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SOIL MANAGEMENT AND AGRODIVERSITY: A CASE STUDY FROM ARUMERU, ARUSHA, TANZANIA

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Introduction

Declining yields and environmental problems associated with many agricultural systems around the world have resulted in an on-going global call for adoption of sustainable ways of agricultural production. The Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGAIR) defined sustainable agriculture as involving "*the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources*" (Plucknet, 1990).

Within PLEC (People, Land Management and Environmental Change) Project, sustainable maintenance or enhancement of environmental quality and conservation of natural resources is addressed within the concept of "*agrodiversity*". Brookfield and Padoch (1994) described agrodiversity as the many ways in which farmers use the natural diversity of the environment for production, not only including their choice of crops but also their management of land, water and biota as a whole. Agrodiversity has also been described as an interaction between management practices, biophysical resources and plants (Brookfield and Stocking, 1999). The four principal elements of agrodiversity include: biophysical diversity, management diversity, agrobiodiversity and organisational diversity. The elements overlap but each of them constitute distinctive parts that have their own rationale.

"Management diversity" (i.e. land transforming operations which influence the behavior of physical and chemical aspects of the soil, surface and near surface physical and biological processes, hydrology, micro-climate etc. (Brookfield and Stocking, 1999) and its impact on agrodiversity) is the focus of this paper. Different methods of managing the land, water and biota for crop production and the maintenance of soil fertility and structure are examined. Diverse soil management methods used by farmers in Arumeru to address diverse constraints all aimed at soil productivity improvement, agrodiversity enhancement and conservation are considered.

Crop production levels in Tanzania are generally below potential, averaging about 905 kg/ha maize and 458 kg/ha for beans (FAO Year Book, 1984). Many farmers associate low yield levels with poor inherent soil fertility and continuous cultivation with few, if any, inputs. The work of Stoorvogel and Smaling (1990) indicated that Tanzanian arable soils lost nutrients at an average net rate of 27, 9 and 21 kg N, P_2O_5 and K_2O per ha per annum in 1983. The rate of loss was projected to increase to 32, 12 and 25 kg N, P_2O_5 and K_2O per ha per annum respectively by year 2000 if the production trends of 1983 were not reversed. Most of the losses were associated with the harvesting of crops, the removal of residues and soil erosion. The amount of nitrogen and phosphorus removed from the soil every year by the main crops was estimated to be 251,448 tons N, and 115,112 tons P_2O_5 by the year 2000. Only 21% and 14% of N and P removed respectively was projected to be replaced through fertilization. This implies continued removal of fertility with concomitant decline in soil productivity. This paper asks how 'management diversity' can help to relieve these projected and serious declines, and whether there are cases of good practice to be found in the PLEC demonstration site in Arumeru.

PLEC works towards promotion of sustainable agricultural production by recognizing the indigenous knowledge accumulated by small scale land users over decades. That this knowledge developed in response to environmental changes and population pressure can be improved through incorporation of scientifically proved practices on farmers' fields. That successful farmers in resource management then become change agents and train other farmers in improved and sustainable agriculture.

Some characteristics of Arumeru PLEC sites of northern Tanzania.

Olgilai and Ng'iresi villages constitute the high altitude, high rainfall sub-humid site, while Kiserian village is the low altitude, low rainfall semi-arid site in Arumeru district. The study sites are located in the area between 36 42'50"E; 3 19'36" and 36 45'00"E; 3 19'36"S. Agroforestry is the major land use system of the sub-humid site while agro-pastoralism is the dominant land use in the semi-arid site. Rainfall pattern is bimodal with long rains from March to May and short rains from November to December. The rainfall pattern and amount is determined by the dual movement of the Inter-tropical Convergence Zone (Fernandes et al. 1984). Table 1 summarizes some major characteristics of the study area.

Table 1. Salient features of PLEC study sites in Arumeru district

Characteristic	Kiserian (Lowlands)		Olgilai/Ngiresi (Uplands)	
Elevetion (m.a.s.l)	1,200		1,900	
Annual rainfall (mm)	500		2,000	
Temperature range	12-30 C		12-30C	
Dominant farming system	Agropastoral		Agroforestry	
Village population (1988)	3,330		2,158	
Major soil characteristics	0-20 cm	40-50 cm	0-20 cm	40-50 cm
Clay (%)	75	81	15	12
Silt (%)	15	11	47	46
Sand (%)	10	8	38	40
PH H2O 1:2.5	6.3	6.4	6.4	6.6
Org.C.(%)	0.8	0.3	3.7	4.5
Tot. N (%)	0.09	0.02	0.39	0.42
C/N ratio	9	15	9	11
Avail.P (ppm)	85.42	28.06	59.36	15.58
CEC (cmo/kg)	20.44	21.39	6.39	5.22
Exch.Ca (cmo/kg)	11.5	12.1	3.5	2.9
Exch, Mg. (cmo/kg)	4.2	5.0	1.3	1.3
Exch. K. (cmo/kg)	0.43	0.34	0.41	0.42
Exch. Na, (cmo/kg)	0.02	0.31	0.03	0.03
Base saturation (%)	79	83	82	89
Classification (FAO/UNESCO)	**Eutric Nitisols**		**Eutric Andosols**	
Other soils in the two sites:	Calcic Vertisols		Mollic Fluvisols	
	Haplic Cambisols		Alic Andosols	

Source: Kaihura (1998).

Review of soil management within dominant cropping systems in Arumeru.

The dominant land use of sub-humid Arumeru is the coffee/banana/maize/beans/trees agroforestry system. The system is unique to the area and has survived for the past 200 years (O'Kting'ati and Kessy, 1991). The coffee and bananas are planted under various trees that are grown for fruit, timber, medicine, animal fodder and shade. Many farmers also keep a few dairy cattle under zero grazing mostly due to population pressure. Crop residues and stover transported from the midlands and lowlands are main sources of fodder for the stall fed animals. The stability of the system is largely attributed to the intimate multi-species, multi-storey associations found in it. These have ensured good soil productivity through (1) provision of continuous ground cover that has helped to conserve soils on erosion prone slopes, and (2) a high degree of nutrient cycling that has ensured nutrient use efficiency (Fernandes et al. 1984).

Under similar environmental and management conditions in neighboring Kilimanjaro region, crop nutrient removal data show that a combined crop of coffee and banana (excluding residues) removes 14.9, 1.2 and 8.7 kg of N,P and K respectively. This translates to a loss of 10, 0.8 and 6.0 kg of N, P and K respectively from an average farmer's field of 0.68 ha. About 2 tonnes of FYM (containing 0.48 % N, 0.17% P and 0.54% K), the main nutrient source for this system, would be required to offset the nutrients removed. It is conceivable that such an amount of manure can be produced from an average farm having at least 2 stall fed dairy cows. The in- and out-flows of nutrients in this system are therefore relatively balanced. This further explains why the system has been stable for a long time. It is however stabilized at a level of low production. As such, it cannot meet the demands put on it by a rapidly growing population. Soil erosion is further constraint for small-scale farmers on the slopes of Mount Meru contributing to fertility decline.

Maize/beans intercropping is a major component of the agro-pastoral system in the lowlands. Intercropping with beans would be expected to contribute to the N economy of the system. However, since harvesting involves pulling out whole plants with their roots, the benefit of additional N is probably negligible. Little increase in organic matter and nitrogen content in the soil can be expected. Every season a modest crop of maize and beans removes 57.6, 12.5 and 55.5 kg/ha of N, P, and K from each hectare, respectively. Nutrient losses from this system are therefore large, particularly for N and K. In addition, farmers from uplands transport crop residues to their homesteads for animal feeding after harvest. Crop residues are also lost through post harvest grazing.

Soil erosion is also more pronounced in the maize/beans system of the lowlands. Soil erosion results in soil fertility decline mainly because the eroded surface soil is richer in plant nutrients and organic matter than the remaining subsoil. Kaihura et al. (1998) observed that on average 64 kg/ha maize and 34 kg/ha cowpea grain was lost per centimetre topsoil loss due to erosion in three agro-ecological zones of Tanzania. It is clear therefore that soil erosion poses a big threat to the sustainability of agriculture including both the uplands and lowlands of Arumeru.

Appropriate soil conservation measures, such as manipulation of the slope characteristics, soil cover and various management factors, can be used to decrease losses of nitrogen. Replenishment and maintenance of organic matter levels in the soil are the most rational remedial management practices. Legume cover crops with diverse uses e.g. *Crotolaria ochroleuca* should be used since they are fast growing nitrogen fixing legumes, can be used as animal fodder and can be ploughed under well before the growing season (Fernandes, et al. 1984).

Soil constraints that limit production in Arumeru district

Farmers of the sub-humid site indicate low fertility, soil erosion, seasonal moisture stress, land pressure and inability to purchase industrial fertilizers as the major production constraints. In addition, the semi-arid lowland farmers complain of unreliable rainfall in terms of amount and distribution. (Kaihura et al., 1998). Effects of each constraint on production and methods of addressing each problem differ between sites. Differences are mainly due to rainfall variations between sites, differential endowments of resources between farmers within sites, individual farmers' knowledge and available inputs within the surroundings. Table 2 summarises the diverse methods of soil management for the major constraints that have been found on the demonstration sites.

Soil management at individual farm level.

Resources management under small scale farming differs between farmers. Differences are mainly accounted for by farm size, access to inputs such as manure and industrial fertilizers, labour availability, ability to cope with changes in soil quality and farmer accumulated knowledge in resources management. Table 5 summarises soil management strategies for erosion and fertility improvement for three farmer categories in the sub-humid Olgilai/Ng'iresi site of Arumeru. The assessment was made on 50 x 20 m^2 plots located on different positions of the landscape.

Table 2. Soil related constraints at PLEC sites of Arumeru and corresponding soil management strategies undertaken by farmers.

Site	Soil constraints	Land use type	Soil management strategy
Olgilai/ Ngiresi	Low soil fertility	Coffee/banana/maize/beans	Manure application; incorporation of crop residues, house refuse, weeds and ashes; planting of agroforestry trees such as *Sesbania sesban, Leucaaena_leucocephala*; compost application (few); incorporation of decomposed trashline materials, heaping of banana stems around coffee tree trunks, application of mineral fertilizers on coffee, import of stover from distant support plots.
		Maize/beans	FYM application, green manuring, incorporation of leaf litter from trees (e.g *Grevillea*), trashlines, mineral fertilizers, crop residues, crop rotations.
		Pastures	Planting of grass-legume mixtures (N-fixation), nutrient recycling trees, tethering of animals.
		Homegardens	Intensive manuring, mulching, mineral fertilizers, ashes,
		Planted forests	Controlled harvesting of trees; controlled bushfires; incorporation of crop residues and decomposed forest litter to planted crops
		Natural forests	Controlled trees/firewood harvesting, controlled bushfires.
		Water source microcatchments	Fallowing
	Soil moisture stress	Coffee/banana/maize/beans	Mulching; incorporation of crop residues; protective canopy from agroforestry system; incorporation of decomposed trashline materials; green cover crops, especially creepers such as *Vigna* spp and *Mucuna*.; biophysical structures.
		Maize/beans	Self-mulching; incorporation of crop residues; incorporation of decomposed trashline material; protective intercropped canopy; timely planting; weed control.
		Pastures	Rotational grazing
		Homegardens	Irrigation during dry periods; mulching; FYM application; construction of sunken beds; application of crop residues and mineral fertilizers.
		Planted forests	Adequate tree spacing; protective crop and tree canopy; decomposition of litter and crop residues
		Natural forests	Controlled harvesting; maintenance of under-storey; litter decomposition
		Water source m-catchments	Fallowing; area enclosure
	Soil erosion	Coffee/banana/maize/beans	Construction of trashlines; mulching; rain interception by tree canopy; planting of hedges of flowers and/or fodder plants; planting of agroforestry trees.
		Maize/beans	Trashlines; crop and tree canopy, crop rotation using spreading plants such as sweet potatoes; application of ashes; incorporation of crop residues; fodder grass strips
		Homegardens	Small scale near the homestead; sunken beds; Large application of manure and/or compost.
		Planted forests	Controlled harvesting and prevention of trespassing
		Natural forests	Controlled harvesting and prevention of trespassing, restricted grazing.
		Water source m-catchments	Vegetation regeneration

Kiserian	Low soil fertility	Woodlots	Indigenous trees mix for diverse uses including fertility improvement; restriction to fertile parts of the landscape, e.g. river-line positions; restricted harvesting and burning; applying animal feed remains and crop stover; tethering of animals in sparsely vegetated and/or degraded woodlots
		Maize/beans	FYM application; incorporation of crop residues; crop rotations
		Pastures/Mbuga	Free range grazing; inclusion of legume grass/fodder species in conserved pastures; erosion control by use of stonelines
		Homegardens	Application of manure from sheep and goats; pigs and chickens; application of cattle manure.
		Agroforestry	Planting of diverse leguminous spices and/or fodder trees; tethering of animals in agricultural land during off-season; replanting of indigenous soil fertility improving trees such as *Ukwaju*; extended cultivation
	Soil moisture stress	Woodlots	Permanent canopy; controlled harvesting of roots, branches and leaves,
		Maize/beans	Planting of biophysical structures and grass strips (few cases); maintenance of rough surfaces; application of FYM; canopy optimisation by mixed cropping of pigeon peas, millet and sometimes sorghum and maize/beans in same fields; deep tillage; construction of sunken beds or tie-ridges.
		Pastures/Mbuga	Construction of biophysical structures for runoff and sediment control
		Homegardens	Small plots around the homestead mostly irrigated by waste water from the house;
		Agroforestry	Ensuring of canopy through planting of diverse fruit trees and more water tolerant trees; surface cover through planting of creeping legumes such as *Mucuna puriens* and *Ngwara***.**
	Soil erosion	Woodlots	Restricted grazing and harvesting.
		Maize/beans	Rough tillage; incorporation of FYM; deep tillage
		Pastures/Mbuga	Reduced herd size; biophysical stuctures; construction of cut-off drains; strengtheing of cut-off drains with sisal and other thorny bushes.
		Homegardens	Small plot sizes; irrigation; manure application.
		Agroforestry	Ensure canopy cover; planting of creeping crops; biophysical structures and live fences

NB: Soil management observations organised according to the three principal soil management strategies. Also applies to support plots and their sustainability.

Table 3. Soil management diversity for three farmer categories in Olgilai/Ng'iresi, Arumeru.

Farmer category	Plot location	Cropping system	Management strategies
Rich	Lower slope of volcanic cone (12-15% slope)	Coffee/Banana system	1. Boundary planting of : - *Moras alba* (Mandela) as fodder for livestock with fruits edible by children. - *Psidium quajava* fruit tree, leaves cure diarrhoea in humans. 2. *Fanya chini* contour planted with *Seteria spp; Desmodium spp* and *Leucaena spp*. The contour controls soil erosion and strengthened by plant species that also are fodder for livestock and improve soil fertility. 3. Fanya chini contour planted with *Seteria* spp; Bananas var Mshale and Taro. Contour for soil erosion control strengthened by *Seteria* grass and bananas. Grass is also fed to animals, banana for food and contour strengthening; Taro planted as food to benefit from the fertility enhanced along the contour by deposited soil. 4. Farmyard manure. Applied for soil fertility improvement in plots close to the homestead for ease of transport. 5. Application of animal feed remains around banana and coffee trunks and occasional shifting of cattle pen. Soil fertility improvement of area between contours and optimisation of urine from the pens. 6. Mulching of maize stover and other house refuse. Soil fertility improvement, erosion control, moisture conservation, soil micro and macro fauna enhancement. 7. Coffee/banana spacing at 3 x 3 m^2. Agro-biodiversity enhancement, crop yield improvement, pests and disease control. 8. Application of decomposed manure in holes and planting of bananas for soil fertility improvement and pest/disease infestation reduction. 9. Pruning of coffee trees at 1m and 1.5m heights. Prunings mulched for soil fertility, moisture and micro/macrobial activity enhancement/maintenance, pruning also improves crop yield, pests and disease control and labour saving at harvest. NB: Some patches of the farm are dominated by *Tegetas minuta* weed, an indicator of good soil fertility to the farmer. Other patches with grasses that are indicators of poor fertility.
	Middle slope of volcanic cone (25% slope)	Coffee/Banana System	1. Application of livestock feed residues and farmyard manure near banana and coffee trunks and sometimes around coffee trunks on sunken weed free beds around trunks. Soil fertility improvement and micro/macrobial activity enhancement and maintenance. 2. *Fanya chini* contour planted with sugarcane *Saccharum* spp and *Grevillea* spp. Soil erosion control, sugarcane for consumption by children and for marketing; *Grevillea* for shade, timber and fertility improvement through high biomass production (litter). 3. Mulching of maize and banana leaves. Fertility improvement, erosion control and micro/macrobial activities enhancement/improvement.
	Upper slope of volcanic cone (30-35%	Maize/Beans system	1. *Fanya chini* contour planted with *Seteria* spp and *Leucaena leucocephala* . Soil erosion control, fodder for animals and fertility improvement. 2. Limited weed control. Fertility improvement by weed incorporation into the soil, weeds also left to reduce

	slope)		runoff and soil loss, some weeds picked and fed to animals.
Average	Middle slope of volcanic cone (20-25% slope)	Banana with remains of round potatoes from previous season crop.	1. Boundary planting of *Sesbania sesban*, *Altrizine gunifera* and *Musa* spp. Security of land from being encroached by neighbours, fodder for livestock and three varieties of bananas i.e *Mshale* for food, *Kisukari* for fruit and *Mkono wa tembo* for roasting. 2. *Fanya chini* contour planted with *Seteria* spp, *Sesbania* spp and several species of grasses. 3. *Fanya chini* planted with *Seteria* spp, *Flamingya* spp , *Sesbania* spp and *Musa* spp. 4. *Fanya chini* contour planted with *Sesbania* spp and *Uriochloa puruloans*. Sesbania for fodder and Uriochloa identified by farmers to replace Seteria grass that competes with crops for moisture. 5. *Fanya chini* contour planted with Rhodes grass, *Desmodium* spp, *Caliandra* spp, *Sesbania* spp, *Grevillea* spp and *Musa* spp. Soil erosion control, fertility improvement, fodder for livestock and bananas for food and animal feed. 6. *Fanya chini* contour planted with *Grevillea* spp, *Seteria* spp, *Sesbania* spp and remnants of flowers from last season. Soil erosion control, fertility improvement, timber, shade, grass and fodder to animals.
Poor	Lower slope of volcanic cone (10-15% slope)	Coffee/Banana with Taro.	1. Boundary planting of *Seteria* spp, Pine trees and *Grevillea* spp. Land security, production optimization, timber, fertility improvement. 2. *Seteria* grass strips (very stunted growth). Income generation through sales.

Table 3 illustrates how soil management differs between farmer categories. The rich farmer has more cropping systems each with different management practices compared with the average and poor farmers. The management intensity is greatest with the most valued crops, in this case coffee and bananas. Such crops are planted near the homestead for easy reach and application of inputs. Away from the homestead are less valuable crops with less management diversity. Table 3 also indicates that erosion control measures contribute to increased diversity for a given cropping system, where the diversity of plants on individual physical structures changes within and between cropping system, and between farmers and farmer categories. Plant and management diversity between farms depends on individual farmers' preferences as explained by individual food preferences, types of livestock chosen, knowledge about different plant species (trees and grasses), farm size, market prices of agricultural products and interests of children (particularly with fruit trees). Reasons for selection of diverse plant species include: soil fertility improvement, erosion control, soil moisture conservation, household food tastes and preferences, animal fodder, income generation, human and animal disease control. It was also noted that each single plant may have a diversity of uses, singly or combined. Multipurpose plants are more preferred than single/dual purpose plants. Almost all plants have an effect on soil management. Table 4 indicates species richness, utility and similarity indices for plots with different management systems.

Soil management effects on species richness, utility and similarity indices.

Differences in soil management by different farmer categories have variable effects on soil fertility and agrodiversity. Poor farmers with limited access to inputs and labour manage soils according to personal circumstances at the given time. Rich farmers with reasonable supply of inputs and labour availability manage differently. Table 6 summarises species richness, utility and similarity indices for different farmer categories and level of soil management for a coffee/banana/maize/beans agroforestry system in Olgilai/Ng'iresi.

Table 6. Species richness, utility and similarity indices for three management systems of a coffee/banana/maize/beans agroforestry field type in Olgilai/Ng'iresi.

Farmer name (category)	Level of soil management	FSR	FUI(%)	FSI(%)
Yangani 3 (Rich)	High level of inputs and soil deposits	15	60	53
Gidiel 5 (Rich)	High level of inputs non depositional phase	09	78	75
Alfayo 1(Aver.)	Average level of inputs	12	67	35
Nassoro 1(Poor)	Low level of inputs	20	55	25
Melami 1(Poor)	Low level of inputs	17	59	49

FSR = Field Species Richness; FUI = Field Utility Index; FSI = Field Similarity Index.

Poor farmers had higher species richness (greatest diversity) than rich and average farmers. They had the lowest utility indices. Weeds contribute to the observed diversity in poor farmers' fields, being used as the main inputs for soil fertility. High level of management by rich farmers is associated with lower species richness but with the highest utility index. Soil management by the rich is also associated with selection of species to grow, which have diverse uses including soil fertility improvement. Earlier studies of soil management at landscape level (Kaihura et al. 1998) showed that field types closer to the household receive greater attention than distant ones. Yangan 3 plot is the closest to the homestead and receives the highest level of inputs such as house refuse, animal feed remains and kraal manure. Being on the depositional phase of the landscape, fertile surface soil from upper slopes adds to its fertility. Improved soil fertility enhances the high diversity of species in the plot. Unlike with poor farmers, those plants with no or limited use value are removed and those with diverse uses are planted or left to grow. Hence there is a lower species diversity (richness) than that with poor farmers. Labour unavailability may also cause limited or no weeding on poor farmers' farms. Gidiel's plot has less species diversity compared with Yangan, but has the highest utility index indicating a high level of selection of preferred plants with diverse uses. The majority of planted species are legumes for nitrogen fixation and soil improvement. The average farmer's plot showed high diversity above that of Gidiel because of planting more shrubs and grasses on contours to control erosion. Gidiel has few trees along the boundaries only and has no contours. Also, the average farmer did not frequently weed his farm. The results suggest that soil management through incorporation of organic materials and use of biophysical structures greatly contributes to species diversity and utility indices on-farm.

Management of soils on steep slopes

Although by-laws preventing cultivation of hilltops and steep slopes exist, farmers continue to cultivate on such restricted parts of the landscape because of population pressure. Management strategies to mitigate degradation processes are employed by farmers such that yields obtained from restricted areas compare favourably with those obtained in valley bottoms.

Biophysical structures are an introduced method of soil management for erosion control common to both sites. They reduce soil movement from upper slopes, establishing a depositional phase above each structure. Soil moisture levels and fertility as identified by soil colour and vegetation and soil fauna and biota are greatly enhanced on the depositional phase above the structure. Vegetation left to grow on traditionally-made structures demonstrates a greater diversity in species and uses compared with introduced structures. Table 5 summarises the species found on a traditional biophysical structure on a steep slope along Kivesi hill, Ng'iresi village, Arumeru.

Table 5: Species diversity on a biological soil conservation structure on a 40% slope field.

Local name	Scientific name	Uses
Olaing'ooruai	??	Medicinal, firewood, fodder, soil conservation, shade.
Olmashinga	Caesalpinia decapetala	Medicinal, firewood, soil conservation, natural fence.
Olchavukalian	Rauvolfia caffra	Medicinal, timber, firewood, soil conservation, shade.
Oloiyaviyav	Croton macrostachyus	Timber, firewood, medicinal, soil conservation, shade
Ngaukau	Plectran thus sp	Medicinal, fencing, settlement of conflicts
Olmakimaro	Conyza bonariens	Medicinal, soil conservation, mulching, pasture.
Olaiteteyai	Commelina benghalensis	Pasture, soil conservation, cleansing of wounds
Engibasirkon	Clerodendrum sp.	Medicinal, firewood, soil conservation, shade.
Olmanyinyikwai	Ocimum suave	Medicinal, shade, firewood, soil conservation
Olpaina (Msindano)	Pinus patula	Timber, shade, firewood, soil conservation.
Olngeriandus	Plumbazo zeylanica	Decorations, fodder, medicinal, soil conservation
Engasiijoi		Beverage, body cleansing, fodder, soil conservation.
Osangari	Digitaria sp.	Pastures, soil conservation.
Emurua	Pennisetum sp.	Pastures, soil conservation, decorations
Enyoru narok	Desmodium repandum	Pastures, soil conservation, ropes,
Engaibooshwai	Momordica calantha	Fruits for children, animal feed, soil conservation
Engivaavua	Tragia brevipes	Medicinal, fodder, soil conservation, ropes.
Olmuchunga	Medicago sativa	Animal feed, soil conservation, medicinal
Olorondoi??	Cyphostemma sp.	
Engilelekuru	Momordica calantha	Medicinal, firewood, soil conservation
Osanguves	Albizia sp.	Timber, firewood, shade, medicinal, body cleansing, soil conservation, fodder.
Olmandelai	Rubus indica	Fruits, fodder, soil conservation.
Olmasui	FERN-general	Soil conservation, thatching, sieving of malt for local beer.
Oltarakwai (Cyprus)	Cupressus lusitanica	Timber, wall sticks to fix mud, soil conservation, grain insects pesticide, fodder to goats.

The traditional structure constitutes several local trees and shrubs combined to check downward soil movement. At the same time it holds deposited soil, which through biological activity transforms into highly productive soil. The structure is positioned on a 40% slope along Kivesi hill. It is a very stable structure continuously checking eroding soil from up slope and making very deep productive soil above it in 1974. Ploughing the land and leaving an uncultivated strip of grass, shrubs and trees made the structure. At the moment the structure is 1.3 m deep. There are 24 different trees and shrubs and grasses, 80% of which are indigenous species with uses that include: settling conflicts within society and among friends, improving soil fertility, human and livestock infertility, several human and livestock diseases, boundary trees, etc. Above the structure are trashlines running parallel to it at constant intervals, with several micro-contours (contour ridges) between the trashlines and the main biological structure. Both the trashlines and the micro-contours reduce the speed of runoff and sediment down slope. Crops are planted on micro-contour ridges. Trashlines are made of banana leaves, weeds and *Grevilea* leaves (known to naturally fertilize the soil). The trashlines are spread after every season, whereby the decomposed organic inputs become the source of nutrients for the coming crop. Between the micro-contours are numerous sources of microbial activity that include ants that turnover subsurface to surface soil thereby mixing the surface fertile soil and the subsurface infertile soil and consequently improving the productive soil depth for plant roots. No labour is needed for the main structure. The trashlines also require little labour input - mainly pruning and mounding in a line. Micro-contours need labour, however. About 40 to 50 meters above, from where the deposited soil originates, the soil is red, shallow and infertile. The efforts made by such farmers demonstrate three key points:

(a) With good soil management, it is possible to improve soil fertility on steep slopes and grow crops sustainably,
(b) Although commercial farming is believed to reduce agro-biodiversity, conservation farming can still support commercial agriculture and conserve agro-biodiversity as is the case of Irish potato production in Olgilai/Ngiresi site and
(c) Traditional conservation structures cost little labour and have uses that include social welfare that is beyond the commonly advocated purposes of introduced erosion control measures. They create a good environment for multiplication of soil biota and fauna, soil fertility and crop/cropping systems diversity. Although some farmers claim that such well-developed structures harbour mice and rats, their advantages far exceed the disadvantages.

Soil samples were collected from the lower, middle and upper part of the farm. The topsoil depth immediately above the structure is 70 cm deep, dark brown clay soil. Topsoil of the middle part of the farm is 50 cm deep, dark brown clay. The surface soil of the upper slope of the farm is less than 10 cm deep with brown subsurface soil exposed. Soil quality indicators have been developed in order to characterise and assess traditional biophysical structures and their performance. These indicators present the assessments from the perspective of land users, and utilise measures such as soil colour, depth, stoniness, ease of cultivation and yield.

Soil management effects on chemical indicators of soil quality in different land utilization types.

Fertility evaluation was carried out during the characterisation of the initial sites. The objective was to establish a general understanding of fertility conditions under existing land use systems. Table 6a summarises the analytical results for soil surface and subsurface chemical properties from four land utilization types (LUT) each with different management practices. The planted forest (*Pinus*) and the agroforestry farm represents the main LUT of the sub-humid site while the Maize/Beans-Fallow system represents the major LUT of the semi-arid site.

Table 6a. Top and subsoil analytical data for pH, exchangeable bases, cation exchange capacity and base saturation for selected locations of Olgilai/Ngiresi and Kiserian sites, Arumeru district.

Land utilization type	Soil management practices	Depth (cm)	pH H_2O	CEC	Ca	Mg	K	Na	BS (%)
				Me/100g					
Planted forest (*Pinus*)	In-situ decomposition of surface litter	0-20	5.8	17.95	7.1	3.8	0.18	0.03	62
		20-50	6.1	16.34	8.4	2.5	0.21	0.02	68
Coffee/Banana agroforestry farm	Application of house refuse, ashes, banana peel, manure, mulching	0-20	6.1	14.13	6.2	3.2	0.44	0.02	70
		20-50	6.3	13.05	7.2	2.1	0.50	0.03	75
Maize/Beans-fallow rotation	Incorporation of weeds, M/B pasture rotation, contouring, little manure.	0-20	7.3	10.65	6.9	2.7	1.37	0.02	100
		20-50	7.4	9.26	6.0	3.6	0.03	0.03	100
Mbuga plain	Free grazing	0-20	7.9	7.26	5.6	1.7	0.57	0.28	100
		20-50	8.2	5.75	5.3	1.4	0.44	0.74	100

Soil reaction (pH) for surface soils in the sub-humid site was 5.8 in the planted forest and 6.1 in the agroforestry farm. For both LUTs pH levels were lower in surface than sub-surface. The cation exchange capacity (CEC) and exchangeable Ca and Mg were higher in the planted forest. Exchangeable potassium (K) and base saturation was however higher in the agroforestry farm.

The data on organic matter available phosphorus (P) and Nitrogen (N) are summarized in Table 6b. The planted forest had more soil contents of organic matter, NH4 and NO3 forms of nitrogen and available phosphorus. For both LUTs available phosphorus was in the low range. Based on levels for nitrogen forms in the soil, microbial activities were greater in the planted forest than the agroforestry farm.

Table 6b. Surface and subsurface soil conditions of organic carbon, available phosphorus and NH_4 and NO_3 nitrogen for Olgilai/Ngiresi and Kiserian sites, Arumeru district.

Land utilization type	Soil management practices	Depth (cm)	OM(%)	CN	Av P-Bray	Av P-Olsen	NH_4-N	HNO_3-N
Planted forest (*Pinus*)	In-situ decomposition of surface litter	0-20	16.86	12	7.42	-	30.80	33.60
		20-50	8.43	9	5.80	-		
Coffee/banana/ agroforestry farm	Application of house refuse, ashes, banana peels, manure, mulching	0-20	7.91	10	1.64	-	23.89	25.38
		20-50	7.34	12	1.69	-	4.48	24.26
Maize/Beans-fallow rotation	Incorporation of weeds, M/B pasture rotation, contouring, little manure.	0-20	6.71	9	-	2.35	24.26	28.00
		20-50	8.43	18	-	2.28	7.47	8.96
Mbuga plain	Free grazing	0-20	2.92	17	-	2.03	-	-
		20-50	0.86	7	-	7.52	-	-

Results for the maize/beans-fallow and mbuga systems of the semi-arid site show that:

Soil reaction (pH) is greater than 7.0 and increases with soil depth for both LUTs. Cation exchange capacity (CEC), exchangeable Ca and Mg, organic matter percent, available phosphorus and nitrogen, were higher in surface than subsurface soils. Also NO_3-N levels are higher than NH_4, suggesting a greater number of oxidizing rather than non-oxidizing micro-organisms.

Comparing soil properties between sites, it was observed that overall, pH levels are higher for semi-arid than sub-humid soils probably due to higher levels of exchangeable bases as indicated by base saturation levels and high levels of sodium. The inherent fertility of the sub-humid soils is higher and soils more resilient to mismanagement compared to semi-arid soils. Semi-arid soils have a high concentration of nutrients in the upper 20cm of the surface soil. Such soils are sensitive to land mismanagement through erosion and continuous cultivation with minimum inputs. The soils of the Mbuga plain under natural grazing were very low in nutrient content and need proper soil management strategies for sustainable grazing.

Conclusions

The farmers of Arumeru are managing a complex and difficult environment by employing a wide range of practices in their farming, management of soils and utilization of vegetation species. Foremost, they have steep slopes, erosion hazard, variable soils and (especially in the Kiserian site) low and unreliable rainfall. What the PLEC project is calling 'agrodiversity' helps them cope with these conditions and to carve out a livelihood from circumstances that are far from easy. An aspect that this paper highlights is the precarious condition of soil fertility and nutrient status. Losses of nutrients by crop removal, erosion and lack of replenishment is potentially ruinous to the sustainability of agriculture. Farmers are responding in both the sub-humid and semi-arid sites of Arumeru with a mixture of management practices that reflect the resources they have available, their local knowledge, the intrinsic quality of soils and their basic needs for production and other uses. Indeed, it appears that the multiple uses of species, coupled with the multi-functionality of many practices, is one of the major and enduring attributes of the land use practices that have been discovered.

With its emphasis on 'management diversity', the PLEC project has documented a large part of this complexity in an effort to understand how 'agrodiversity' meets the needs of resource-poor farmers in a difficult environment. Much is yet to be discovered. It is not known how the soil management systems contribute to the economic and social needs of households, other than in general terms. We have yet to find out how far the expereinces in Arumeru can be translated to other sites that appear to be less endowed with examples of good practice. Nevertheless, enough has been discovered in Arumeru to draw strong policy conclusions that here are agricultural systems that have withstood the test of time, of rapid urbanisation in nearby Arusha and other pressures, and are therefore worth emulation. At the very least they are worth further examination, utlising the skills of the farmer network built up in the PLEC project to inform others.

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