103, at 3 m high) from November 2008. The rainy season in the research village was from June to September, and the precipitation was 453 mm in 2009, 525 mm in 2010 and 389 mm in 2011. The national meteorological station in Dogondoutchi started taking measurements in 1923 and the average precipitation was 465 mm during the 30 years from 1981 to 2010. The dry season spans eight months, from October to May. The maximum temperature usually reaches higher than 35 C° during the periods of October to November and February to May. The minimum temperature is below 20 C° in the morning, and rises rapidly immediately after sunrise. As a meteorological feature, daily temperature variation is large.

Wadi flows from east to westward at the north and south of the village site. Water flows immediately after rainfall. Based on the metrological measurements, the village is exposed to air turbulence and violent winds, stronger than 20 m/s, immediately before a rainfall. At times wind speed exceeds 10 m/s, blowing from the directions of east, northeast, and southeast. The strong wind raises a sandstorm from eastward. During the dry season, dry, hot wind blows from northward and eastward, and this wind is called Harmattan. Harmattan causes air turbulence and wind erosion on the ground.

The soil type of the research area is Arenosols (FAO/UNESCO 1971). Arenosols is a sandy soil with poor organic matter, organic nitrogen, and phosphoric acid. The distribution of this soil type is over a wide area of central Mali, southern Niger, and northern Chad. This type of distribution is regarded as dryland highly susceptible to water and wind erosion (Middleton and Thomas 1997).

3. Methods

The author aimed to elucidate the revegetating effects of urban refuse input on the solid sedimentary layer occurring in degraded land. A fenced area of 45 m north-south by 50 m east-west kept out people and livestock with barbed wire in August 2008. The area was sloped east to west by 3° within which five 4 m by 30 m plots were prepared (Fig. 2). Each plot was equipped with 2 TDR soil moisture sensors (Campbell Scientific Inc. C-CS-616: resolution 0.1%, accuracy ± 2.5 %) at 20 m from each eastern edge buried at 5 cm and 30 cm deep, respectively. Soil was observed until 30 cm deep at the time the TDR sensor was buried in August 2008 and soil color was classified using Standard Soil Color Charts. Soil hardness was also measured 5 times using a soil hardness tester (Fujiwara Scientific Company Ltd., Yamanaka Pocket type) and the average was calculated. Soil samples were taken at 0-5, 10-15, and 25-30 cm depth. The soil moisture sensor was buried close to the original state as possible.

In November 2008, the author began the urban refuse project on each plot. No refuse was scattered onto Plot 1 for comparison. Plot 2 was scattered with 600 kg (5 kg/m^2) of refuse, Plot 3 with 1,200 kg (10 kg/m^2), Plot 4 with 2,400 kg (20kg/m^2), and Plot 5 with 5,400 kg (45 kg/m^2) of refuse (Fig. 3). The refuse was brought by tractor from the town of Dogondoutchi 7 km away from the village. The refuse had much sand, plant residue from livestock feed, animal excreta, used plastic bags, old cloth and sandals, broken pots and plates. To take into account the future use of such refuse against land degradation, the author left the nonorganic matter in the refuse (Fig. 3). The author conducted a three-point random sampling of the urban refuse as it was scattered on the plots. After this, rainfall, air temperature and humidity, and soil moisture (volumetric water content) were taken at one-hour intervals, which were automatically recorded using a data logger (Campbell Scientific Inc. C-CR1000). Data was taken for 1,042 days from 1 November 2008 to 8 September 2011.

After refuse was scattered, no plant was sown to the plots to observe the changes in soil property and plant germination. In June 2009, 7 months after scattering the plots with refuse, soil 30 cm deep was observed, and the layers were classified using Hausa terms as well as the color charts, and hardness was measured five times,

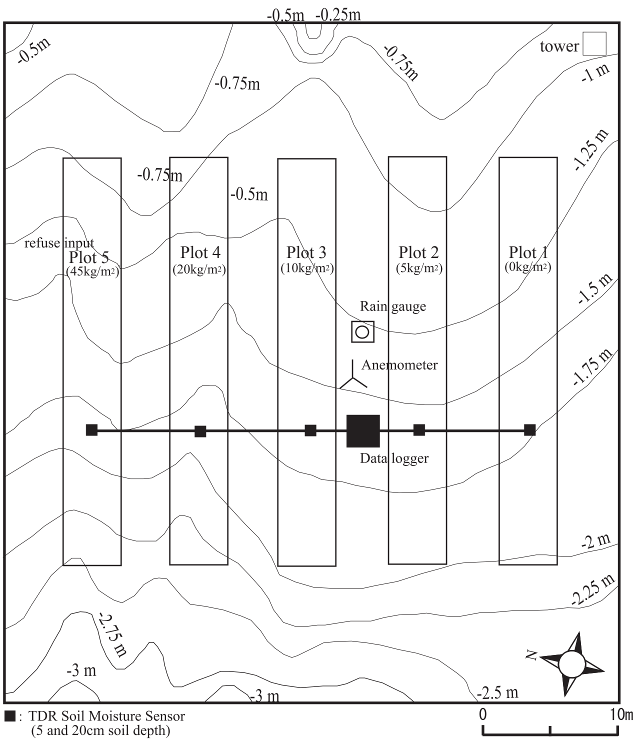

Fig. 2. The refuse input experimental site on the degraded land of 45 x 50 meters

Fig. 3. Five plots of urban refuse input: (a) Plot 1 (no refuse), (b) Plot 2 (5 kg/m^2), (c) Plot 3 (10 kg/m^2), (d) Plot 4 (20 kg/m^2), (e) Plot 5 (45 kg/m^2)

for which an average was calculated. Soil hardness was classified into five groups: loose (1.4 kg/cm^2, 10 mm at the measurement scale), soft (1.4-4.6 kg/cm^2, 11-18 mm), slightly hard (4.6-11.7 kg/cm^2, 19-24 mm), hard (11.8-24.5 kg/cm^2, 25-28 mm), and very hard (over 24.5 kg/cm^2, 29 mm). Soil samples were taken for all groups.

In November 2009, 12 months after scattering refuse, soil layers were observed, soil hardness was measured, and soil samples taken again. All the plants in each plot were cut at their base, and plant names were identified in Hausa language. One Fulbe pastoralist and one Hausa cultivator were interviewed for information on livestock

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

	pH	Total (g kg^{-1})		C/N	E xch.Base cmol(+)/kg				P	soil color	sand	silt	clay
	(H_2O)	N	C		Na^+	K	Mg^{2+}	Ca^{2+}	Mg kg^{-1}			(%)	
1) *kasa* (surface condition)													
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 gray)	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* (surface condition)													
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* (surface condition)													
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
10 ～ 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

preference of the plants. All the plant species were identified and the air-dried weights of each plant species were measured. The cut plants were not put back into the plots, but rather, taken away as valuable livestock feed. This was repeated 24 months later in November 2010, and 36 months later in November 2011.

The soil samples were air-dried on the premise, sifted with 2 mm mesh sieve, vacuum-packed into plastic bags, and air lifted to Japan, then analyzed for pH, electrical conductivity, total carbon, total nitrogen, and available phosphate. pH (soil: water ratio of 1: 5) was measured using the glass electrode method (Mettler Toledo S20). EC (soil: water ratio of 1: 5) was measured with specific conductivity meter (YSI DO55). Total carbon and total nitrogen were measured first by using a 0.5 mm sieve, then measured using a Dry combustion method (Sumika Chemical Analysis Service Ltd. Sumigraph NC22F). Available phosphate was analyzed using the Bray No. 2 method, with an ultraviolet spectrophotometer (Hach Co. DR2800).

4. Results

Local Hausa Knowledge on Land Degradation and Rehabilitation

The Hausa farmers recognized the condition changes in the soil resulting from continuous millet cultivation (Oyama 2009). Soil containing high organic matter yields high crop productivity. The Hausa call this land type, *kasa* or *kasa taki* (sand with organic matter). Compared to *foko* and *leso* types of land explained later, the *kasa taki* layer (brownish gray, 5YR 6/1 on the Standard Soil Color Chart) 0-3 cm deep shows weak acidity and abundant soil nutrients (Table 1). A rich aggregate structure and high soil porosity were observed on the surface ground. Underneath sand with organic matter, there were innumerable termite holes. Such soil is called *kasa gara* ("termite sand") by the Hausa. The termite sand lies at the depth of 3-12cm and this soil nutrition was poor (Table 1). A solid, sedimentary clay layer (dull orange, 5YR 7/3), identified as *foko*, lies under the *kasa taki* layer. The growth condition of *kasa taki* topsoil for millet was favourable, and the average stem height was 156 cm on 20 August 2003. Air dried weight of the millet gain was 1.1 t/ha in the middle of October.

The *kasa* soil type changes into *leso*, after a few years of continuous millet cultivation without manure input (Fig. 4). This *leso* soil type was recognized as having an early degraded soil condition with lower millet yields. The *leso* soil type has an aggregate structure of white or pale orange sandy soil (5YR 8/4) containing little silt and clay (Table 1). The *leso* topsoil accumulated up to 9 cm in depth. Under the *leso* topsoil, bright reddish brown (5YR 5/6) sandy soil formed a solid, sedimentary layer of *foko*. This sandy soil layer, *leso,* did not disturb the root growth of the crop, but soil nutrition was poor (Table 1). 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 fell to 0.1 t/ha.

After *leso* soil is recognized on the field, the cultivators usually tend to the land by fertilizing it with domestic

Fig. 4. The early land degradation: After a few years continuous millet cultivation, the soil containing organic matter was changed to the poor nutrition sandy soil by leaching and wind erosion.

animal excreta and plant residue of livestock fodder and millet panicles. They also waste no time in contracting the pastoral people to set up camps to provide the excreta for fields. The Hausa often fail to tend to the fields in time, and continue millet cultivation without manure input, because of land shortage in the village. The millet yield from the degraded *leso* soil becomes low, but they cultivate millet continuously in the degraded *leso* soil.

A few years of continuous cultivation without land care leads to wind and water erosion of the topsoil, and exposes the solid sedimentary layer. This sedimentary layer called *foko* has extremely low plant productivity. According to the result of X-ray Diffraction analysis (JEOL Ltd, JEOL-3530), the property of the *foko* layer is mainly quartz sand (87.1%) containing aluminium oxide (8.9%) and acidic sulphate (1.6%). The *foko* soil shows strong acidity and poor soil nutrition (Table 1). The clay layer is runny when wet, but hardens after it dries. When the *foko* layer is exposed at the surface, the crop growth at the root is much hampered, due to the soil's single-grain structure and poor chemical constitution. The solid *foko* layer greatly impedes water infiltration into the ground. The millet germination rate was low, and most of the plants died, even after germination. All the millet withered, with only a 7 cm stem height, on August 20. The millet grain yield was nil (Oyama 2009).

According to the Hausa villagers, it is possible to artificially recover plant productivity in the degraded *leso* and *foko* soils. To do so, they made contracts with the pastoral people to gain animal excreta for their farms (Oyama and Mammane 2010). They also carried household refuse, *taki* in Hausa language, such as plant residue from forage and crops, pearl millet stems, livestock excreta, worn clothes and vinyl sandals from the homestead into the degraded land (Fig. 5). They also recognized the importance of biological activities of termites, *gara* in Hausa, decomposing the refuse. Organic matter, especially plant residue and livestock excreta are favorite food for termites. According to the Hausa, worn clothes and even vinyl sandals, plastic bags, and metal dishes and pots are important for this method of soil and crop yield improvement.

Refuse Input and Plant Production Recovery

Plot 1 with no refuse input showed no visible change nor plant growth in 3 years (Fig. 6). Plot 2 scattered with 600 kg (5kg/m^2) refuse had 16 plant species weighing 310g (25.83 kg/ha) after one year (Table 2-1). The predominant plant species was *Amarantus* spp. (8.00 kg/ha), *Borreria radiata* and *B. stachydea* (6.58 kg/ha), and pearl millet, or *Pennisetum glaucum* (3.83 kg/ha). The Hausa eat the leaves of *Amarantus* spp. The other plant species were mostly favored by the livestock. After 2 years, the plants were reduced to 4 species, weighing 34 g (2.83 kg/ha), with a small growth of *Digitaria longiflora* (1.25 kg/ha), *B. radiata* and *B. stachydea* (0.67 kg/ha), and *Zornia glochidiata*. *Z. glochidiata* is esteemed highly as livestock feed by the Fulbe as the most desirable feed during the rainy season. After 3 years, there was no plant growth.

Plot 3 had 1,200 kg (10kg/m^2) refuse input. After one year, there were 16 plant species of 4,003 g (333.58 kg/ha) in weight (Table 2-2). The predominant plant species were pearl millet, or *P. glaucum* (241.08 kg/ha), *Jaquemontia tamnifolia* (50.83 kg/ha), and *Amaranthus* spp (15.67 kg/ha). There was much pearl millet growth probably because the seeds were in the refuse as thresh leftover. After 2 years, there were 12 plant species weighing 1,002 g (83.50 kg/ha), obviously less than the previous year. The predominant species were *Z. glochidiata* (30.17 kg/ha), *Polycarpacea linearifolia* (14.33 kg/ha), and *D. longiflora* (12.25 kg/ha). Six plant species, such as *P. Lineariflora* (14.33 kg/ha), *Gynandropsis gynandra* (5.33 kg/ha), *B.*

Fig. 5. Refuse input on the degraded land of the farmland

(a) The farmers carried the refuse from the homestead onto the degraded ground of his farmland by an ox carriage.
(b) A widow woman carried the refuse every day for improving the soil condition of the farmland for her young son.
(c) The Hausa farmers recognized the land and soil condition of their farmland, and they carried the refuse for coping with land degradation.
(d) The refuse from the homestead in the village was mainly plant residue and livestock dung. These are important for improving the soil condition and crop yields.
(e) Some farmers carried the urban refuse, containing plant residue, livestock excreta, wasted plastic bags, vinyl sandals and other refuse from township. This urban refuse application was limited by the residents living at approximately 2 km from the township.
(f) The farmers often put the refuse at the mound shape. According to the farmers, this mound shape plays an important role for catching blown sand and improving the soil condition.

radiate and *B. stachydea* (4.92 kg/ha), and *Brachiaria xantholeuca* (3.00 kg/ha), were seen only from the second year. In the third year, there were 3 plant species weighing 535 g (44.58 kg/ha): *Z. glochiata* (36.92 kg/ha), *B. radiata* and *B. stachydea* (5.83 kg/ha), and *Balanites aegyptiaca* (1.83 kg/ha). *B. aegyptiaca,* only seen from the third year, had its leaves utilized by the livestock as well as the Hausa people during famine. The fruit is edible as well. These are called "famine food (*abincin nyunwa*)" in Hausa societies. Germination was probably from the refuse. The

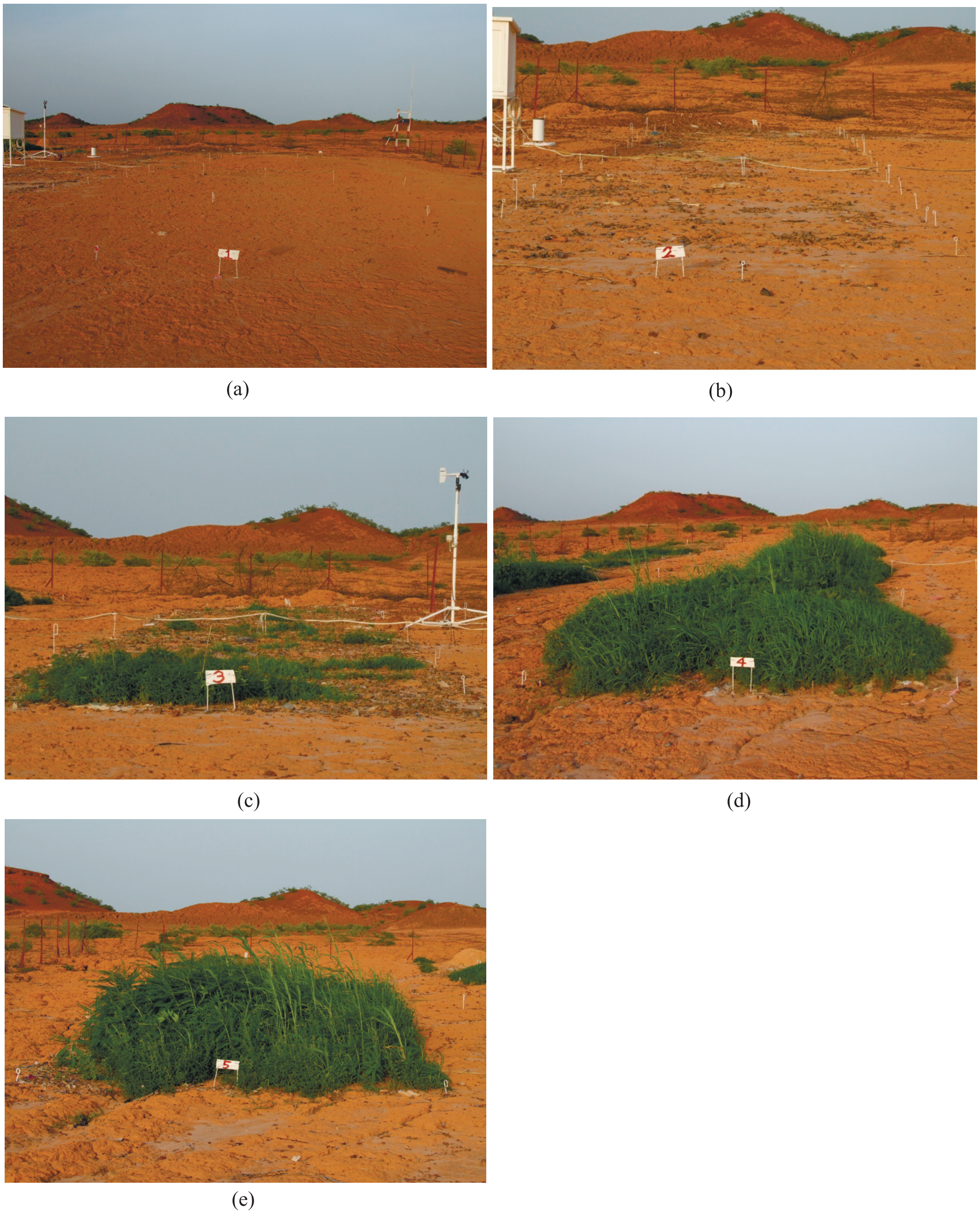

Fig. 6. Plant growth after two years from refuse input (August 2010): (a) Plot 1 (no refuse), (b) Plot 2 (5 kg/m^2), (c) Plot 3 (10 kg/m^2), (d) Plot 4 (20 kg/m^2), (e) Plot 5 (45 kg/m^2)

plant species in Plot 3 were all favored as livestock feed.

Plot 4 with 24,000 kg (20 kg/m^2) refuse input had many plant species grow. After one year, the plot contained 35 species weighing 59,547 g (4962.25 kg/ha) in total (Table 2-3). The predominant plant species were pearl millet (*P. gluacum*) weighing 4257.17 kg/ha, *Hibiscus sabdariffa* (225.50 kg/ha), and *B. radiata* and *B. stachydea* (166.08 kg/ha). *H. subdariffa* is cooked and eaten by the Hausa as a side dish. Pearl millet weighed 85.8% of the total. After two years there were 17 plant

Table 2-1. Plant growth on Plot 2 (urban refuse input 5 kg/m^2)

Air dried weight: kg ha^{-1}

	plant species	Hausa name	Preference of livestock*	1 year after	%	2 years after	%	3 years after	%
1	*Amaranthus* spp.	*rukubu*	++	8.00	31.0				
2	*Borreria radiata, B. stachydea*	*kumuguduwa*	++	6.58	25.5	0.67	23.7		
3	*Pennisetum glaucum*	*hatsi*	++	3.83	14.8				
4	*Gynandropsis gynandra*	*ranje daji*	+	2.42	9.4	0.33	11.7		
5	*Zornia glochidiata*	*maras*	++	2.00	7.7	0.58	20.5		
6	*Digitaria longiflora*	*birbirwa*	++	1.08	4.2	1.25	44.2		
7	*Alysicarpus rugosus*	*gadagi*	++	0.33	1.3				
8	*Dactyloctenium aegyptiun*	*atuku*	++	0.33	1.3				
9	*Celosia trigyna*	*nannafa*	++	0.25	1.0				
10	*Corchorus tridens*	*koku*	-	0.25	1.0				
11	*Hibiscus sabdariffa*	*sure, yakuwa*	++	0.17	0.7				
12	not identified	*chinchiya malalaki*	?	0.17	0.7				
13	*Pennisetum pedicellatum*	*janbako*	++	0.17	0.7				
14	*Jacquemontia tamnifolia*	*kukumbara*	++	0.08	0.3				
15	*Brachiaria xantholeuca*	*hatsin tsutsu*	++	0.08	0.3				
16	*Cassia mimosoides*	*bagaruwa kasa*	++	0.08	0.3				
	total			25.83	100	2.83	100	0	

plot area: 120m^2 (3 x 40m)
*: the interviews from a pastoral Fulbe and a Hausa farmer about plant preference of cattle, sheep and goat.
++: very favorable, +: favorable, -: unfavorable, ?: unknown

Table 2-2. Plant growth on Plot 3 (urban refuse input 10 kg/m^2)

Air dried weight: kg ha^{-1}

	plant species	Hausa name	Preference of livestock*	1 year after	%	2 years after	%	3 years after	%
1	*Pennisetum glaucum*	*hatsi*	++	241.08	72.3				
2	*Jacquemontia tamnifolia*	*kukumbara*	++	50.83	15.2				
3	*Amaranthus* spp.	*rukubu*	++	15.67	4.7	3.08	3.7		
4	*Zornia glochidiata*	*maras*	++	15.17	4.5	30.17	36.1	36.92	82.8
5	*Hibiscus sabdariffa*	*sure, yakuwa*	++	2.00	0.6	4.25	5.1		
6	*Cynodon dactylon*	*halkiya*	+	1.83	0.5				
7	*Commelina benghalensis*	*balasa kura*	++	1.42	0.4	0.25	0.3		
8	*Dactyloctenium aegyptiun*	*atuku*	++	1.17	0.4				
9	*Alysicarpus rugosus*	*gadagi*	++	1.08	0.3	2.33	2.8		
10	*Corchorus tridens*	*koku*	-	0.91	0.3				
11	*Trubulus terrestris*	*saida*	++	0.83	0.2				
12	*Digitaria longiflora*	*birbirwa*	++	0.58	0.2	12.25	14.7		
13	not identified	*chinchiya malalaki*	?	0.25	0.1				
14	*Indigofera astragalina*	*hakorin doki*	++	0.25	0.1				
15	*Sida cordifolia*	*garmani*	++	0.25	0.1				
16	*Indigofera tinctoria*	*baba*	-	0.25	0.1				
17	*Polycarpaea linearifolia*	*kansofwa*	++			14.33	17.2		
18	*Gynandropsis gynandra*	*ranje daji*	+			5.33	6.4		
19	*Borreria radiata, B. stachydea*	*kumuguduwa*	++			4.92	5.9	5.83	13.1
20	*Brachiaria xantholeuca*	*hatsin tsutsu*	++			3.00	3.6		
21	*Stylosanthes erecta*	*tsirafoko*	++			2.33	2.8		
22	*Celosia trigyna*	*nannafa*	++			1.25	1.5		
23	*Balanites aegyptiaca*	*aduwa*	+					1.83	4.1
	total			333.58	100	83.50	100	44.58	100

Table 2-3. Plant growth on Plot 4 (urban refuse input 20 kg/m^2)

Air dried weight: kg ha^{-1}

	plant species	Hausa name	Preference of livestock*	1 year after	%	2 years after	%	3 years after	%
1	*Pennisetum glaucum*	*hatsi*	++	4257.17	85.8	18.33	0.6		
2	*Hibiscus sabdariffa*	*sure, yakuwa*	++	225.50	4.5	785.25	24.9	53.33	4.1
3	*Borreria radiata, B. stachydea*	*kumuguduwa*	++	166.08	3.3	1235.83	39.1	714.25	54.7
4	*Schizachyrium exile*	*kyasuwa*	++	86.83	1.7	230.42	7.3	231.25	17.7
5	*Indigofera prieureana*	*kyamuro*	++	65.08	1.3	595.83	18.9	173.50	13.3
6	*Cucumis melo*	*buruji*	++	37.42	0.8				
7	*Amaranthus* spp.	*rukubu*	++	19.33	0.4	2.92	0.1		
8	*Gynandropsis gynandra*	*ranjen daji (ranwari)*	+	14.00	0.3	101.92	3.2	1.67	0.1
9	*Ceratotheca sesamoides*	*ramuti*	++	13.42	0.3				
10	*Jacquemontia tamnifolia*	*kukumbara*	++	9.50	0.2				
11	*Cyperus esculentus*	*aya*	++	7.92	0.2				
12	*Sorghum bicolor*	*dawa*	++	7.33	0.1				
13	Alysicarpus rugosus	*gadagi*	++	6.25	0.1	34.58	1.1		
14	*Cenchrus biflorus, C. prieurii*	*kalengia*	++	5.25	0.1				
15	not identified	*masun katangari*	+	5.17	0.1				
16	*Hibiscus esculentus*	*kubewa*	++	4.75	0.1				
17	not identified	*koikota (korukota)*	?	4.33	0.1	8.17	0.3		
18	*Pergularia tomentosa*	*fataka*	+	3.25	0.1				
19	*Commelina forskalaei*	*balasa*	++	5.67	0.1				
20	*Citrullus lanatus*	*guna shanu (wachi)*	++	3.92	0.1				
21	*Corchorus tridens*	*koku*	-	2.33	0				
22	not identified	*dan wari*	?	1.83	0				
23	*Cynodon dactylon*	*halkiya*	+	1.50	0	11.33	0.4		
24	not identified	*chawa doguwa*	?	1.50	0				
25	*Sida cordifolia*	*garmani*	++	1.50	0				
26	*Indigofera tinctoria*	*baba*	-	1.25	0	12.50	0.4		
27	*Commelina benghalensis*	*balasa kura*	++	1.00	0				
28	*Dactyloctenium aegyptiun*	*atuku*	++	0.92	0			1.75	0.1
29	*Mitracarpus scaber*	*yaruwachi*	-	0.67	0				
30	*Acanthospermum hispidum*	*kashin yau*	-	0.50	0				
31	*Merremia tridentata*	*yambururu*	++	0.33	0				
32	*Gossypium herbaceum*	*kada*	++	0.25	0				
33	*Vigna unguiculata*	*wake*	++	0.25	0				
34	*Cymbopogon giganteus*	*sabre*	++	0.17	0	29.17	0.9	86.33	6.6
35	not identified	*chinchiya malalaki*	?	0.08	0				
36	*Balanites aegyptiaca*	*aduwa*	+			72.50	2.3	3.33	0.3
37	*Ipomoea vegans*	*walkindam*	++			6.25	0.2	11.50	0.9
38	not identified	*sarumai yadiya*	++			4.83	0.2		
39	not identified	*yaryadi*	?			4.58	0.1		
40	*Zornia glochidiata*	*maras*	++			4.17	0.1	4.33	0.3
41	*Cassia obtusifolia*	*tafasa*	++					15.17	1.2
42	not identified	*yare*	-					4.42	0.3
43	*Indigofera astragalina*	*hakorin doki*	++					2.25	0.2
44	*Aristida mutabilis*	*katsaura*	++					1.50	0.1
45	*Pennisetum pedicellatum*	*janbako*	++					1.25	0.1
46	*Gymnospria senegalensis*	*namijin yariya*	+					0.33	0
	total			4962.25	100	3158.58	100	1306.17	100

Table 2-4. Plant growth on Plot 5 (urban refuse input 45kg/m^2)

Air dried weight: kg ha^{-1}

	plant species	Hausa name	Preference of livestock*	1 year after	%	2 years after	%	3 years after	%
1	*Pennisetum glaucum*	*hatsi*	++	3496.42	95.7	64.58	7.2		
2	*Schizachyrium exile*	*kyasuwa*	++	51.00	1.4	83.75	9.3	119.50	15.8
3	*Borreria radiata, B. stachydea*	*kumuguduwa*	++	38.08	1.0	128.50	14.3	197.92	26.1
4	*Hibiscus sabdariffa*	*sure, yakuwa*	++	35.58	1.0	79.58	8.8		
5	*Amaranthus* spp.	*rukubu*	++	12.92	0.4	9.58	1.1	5.67	0.7
6	*Cenchrus biflorus, C. prieurii*	*kalengia*	++	6.50	0.2				
7	*Corchorus tridens*	*koku*	-	2.50	0.1	0.67	0.1		
8	*Portulaca oleracea*	*halusin sa*	++	2.25	0.1	42.08	4.7	50.67	6.7
9	*Dactyloctenium aegyptiun*	*atuku*	++	2.25	0.1			73.42	9.7
10	*Cynodon dactylon*	*halkiya*	+	1.50	0				
11	not identified	*masun katangare*	+	1.42	0				
12	*Commelina forskalaei*	*balasa*	++	1.25	0				
13	*Nothosaerva brachiata*	*ranje*	++	0.67	0	12.50	1.4	0.42	0.1
14	*Commelina benghalensis*	*balasa kura*	++	0.58	0				
15	*Sida cordifolia*	*garmani*	++	0.58	0				
16	not identified	*yare*	-	0.25	0	4.83	0.5	84.42	11.1
17	*Jacquemontia tamnifolia*	*kukumbara*	++	0.17	0				0
18	*Indigofera prieureana*	*kyamuro*	++			370.83	41.2	211.08	27.8
19	*Gynandropsis gynandra*	*ranje daji*	+			22.92	2.5	1.92	0.3
20	*Digitaria longiflora*	*birbirwa*	++			21.33	2.4		
21	*Acanthospermum hispidum*	*kashin yau*	-			21.33	2.4		
22	*Alysicarpus rugosus*	*gadagi*	++			15.67	1.7	1.25	0.2
23	*Celosia trigyna*	*nannafa*	++			14.83	1.6		
24	*Sesamum alatum*	*ramutin bariwa*	+			3.75	0.4		
25	*Cymbopogon giganteus*	*sabre*	++			2.67	0.3		
26	*Tephrosia purpurea*	*masa*	-			0.58	0.1		
27	*Indigofera tinctoria*	*baba*	-					8.17	1.1
28	*Brachiaria xantholeuca*	*hatsin tsutsu*	++					3.00	0.4
29	*Zornia glochidiata*	*maras*	++					0.83	0.1
	total			3653.92	100	900.00	100	758.25	100

species weighing 37,903 g (3158.58 kg/ha). The weight of pearl millet decreased to 0.6 % of the total at 18.33 kg/ha. The predominant plant species were *B. radiata* and *B. stachydea* (1235.83 kg/ha), *H. sabdariffa* (785.25 kg/ha), and *Indigofera prieureana* (595.83 kg/ha). Five plant species, *B. aegyptiaca*, *Ipomoea vegan, Z. glochidiata,* and two unkown species newly germinated after two years. After three years, plant species counted 16 and weighed 15,674 g (1306.17 kg/ha). Among these, *B. radiata* and *B. stachydea* (714.25 kg/ha), *Schizachyrium exile* (231.25 kg/ha), *I. priureana* (173.50 kg/ha) were predominant. Six plant species (*Cassia obtusifolia, Indigofera astragalina, Aristida mutabilis, Pennisetum pedicellatum, Gymnospria senegalensis*, one unknown) newly germinated after three years. There was no pearl millet. Most plant species on Plot 4 were favored as livestock feed.

Plot 5 with 5,400 kg (45 kg/m^2) refuse input saw 17 plant species, 43,847 g (3653.92 kg/ha) after one year (Table 2-4). Among these, pearl millet weighed 3496.42 kg/ha, *S. exile* weighed 51.00 kg/ha, and *B. radiata* and *B. stachydea* weighed 38.08 kg/ha. Pearl millet weight was 95.7% of the total. Some residents of Dogondoutchi town owned millet fields and threshed their millet. The refuse contained many millet seeds left over from threshing, and these were thought to have germinated. Two years later, plant species counted 18, weighing 10,800 g (900.00 kg/ha). The weight of pearl millet decreased to 7.2% of the total, weighing 64.58 kg/ha. The predominant plant species were *I. preuriana* (370.83 kg/ha), *B. radiata* and *B. stachydea* (128.50 kg/ha), and *S. exile* (83.75 kg/ha). Nine species were only seen after two years: *I. preuriana*, *G. gynandra*, *D. longiflora*, *Acanthospermum hispidum*, *Alysicarpus rugosus*, *Celosia trigyna*, *Sesamum alatum*, *Cymbopogon giganteus*, and *Tephrosia purpurea*. After three years, plant species counted 13, and weighed 9,099 g (758.25 kg/ha). Predominant were *I. preuriana* (211.08 kg/ha), *B. radiata* and *B. stachydea* (197.92 kg/ha), and *S. exile* (119.50 kg/ha). No pearl millet was seen after three years as in Plot 4. After three years, three species newly germinated: *Indigofera tinctoria, Brachiaria xantholeuca,* and *Zornia glochidiata.* As in Plots 2, 3, and 4, the plant species on Plot 5 were mostly favored as livestock feed. Interviews with the Fulbe pastoralist and the Hausa cultivator revealed that Plots 2 and 3 did not have enough plant growth to be a grazing field, but growth in Plots 4 and 5 were sufficient until the third year after refuse application. This means at least 20 kg/m^2 of urban refuse were necessary for plant recovery, from the viewpoint from the residents of pastoralists and farmers.

Refuse Input and Soil Recovery

The 3 point sampling of refuse was weakly alkaline with pH at 8.6-8.9. Electrical conductivity (EC) was 939-1,325 μS/cm, rich in mineral salts, and contained much nitrogen, carbon, and phosphates (Table 3). The contained sand color was grayish yellow brown (10YR 5/2). The Hausa that live in the town call refuse *shara* and *jibuji*, whereas the Hausa that live in the countryside call it *taki*, meaning fertilizer, realizing its soil nourishing utility.

In August 2008, the soil profile of Plot 1 (0-30 cm deep), without any soil input, was packed with dull, orange-colored (7.5YR 7/4) minute sand. Absolute hardness at 5 cm from the surface was 48.0 kg/cm^2; at 15 cm, 40.0 kg/cm^2; and at 30 cm, 42.0 kg/cm^2. The hardness category was very hard (Fig. 7). The sedimentary layer of the degraded soil surface is called *foko raka* by the Hausa. When the soil was wet, soil hardness decreased drastically. This sedimentary layer was strongly acidic at pH 4.5, EC was low at 41-88 μS/cm, contained little salts as well as little nitrogen, carbon, and phosphates (Table 3). Neither physical nor chemical soil properties were suitable for plant growth. When the exposed sedimentary layer is very hard or hard, rain does not infiltrate the surface, and promotes surface runoff, according to the field observation. Plot 1 with such hardened surface saw no plant growth. With no refuse input, the surface remained very hard or hard after 7, 12, 24, and 36 months later. The sedimentary layer lied until 30 cm from the surface (Fig. 7).

Plot 2 had refuse input 0.5-1 cm deep. This amount was not ample, and unevenly scattered on some spots. Underneath the refuse, the hardened sedimentary layer as seen in Plot 1 had remained, the hardness being very hard at 5, 15, and 30 cm deep. Soil color was dull orange (7.5 YR 7/4) as in Plot 1 (Fig. 7). Seven months later, soil containing some organic matter had accumulated 1 cm deep. The soil color changed to dull yellow orange (10 YR 6/4). This soil type was called *kasa taki* ("manure sand") by the Hausa. It contained much organic matter, high EC (806 μS/cm) with rich mineral salts. The soil also contained much carbon and nitrogen (Table 3). The refuse supplied much plant nutrients. Under 1-10 cm of the refuse layer, there was not much organic matter, but many termite holes and tunnels in June 2009. Termites do not take well to dry and sunny conditions (Lee and Wood 1971; Abe 1991), and are susceptible to predators such as black ants and birds, according to the field observation. Termites had gathered when refuse was scattered onto the plot, building shelters surrounding the organic matter to feed. Underneath each refuse, there were innumerable termite holes. Such soil is called *kasa gara* ("termite sand") by the Hausa. There was a *foko raka* sedimentary layer in Plot 2 at the start of the experiment deeper than 10 cm, with no termite hole. 12 months later, the soil surface had 1 cm thick *kasa taki*, under which there was 1-2 cm deep *foko raka*, under which was the sedimentary layer. 24 months later, wind-blown sand 1 cm thick had accumulated on the topsoil. Blown sand is coarse and easily identified. It is called *kasa iska* ("sand of wind" and "blown sand") by the Hausa. Rather than *foko raka,* there was 1 cm deep *kasa gara* "termite sand," then from 2 cm depth was the sedimentary layer. After 36 months, there was only 1 cm layer of blown sand under which was the sedimentary layer. After wind and water erosion had removed the topsoil and termite activity had eaten away the organic matter at *kasa taki*, land degradation resumed (Fig. 7).

Plot 3 had refuse scattered evenly with a thickness of 1.5 cm. Under this there was the very hard and packed sedimentary layer. Soil hardness at 5, 15, and 30 cm were all very hard, and the soil color was dull orange (7.5 YR 7/4). After 7 months, soil containing much organic matter had

Table 3. Chemical property of urban refuse and the refuse input effects to the soil property of the degraded land

	soil depth (cm)	Soil color	pH (H_2O)	EC μS/cm	N g kg^{-1}	C g kg^{-1}	CN Ratio	P mg kg^{-1}	soil classification (Hausa)	soil classification (English)
1) urban refuse 1		10YR 5/2 grayish yellow brown	8.6	1325	1.92	23.40	12.2	832	*shara*	refuse
2		〃	8.9	982	5.71	74.06	13.0	695	〃	〃
3		〃	9.0	939	6.20	61.32	9.9	848	〃	〃
2) before refuse input	(Aug. 2008)									
	0-5	7.5YR 7/4 dull orange	4.8	41	0.13	1.03	7.9	11	*foko raka*	sedimentary layer
	10-15	7.5YR 7/4 dull orange	4.0	88	0.14	1.02	7.3	7	〃	〃
	25-30	7.5YR 7/4 dull orange	4.1	42	0.1	0.88	8.8	10	〃	〃
3) after a half year	(Jun. 2009)									
3-1) Plot 1 (0kg/m^2)	0-5	7.5YR 7/4 dull orange	4.7	48	0.15	1.22	8.1	9	*foko raka*	sedimentary layer
	10-15	7.5YR 7/4 dull orange	4.4	100	0.17	1.19	7.0	5	〃	〃
	25-30	7.5YR 7/4 dull orange	4.9	76	0.16	1.19	7.4	6	〃	〃
3-2) Plot 2 (5kg/m^2)	0-2	10YR 6/4 dull yellow orange	6.7	806	3.71	70.92	19.1	476	*kasa taki*	manure sand
	2-10	7.5YR 7/4 dull orange	5.1	58	0.15	1.27	8.5	24	*kasa gara*	termite sand
	10-30	7.5YR 7/4 dull orange	4.6	60	0.16	1.35	8.4	7	*kasa foko*	sedimentary layer
3-3) Plot 3 (10kg/m^2)	0-4	10YR 6/4 dull yellow orange	6.9	666	1.43	35.20	24.6	431	*kasa taki*	manure sand
	4-17	7.5YR 7/4 dull orange	5.2	124	0.19	2.21	11.6	38	*kasa gara*	termite sand
	17-30	7.5YR 7/4 dull orange	4.7	50	0.15	1.39	9.3	7	*foko raka*	sedimentary layer
3-4) Plot 4 (20kg/m^2)	0-5	10YR 6/4 dull yellow orange	7.6	276	1.82	30.75	16.9	356	*kasa taki*	manure sand
	5-17	7.5YR 7/4 dull orange	5.0	85	0.13	1.30	10.0	17	*kasa gara*	termite sand
	7-30	7.5YR 7/4 dull orange	5.7	57	0.13	1.29	9.9	15	*foko raka*	sedimentary layer
3-5) Plot 5 (45kg/m^2)	0-8	10YR 6/4 dull yellow orange	7.4	478	2.27	38.94	17.2	276	*kasa taki*	manure sand
	8-23	7.5YR 7/4 dull orange	5.1	72	0.15	1.13	7.5	8	*kasa gara*	termite sand
	23-30	7.5YR 7/4 dull orange	4.9	73	0.12	0.92	7.7	7	*foko raka*	sedimentary layer

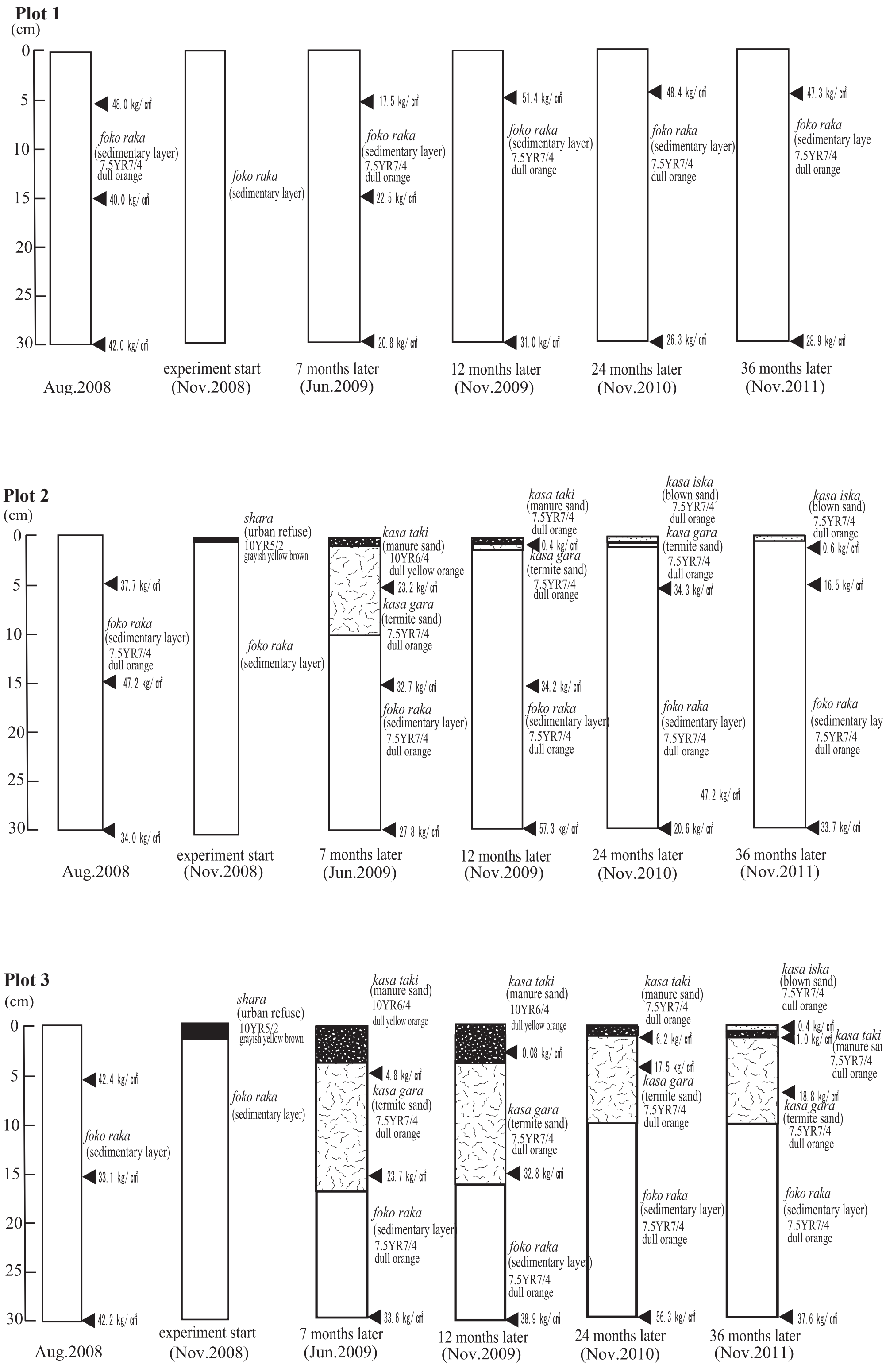

Fig. 7. The soil profiles of five plots after refuse input

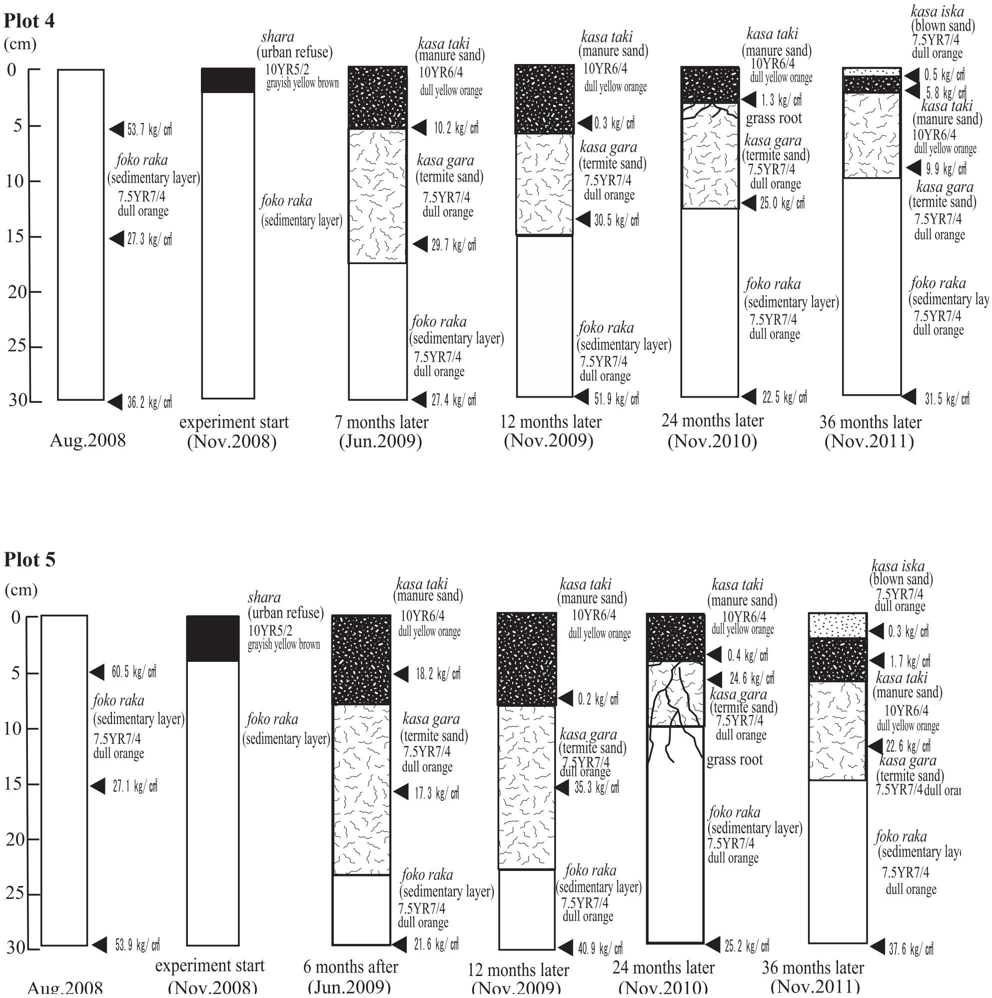

Fig. 7. The soil profiles of five plots after refuse input (Continued)

accumulated 4 cm thick. Soil color has dull yellow orange (10YR 6/4). There were much mineral salts, nitrogen, carbon and phosphate from the refuse, with pH at 6.9 and neutral (Table 3). Innumerable termite holes dotted 4-17 cm deep, and the soil had turned into *kasa gara,* "termite sand." At 5 cm deep, the soil was porous, and hardness was slightly hard. At 15 cm deep, the soil was hard. The termite sand had nutrients deriving from the refuse, but the sedimentary layer underneath had no such chemical property. Termite sand as well as the sedimentary layer were both colored dull orange (7.5YR 7/4).

After 12 months, Plot 4 had an accumulated surface layer 4 cm thick, porous and rich in nutrients. At 4-12 cm deep, there were numerous termite holes, and under 12 cm deep was the sedimentary layer. After 24 months, the *foko raka* "manure sand" shrank to 2 cm thick, underneath which was 2-10 cm deep *kasa gara* "termite sand." *Foko raka* was slightly hard, and *kasa gara* was hard. Underneath was the very hard sedimentary layer. After 36 months, wind-blown sand (*kasa iska*) had accumulated 1 cm, and underneath, an equal depth of manure sand (*kasa taki*). Both soil layers were loose. Below these two soil types, there were termite holes, and below 10 cm deep, there was the sedimentary layer. The hardness at 30 cm deep was very hard at 37.6 kg/cm^2 (Fig. 7). Plot 3 saw a reduction in organic matter and *foko raka* soil after 2 years and land degradation resumed.

Plot 4 was scattered with a 2 cm layer of refuse. Soil hardness at 5, 15, and 30 cm were all very hard, and soil color was dull orange (7.5 YR7/4). Seven months later, soil with much organic matter had accumulated for 5 cm thickness and the porous soil was slightly hard. This surface soil was neutral at pH 7.6 as was the case for plot 3. It contained much mineral salts, nitrogen, carbon, and phosphate deriving from the refuse. The soil color was dull yellow orange (10YR 6/4), and contained much organic matter from the refuse. "Termite sand" 5-17 cm deep to sedimentary layer 17-30 cm deep had improvement in chemical property due to the refuse but limited and did not contain much nutrients. Both soils were colored dull orange (7.5YR 7/4) (Table 3). After 12 months "manure sand" had accumulate 6 cm deep. Soil hardness was loose and the color was dull yellow orange (10YR 6/4). "Termite sand" was 6 to 15 cm deep, and the soil was very hard. Below 15 cm deep was the sedimentary layer and soil hardness was very hard. "Termite sand" and the sedimentary layer were dull orange (7.5YR 7/4).

After 24 months "manure sand" was 3 cm deep. It was loose and dull yellow orange (10YR 6/4). The effect of refuse scattering was apparent. "Termite sand" was 3-13 cm deep underneath which was the sedimentary layer. Soil hardness for the former was very hard, and the latter was hard. Both were colored dull orange (7.5YR 7/4). Plant roots were found until 5 cm deep and they reached the "termite sand" through "manure sand". After 36 months, wind-blown sand had accumulated 1 cm deep. The color was dull orange and the hardness was loose. "Manure sand" was 1-3 cm deep and dull yellow orange (10YR 6/4). The soil hardness was slightly soft. From 3-10 cm deep there were many termite holes. This soil was "termite sand" and slightly hard. Below 10 cm deep was the sedimentary layer, and very hard (Fig. 7). From 12-24 months later, decomposition of the organic matter and reduction in organic and "manure sand" due to erosion and termite activity was found, and land degradation resumed after 24 months.

Plot 5 had a 4 cm layer of refuse scattered. Soil hardness at 5, 15, 30 cm were all very hard, and color was dull orange (7.5YR 7/4). After 7 months soil with much organic matter was 8 cm deep, but the hardness was very hard. The pH was 7.4, almost neutral, and contained much mineral salts, nitrogen, carbon, and phosphate, all deriving from the refuse (Table 3). Soil color was dull yellow orange (10YR 6/4). "Termite sand" at 8-24 cm deep and sedimentary layer at 24-30 cm deep had limited chemical property improvement and not much nutrients. Both were colored dull orange (7.5YR 7/4). 12 months later "manure sand" had accumulate 6 cm deep with much organic matter, loose, and colored dull yellow orange (10YR 6/4). Very hard "termite sand" was from 6-24 cm deep. Below 24 cm deep was the sedimentary layer and very hard. Both were colored dull yellow orange (7.5YR 7/4).

After 24 months, "manure sand" was 4 cm deep, loose, and dull yellow orange (10YR 6/4). "Termite sand" was from 4-10 cm, below which was the sedimentary layer. "Termite sand" was very hard and the sedimentary layer was hard. Both were colored dull orange (7.5YR 7/4). Plant roots were 13 cm deep into "manure sand" through "termite sand" to sedimentary layer. After 36 months, there was 2 cm deep, loose blown sand, colored dull orange. Under this at 2-6 cm deep was the "manure sand" of dull yellow orange (10YR 6/4). The soil hardness was soft. From 6-15 cm deep was the very hard "termite sand" (Fig. 7). As was the case with Plot 4, organic matter and "manure sand" were greatly reduced due to decomposition and termite activity. However, because the refuse input was large, wind-blown sand was effectively trapped and accumulated. "Manure sand" did not decrease drastically.

Refuse Input and Soil Moisture

Of the 1,042 days observed, there was rainfall over 0.5 mm for 35 times in 2009, 34 times in 2010, and 21 times in 2011, a total of 90 times. The author compared soil moisture for all the 5 plots with or without refuse input at 5 cm depth. Soil moisture was higher for Plots 3, 4, and 5 with more than 10 kg/m^2 refuse input, than for Plot 1 without refuse input (Fig. 8). For Plot 2 with 5 kg/m^2 of input, soil moisture was lower than for Plot 1. A small amount of refuse input did not promote more moisture infiltration in the soil. With more than 10 kg/m^2 refuse, water was able to easily infiltrate the soil. This tendency was repeated for soil moisture measured at 20 cm depth (Fig. 9). Refuse input increased soil porosity as well as termite activity, which promoted rainwater infiltration and retention.

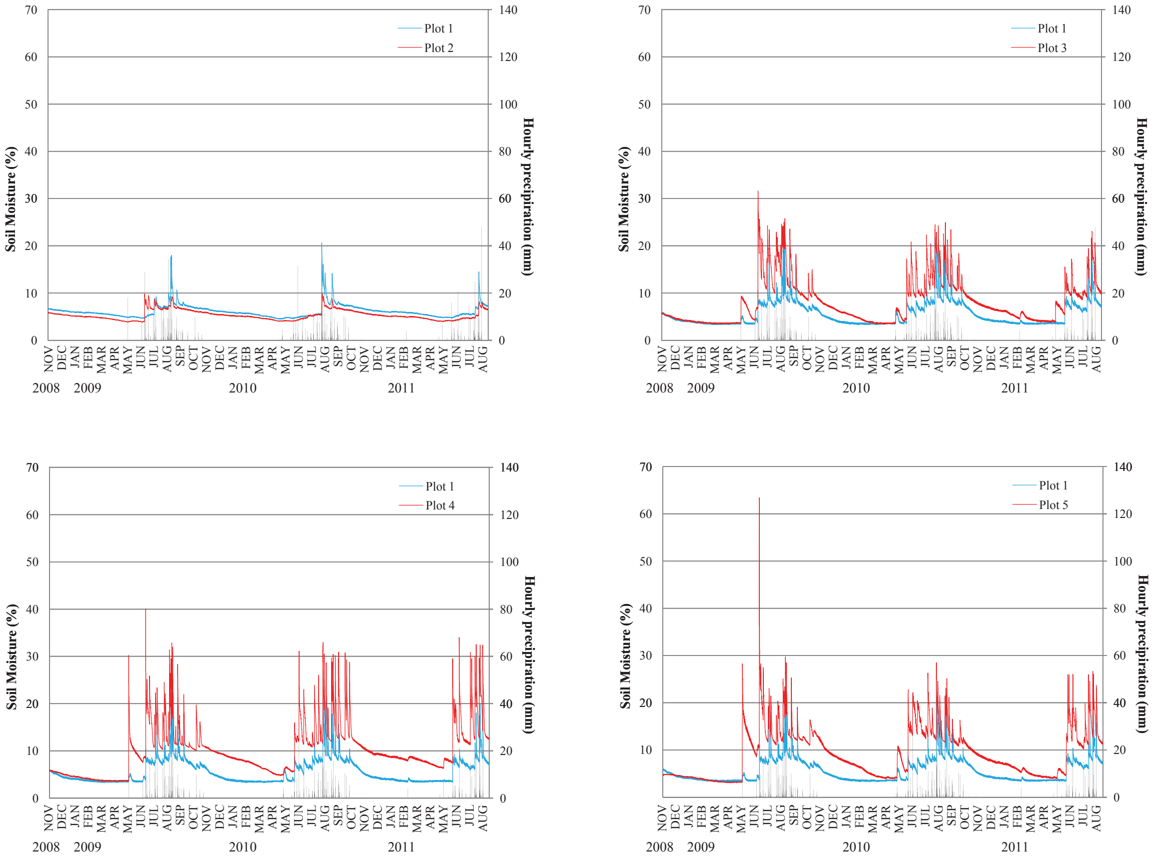

Fig. 8. Refuse input and soil moisture dynamics at 5cm soil depth: (a) Plot 1 (no refuse), (b) Plot 2 (5 kg/m^2), (c) Plot 3 (10 kg/m^2), (d) Plot 4 (20 kg/m^2), (e) Plot 5 (45 kg/m^2)

The author measured the increase in water infiltration and retention as a result of refuse input to the experimental plots. For this, the changes in soil moisture before and after rainfall needed to be calculated. The author measured soil moisture immediately before rainfall and the maximum soil moisture after the rainfall. It may be possible that soil moisture was enhanced due to the previous rainfall during the rain season, or that there would be another rainfall before the maximum soil moisture could be measured. However, rainfall condition was deemed equal for all plots so that soil moisture was measured using the same method for each rainfall for all the plots.

For example, on 17 June 2009, there was 11.5 mm of rainfall at 4 AM, 29.0 mm at 5 AM, and 1.0 mm at 6 AM, for a total of 41.5 mm. Soil moisture for Plot 2 at 5 cm depth was 3.41% immediately before rainfall at 3 AM the same day, which increased to a maximum of 11.54% at noon on the same day. The change in soil moisture was calculated as the difference in the two measurements, i.e. 8.13% increase due to 41.5 mm rainfall. Soil moisture changes were observed for each of the other plots for the same rainfall at 5 cm depth: 10.63% from 3.75% (7 hours after rainfall at 10 AM on June 17) for Plot 1, 31. 63% from 6.73% (13 hours after rainfall at 16 PM on June 17) for Plot 3, 40.08% from 8.49% (2 hours after rainfall at 17 PM on June 17) for Plot 4, and 63.45% from 10.53% (2 hours after rainfall at 17 PM on June 17) for Plot 5. As the increase for each plot shows, soil moisture could increase with the amount of refuse input.

The author elucidated in the previous section that refuse input changed the physical and chemical properties of the soil and plant growth. Refuse input could promote the accumulation of "manure sand," under which "termite

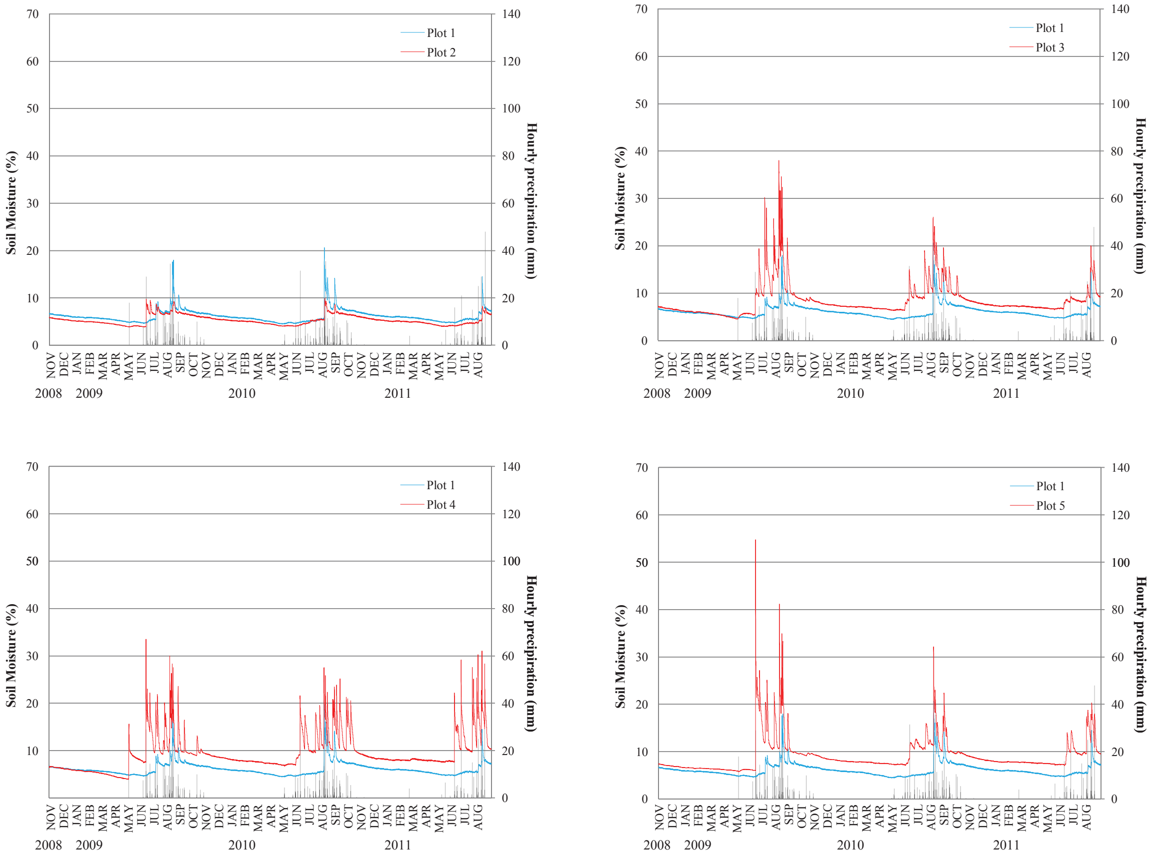

Fig. 9. Refuse input and soil moisture dynamics at 20cm soil depth: (a) Plot 1 (no refuse), (b) Plot 2 (5 kg/m^2), (c) Plot 3 (10 kg/m^2), (d) Plot 4 (20 kg/m^2), (e) Plot 5 (45 kg/m^2)

sand" was formed due to elevated termite activity (Fig.10). However, this "termite sand" layer decreased after a few years and land degradation resumed. Soil moisture, or the rainwater infiltration into the soil could be related to soil composition as well as its property changes for the rainy seasons in the 3 years of 2009, 2010, and 2011.

As the slope for the linear regression between rainfall and soil moisture indicates, a small amount of refuse input of 5 kg/m^2 did not have much effect on the degraded land in terms of rainfall infiltration. Refuse input of around 10 kg/m^2 could help to increase rainfall penetration and retention, but the effect might last for only about one year. Because rainfall varies year to year, more observation is necessary, but as soil moisture changes recorded for the 3 years of the study indicates, refuse input of 20 kg/m^2 can remarkably improve soil moisture for only the first year as well, whereas land degradation afterwards was somewhat slower (Fig. 10).

5. Discussions

The Philosophy behind Using Urban Refuse for Land Rehabilitation and Land Care System

There would be little disagreement between scientists and farmers bout the beneficial qualities of organic matter (Warren *et al*. 2003). The idea to utilize urban refuse for land rehabilitation is to put to use the indigenous knowledge and daily practice of the Hausa cultivators who live in south central Niger. The Hausa reside in the semiarid climate and know that the fields are prone to land degradation, and have not been passive to the severe conditions. When they recognize that soil fertility decreased, they either contract the Fulbe and Tuareg nomads to stay at their homestead, to benefit

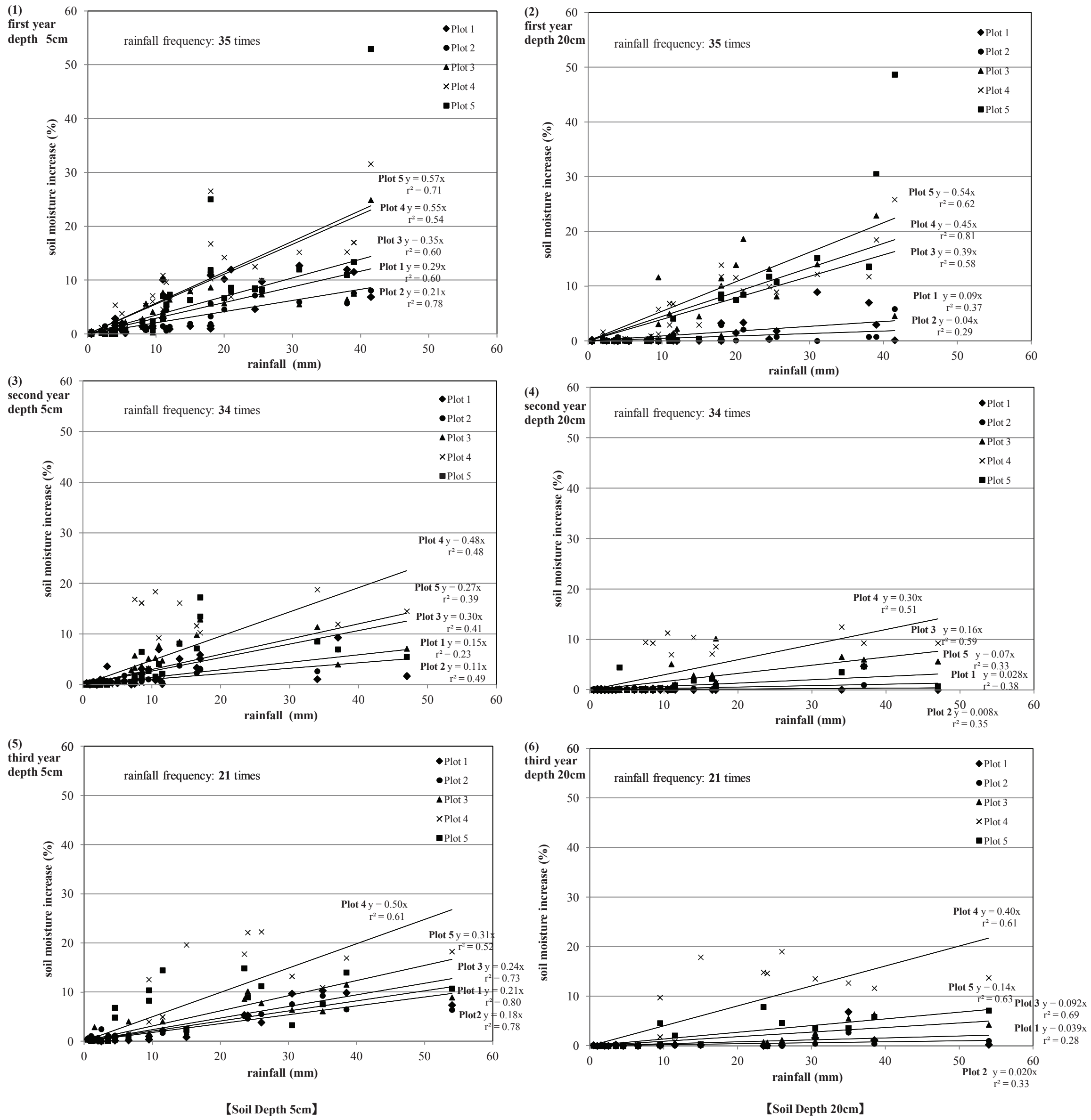

Fig. 10. Rainfall and soil moisture increase of 5 plots.

from their livestock excreta to improve their soil, or they scattered refuse onto their fields for the same purpose. The recycling on the homestead existed between peoples' daily living and farming or livestock raising (Orr 1995).

The crops and meat that people eat are all derived from the nutrients in the soil. With the daily living on the homestead at the core, organic matter would recycle from people and livestock to the soil in the fields, to crops and livestock, and back to the homestead. Termite activity facilitated this process.

However, after the 1960s, major traffic networks gradually expanded in southern Niger, and regular markets opened along the roads. The cycle of organic matter was severely disturbed as regular markets counted 2,277 as of 2005 (unpublished data from Ministry of Commerce, Niger Government) and the farmers sold quite an amount of millet, cowpea, groundnuts, livestock, firewood, livestock feed and firewood to the markets at a frequent interval.

The villagers the author studied would say, "The excreta and refuse are hard to come by these days," and this may be due to not only population growth and farmland area increase in the villages, but the amount of farm products taken out of the villages and sold. The population for the capital Niamey was 18,000 in 1905. This grew to 233,414 in 1977, 398,300 in 1988, and 675,000 in 2001.

The demand for foodstuff in Niamey from the ever-increasing population continued to grow as well, consuming enormous amounts of crops and livestock from the countryside. It is only natural that in this process, Niamey produced an increasing amount of urban refuse. Because the infrastructure to process the refuse remained quite inadequate in Niger, the urban areas have become overridden with refuse and unsanitary. Infrastructure in Niamey is not any exception, and in some rainy seasons, infectious diseases, such as cholera and typhoid, have taken their death toll.

On the other hand, the farming areas cannot obtain enough organic matter, and the soil nutrients are depleted, resulting in poor crop productivity. This is desertification, and the imbalance is as stark as in the urban areas. In other words, land degradation in the farms and refuse proliferation in the urban areas are flip sides of a coin. The author would argue that the problem lies in the imbalance in the cycle of organic matter. Urban refuse have much organic content in the forms of excreta and leftover foodstuffs rich in nutrients. The author submits that the urban refuse is an advantageous resource to improve the depleted soil in the farmland and that it should be utilized for land rehabilitation and land care.

Seven Effects Combination of the Urban Refuse Input on Land Rehabilitation

With refuse input, rainwater that otherwise would run off percolated into the ground through termite tunnels in the hardened sedimentary layer. The amount of refuse, up to a point, was directly related to water infiltration. The heaps of refuse were able to catch the wind-blown sand as well as organic matter carried by the Harmattan sandstorm during dry season and air turbulence during rainy season, and dispersed the rainwater running off on the ground. The wind-blown sand, along with clay and silt moved to the soil surface by the termites were also important for improving the physical property of the soil for millet cultivation (Oyama 2009). The refuse on the sedimentary layer prevented further soil erosion and exposure.

The study revealed that the urban refuse input on degraded land improve plant growth through combinations of 7 factors identified below (Fig. 11). The soil type of Arenosols is prone to damage from water and wind erosion (Bleich and Hammer 1996). But low mounds with intricate elevations on the flat topography in effect (1) trapped sand and organic matter blown in from the strong winds. This effect is the same that Michaels *et al.* (1995) aimed the wind erosion control using millet residue, but crop residue are not usually left in the region because of complete livestock grazing. The Hausa people welcomed the plastic sandals, bags, metal pots and plates in the refuse to scatter onto their fields because these do not easily decompose and are not utilized so much by termites so that they cover the soil as well as catch the wind-blown sand longer than organic matter.

Next, the author considers the effect of elevated termite biological activity due to refuse input. Most refuse comprises pearl millet stalks and leaves, left over livestock feed, and animal excreta. Refuse input induces the termites to gather. They harbor in their guts and nests symbiotic microorganisms such as bacteria, protozoa and fungi that decompose cellulose and lignin, fix nitrogen and produce methane (Lee and Wood 1971; Benemann 1973; Abe 1991). The termite biological activities alter the chemical property of the soil, and the termite mounds have concentrated soil fertility (Benemann 1973; Adepegba and Adegoke 1974; Pomeroy 1976; Bagine 1984).

Through this termite activity, (2) termite shelters over the organic matter have concentrated amounts of organic matter and termites elevate the small grain clay and silt in the soil and mixes them with wind-blown sand, (3) termite tunnels penetrate the sedimentary layer which allows rainwater to infiltrate easily through the tunnels, and (4) the aggregated soil structure is created as they solidify grains of sand with their saliva when termites build the mounds. According to the observation result, the aggregated soil structure is porous, and allows plant roots to grow and penetrate as well as contains oxygen and moisture all necessary for plant growth.

These all contribute to ameliorating poor nutrient

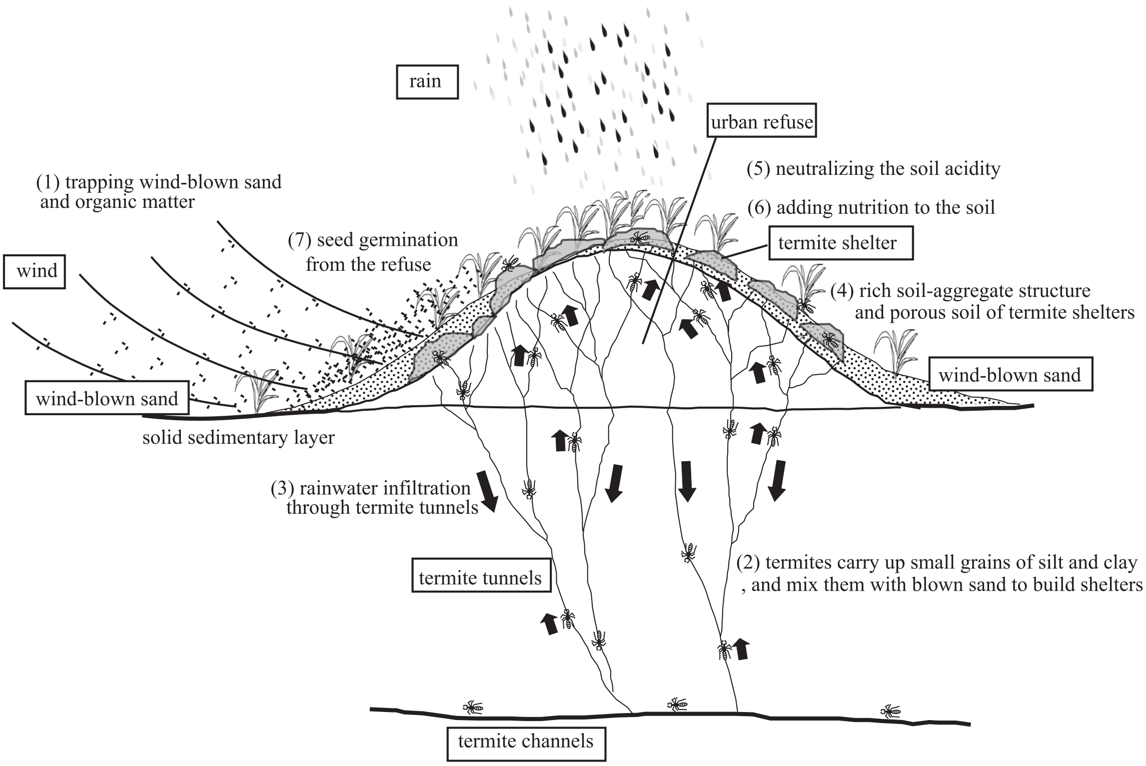

Fig. 11. Seven effects of the urban refuse input on land rehabilitation and combating desertification.

content and strong acidity indicated in the high pH of the parched degraded land. Organic matter including livestock excreta contains much nitrogen, phosphate, and potassium, and the chemical properties of the soil are much improved. Urban refuse and excreta are neutral to alkaline, and (5) neutralize the soil acidity (pH 4.5) of the degraded land, (6) adding nutrients to the soil. Finally, (7) urban refuse contains many seeds of edible matter including pearl millet, *Hibiscus subdarefa, Balanites egyptiaca*, and plants favored as feed for livestock. These naturally germinate with the arrival of the rainy season, and the experimental plots saw their growth thanks to moisture and nutrients from the refuse. The above seven effects can be combined to improve soil fertility and plant growth productivity.

6. Conclusion

This paper described in detail the results of an experiment with urban refuse input on soil for three years to identify changes in soil properties and plant regeneration. The experiment revealed that urban refuse is capable of preparing grazing ground and pearl millet fields.

The Hausa farmer and the Fulbe nomad interviewed for the experiment also agreed that the refuse amount at 20 kg/m^2 scattered over Plot 4 was effective in preparing pearl millet fields and grazing grassland. Because the Sahel area has seen rapid population growth, and land use pressure by both farmers and pastoralists are high, it is critical that degraded land is rehabilitated for new farmland and grazing grassland. According to the plant growth observation, the critical amount of urban refuse was at least 20 kg/m^2, approximately 2 cm thick on the ground for land rehabilitation.

However, the improved soil property and plant growth deteriorated after a few years from refuse input, due to depletion of nutrients through termite activity, grazing, and utilization by people, and erosion. In order to maintain plant productivity recovered using urban refuse, it is necessary for continuous refuse input to compensate for nutrient depletion. For this experiment, the author asked a tractor owner in the township to use his tractor for 10,000CFA (approximately USD20 in 2010) per one time, was enabling to carry 3.5 tons urban refuse for 7 km from township. The transport cost of urban refuse, primarily external diseconomy, is problem to be solved. Furthermore, urban refuse may have dangerous contents, such as heavy metals (Pasquini and Harris 2005; Bolan *et al.* 2010; Adejumo *et al*. 2011). Future refuse utilization must be fine-tuned.

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