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Full Length Research Paper

Properties and management of gravelly soils developed on ferruginous cuirass in Mali

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In Mali, different types of gravelly soils on Cuirass were identified in association with a native vegetation including many species of tree, shrub and herbaceous. All these soils are developed by degradation of ferruginous cuirass, a material largely observed in West Africa Sudanian and Sudano-Guinean zones. Gravelly soils of Mali have a variable depth (< 10 to 95 cm depth) and gavel content (15 to 60%) and are ranged in three textural classes (silty, sandy loam and clayey loam). Their marginal status for agriculture are always justified by pedologists but they are used both for cropping and breeding (when annual rainfall ≥ 800 mm) or only for breeding (when annual rainfall < 800 mm). In manual cultivation system, many farmers prefer gravelly soils where weed control is easy. In mechanized agriculture, the gravelly soils on cuirass are used when deep soils of lowlands are not available. Agriculture use of cuirass lands favours deforestation, increase runoff, soil erosion and inundation risk at watershed scale. So, better management systems are needed and research programs must identify techniques for harvesting runoff from cuirass table and its stockage for complementary irrigation. However, the field experimentations must identify ways to improve fodder production and conservation.

Key words: Ferruginous cuirass, gravelly soils, land use, landscape degradation, West Africa contrasted climate zones.

INTRODUCTION

In the Sudanese zones of West Africa, there are large areas where the ferruginous Cuirass is present, covered or not with a shallow or moderate depth gravelly material. Studies of this landscape had permitted production of a relatively abundant literature (Maignien, 1958; Tricart and Cailleux, 1974; Michel, 1973; Leprun, 1977, 1979; Boeglin, 1990; Bantsimba, 2001). The genesis of Cuirass materials, their mineralogical and geochemical characteristics, as well as their influence on the current dynamic of reliefs have been studied with special attention in regional geology and geomorphologic research programs, and mineral exploration. Moreover, the description and evaluation of soils located on cuirassed reliefs were made during pedological surveys (Anonyme, 2001). These soils have generally been recognized marginally for agriculture and native vegetation development (Anonyme, 2001; PIRT, 1983). Gravely soils on Cuirass deserve to be reviewed in order to develop new strategies for land management in the current context of general degradation and reduced

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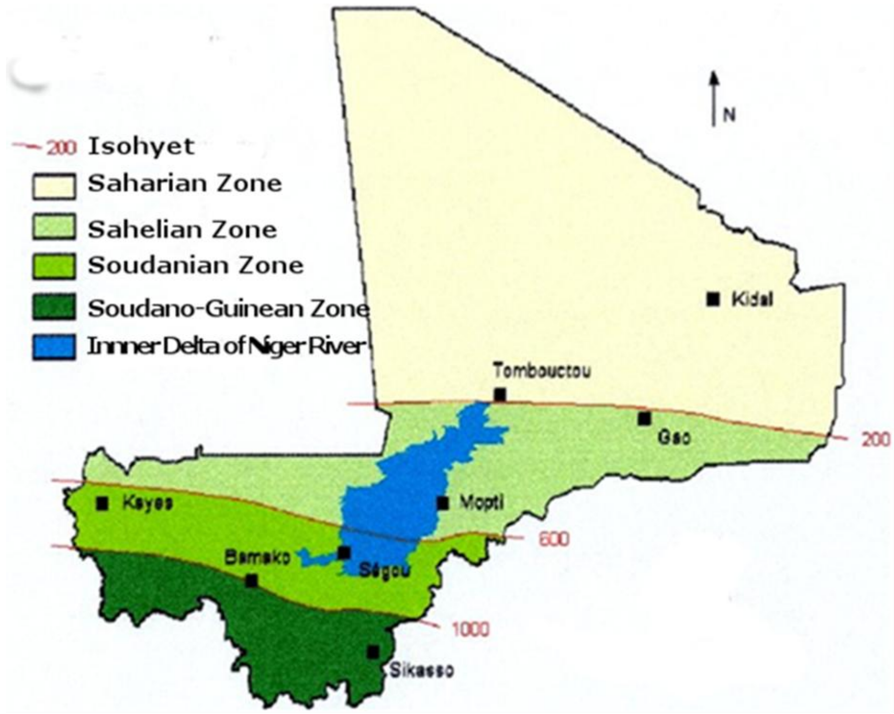

Figure 1. Agroecological map of Mali according Labo SEP, quoted by Coulibaly (2003).

Figure 2. Gravelly soil profile observed in Bagoe watershed, Sikasso region (Photo I: Kassogué).

productivity of Sudano-Sahelian ecosystems. The present paper aims to underline the pedological properties of shallow and moderate depth gravelly soils), their capability and current uses and a discussion about research needs for new strategies to manage this landscape.

STUDY AREA

Localisation of the study area

Gravelly soils developed on ferruginous Cuirass in Mali are mainly surveyed in Sudanian and Sudano-Guinean zones (Figures 1 and 2), which are largely represented in West Africa.

Climate context

The current climate of Sudanian and Sudano-Guinean zones where cuirass materials are observed in West Africa, is characterized by a high variability of parameters as annual rainfall: more than 1300 mm (in south) to 600 - 550 mm (in north). Some current climatic characteristics measured at Sikasso station, located at 5°6'W and 11°3'N are shown in Tables 1 and 2 according to Malian Meteorological Service (Sangaré, 2011). In the Sudano-Gunean zone, maximum temperature is over 30° all the year. Air humidity is very low from January to March (43 to 50% for maximum value and 13 to 17% for minimum value), in relation with Harmattan (a dry wind) presence. When Monsoon come in the Sudanian zones (around April and May) air humidity increases and get its most high values (more than 90% for maximum value and around 60% for minimum value) during the period July to October. The mean annual rainfall, for the period 1980 to 2008 was 1105.4±16 mm; only in four months (June to

Table 1. Means of temperature and air humidity at Sikasso Station from 1980 to 2009 (Sangaré, 2011).

Parameter		J	F	M	A	M	J	J	A	S	O	N	D
Temperature (°C)	Min	18	21	24	26	25	23	22	22	22	22	20	17
	Max	33	35	37	37	35	33	30	30	31	33	34	33
Air humidity (%)	Min	15	13	17	29	40	52	60	64	59	46	25	17
	Max	48	43	50	70	81	89	94	95	95	91	79	61

Table 2. Means of rainfall and evaporation at Sikasso Station from 1980 to 2009 (Sangaré, 2011).

Parameter	J	F	M	A	M	J	J	A	S	O	N	D
Rainfall (mm)	1.3±0.0	5.0±1.6	9.6±12.4	48.4±8.2	99.1±39.6	155.1±17.3	221.2±53.1	285.1±37.7	198.0±19.0	76.2±101.2	6.6±3.5	0.0±0.0
Evaporation Piche (mm)	269.5±33	282.7±34	303.6±48	218.8±37	164.6±34	103.4±18	70.9±12	54.8±8	59.4±8	96.1±24	175.6±27	232.8±29

Table 3. Geochemistry and mineralogy of Cuirass and gravel in Kangaba sector (Mali) according to DNGM, ORSTOM, CNRS (1986).

Element	Cuirass (%)	Gravels (%)
SiO_2	33.04	58.76
Al_2O_3	19.02	17.01
Fe_2O_3	43.9	18.74
TiO_2	0.89	1.34
MgO	0.2	0.23
K_2O	0.37	0. 38
MnO	0.03	0.02
Quartz	17.5	38.74
Gibbsite	11.98	0.02
Kaolinite	1.74	43.04
Goethite	45.27	7.67
Hematite	14.67	11.84

September), rainfall was superior to evaporation.

Paleoclimatic considerations are usually mentioned when talking about cuirass materials currently observed in West Africa and other tropical regions. Cuirass materials and reliefs are the result of a long evolution, more than 100 Ma (Tardy, 1991), influenced by alternating humid and arid climates in the past, during geological times. These considerations allowed scientists to consider Cuirass materials as an important paleoclimatic marker in the tropics (Gunnell, 1996). Most Cuirass land in West Africa are actually located in very contrasted climate conditions (wet from May-June to October and severely dry the rest of the year).

Geological context

Cuirass reliefs and the associated soils in West Africa are formed from different rock types, granite, shale, sandstone, greenstone (Boeglin, 1990; Bantsimba, 2001). According to their mineralogical characteristics, different types of cuirass are distinguished: bauxite or aluminous cuirass, alumino-ferruginous cuirass and ferruginous cuirass (Boeglin, 1990). Ferruginous cuirass, on which are located shallow and moderate depth gravelly soils, which is subject of the present paper, is characterized by the preponderance of goethite, Fe_2O_3 and SiO_2 (Table 3). The associate gravel (≥ 2 mm) is rich in goethite, SiO_2 and kaolinite. Geomorphologic studies showed the important role of cuirass in the organization of actual relief in the Sudanese zones of West Africa, where different categories of surface covered by cuirass are observed (Michel, 1973). Among these surfaces, there are glacis which are quaternary reliefs characterized by the presence of ferruginous cuirass and gravelly soils (Michel, 1973).

The formation process of cuirassed materials has been described by many researchers (for example, Tricart and

Cailleux, 1974; NcFarlane, 1976; Tardy, 1991). It is widely known today that cuirassed materials (or laterite) are the result of enrichment of superficial geological material in iron or alumina, or a mixture of both, and their induration. It should be noted, that the enrichment in iron, for example, can be the result of one of the two following process:

i) A relative accumulation by departure of other elements;
ii) An absolute accumulation as result of migration in the cuirass development site.

About current evolution of old ferruginous cuirass materials (mainly formed during the old and middle Quaternary), ubiquitous in West Africa, Leprun (1977) explained the process running on a toposequence in Thion (Burkina Faso), located on biotite and amphibole migmatite. This evolution is characterized by:

i) Old soil profile internal degradation by geochemical weathering;
ii) Surface degradation by mechanical process.

So, the cuirass is attacked in its mass and basics by hydrodynamic and geochemical mechanisms which magnitude increases with the degree of slope; the result is lithosols transformation in gravelly soils. At the landscape scale, relief formation process will be strongly influenced by current destruction of old cuirassed material and will differ, depending on the climate zone, the anterior cuirassed relief and the original rock.

METHODOLOGY

This article is based on a synthesis of accumulated data on Cuirassed reliefs and soils identified in Mali during studies for rural development program. These data were supplemented by detail soil descriptions, indigenous knowledge and agricultural surveys.

Extracting data from Malian Atlas of land resources

The inventory project of Mali land resources led from 1975 to 1981 provided important data on the major soils of the country and the state of land use and management. Some data from these studies are synthesized in this work.

Soil profile description and soil sampling

Some supplementary soil profiles (about 50) have been described in Malian Sudanian and Sudano-Guinean zones. The main criteria for describing soils *in situ* were the tickness of the profile, horizons colour, texture and porosity, the behavior of roots and the traces left by water saturation above hardpan (cuirass). Soil samples were taken in representative soil profiles.

Laboratory analysis

These analyses mainly concern the determination of particle size distribution with the international method (Baize, 1984), measurements of pH by electrometric method in the ration 1/2.5 and carbon by Anne method (Baize, 1984).

Agricultural practices surveying

Surveys were conducted with 51 farmers distributed in 17 villages. The questions focused on indigeneous knowledge of soil resources, land use practices, actual agricultural techniques application to gravelly soils and crops grown on the gravelly soils.

CHARACTERISTICS AND ALTERNATIVE MANAGEMENT OPTIONS OF GRAVELLY SOILS ON CUIRASS

Characteristics of gravelly soils on Cuirass

Typology and morphologic characteristics

Soil surveys in Mali led to the distinction of seven soil-vegetation units under the name of Cuirass land (*Terrains cuirassés*, TC), noted TC1 to TC7 (PIRT, 1983). These units are spatially distributed in annual rainfall context range from 250 to over 1100 mm/yr. Only soil profiles of units TC2 (formed on alluvial material) and TC7 (formed in colluvial and often alluvial material) are not gravelly, except at the lower layers of the profile, the contact between alluvium or colluviums and Cuirass. Soils of the other units (Table 4), subjects of the present article, are mainly gravelly, derived from the degradation of ferruginous cuirass. They occupy different topographic positions (upland and slope of different gradients) and are different types of soil, according to PIRT (1983): Cambic Cuirorthids, Cuirustalfs aridic, Typic Cuirustalf, mollic Cuirorthents.

Morphological descriptions of these soils are depicted as follows:

i) The thickness of the soil profile (always less than 100 cm above ferruginous cuirass); profile depth is usually variable in each soil type and from a soil type to another (Table 4);
ii) Ferruginous gravels on the surface, but also in the soil profile;
iii) Ferruginous blocks on the surface;
iv) the hue of topsoil (0 to 10 cm) colour is variable according to Revised Standard Soil colour Charts (10YR in flat position and 7.5YR on slope); it is generally 7.5YR or 5YR under surface.

Texture, pH and organic matter status

Soils content in gravel is variable (15 to 60%) and three textural classes are distinguished: silty, sandy loam, clayey loam. All these soils have an acidic pH (5.1 to 6.0), and organic matter content generally close to 2%.

Table 4. Some characteristics of gravelly soils on ferruginous cuirass in Mali.

Characteristic		Soil vegetation units				
		TC1	TC3	TC4	TC5	TC6
Annual rainfall (mm) of reference station		250 – 550	550 -800	800-1150	> 800	>1100
Typical soil		Cambic Cuirorthids	Cuirustalf aridic	Typic Cuirustalf	Mollic Cuirorthents	Typic Cuirustalfs
Soil depth (cm)		20 to 70	25 to 85	60	< 10 to 35	< 10 to 35
Presence of ferruginous block and gravel		+	+	+	+	+
Vegetation species	Total number of species observed with high frequency	21	29	46	34	45
	3 main woody species	(1) (2) (3)	(1) (3) (4)	(4) (5) (6)	(4) (6) (7)	(8) (9) (10)
	3 main herbaceous species	(a) (b) (c)	(d) (e) (f)	(f) (g) (h)	(f) (i) (g)	(g) (j) (k)

(1) Pterocarpus lucens (2) Boscia senegalensis (3) Combretum micranthum (4) *Combretum glutinosum ;* (5) *Bombax costatum* (6) *Pterocarpus erinaceus* (7) *Lanea microcarpa* (8) *Isoberlinia doka* (9) *Detarium microcarpum,* (10) *Anona senegalensis;* a)*Schoenefeldia gracilis* (b) *Aristia SPP* (c) *Cenchrus biflorus* (d) *Loudetia togoensis* (e) *Diheteropogon ragerupii (f) Andropogon pseudapricus* (g) *Andropogon gayanus* (h) *Pennisetum pedicellatum* (i) *Ctenium SPP* (j) *Cochlospermum glutinosum.;* (+) means Yes. NB: Soil typology refers to Malian Land Resources Atlas (PIRT, 1983).

Soil-Water relationship

Gravelly soils on Cuirass have low water storage capacity when they are located on slope (4 to 6%). The average annual runoff coefficient is high enough: 41.2% in Djitiko watershed, according to measurements on experimental plot (Diallo et al., 2004). Due to runoff process, water volume lost on a surface bearing shallow gravelly soil (<40 cm) can reach 504,000 to 307,500 m^3/ ha/yr in Sudanian zone, depending on the isohyets and land use (Diallo and Roose, 2008).

Associated native vegetation

Vegetation installed on gravelly soils includes trees and shrubs in the woody stratum, and mainly grasses in the herbaceous layer. Many plant species are observed (Table 4). This biodiversity is mainly a function of the rainfall range. Only in the case of TC5, where the thickness of the soil is very low (usually less than 30 cm), soil material has more impact, than rainfall (greater than 800 mm/yr), on native vegetation. Woody vegetation of this unit occurs generally as groves scattered in abundant herbaceous stratum (PIRT, 1983). A site of unit TC5 is shown in Figure 3.

Alternative management options of soils

The characteristics of gravelly soils on cuirass, especially thin profile and high content in gravel were always arguments for soil scientists who drew attention to the marginal status of these soils. All these constraints are well known by farmers who practice mechanization. The current uses of these soils (Table 5) are linked to climatic factors agricultural techniques evolution and land availability in each agricultural village.

Climatic factors and land use

In situation where annual rainfall is 800 mm and plus, gravelly soils are used both for cropping and breeding. In this climate context TC4, TC5 and TC6 are observed as indicated in Table 5. The units TC4 and TC6 have the same assignments: sorghum, millet, maize, peanut and often cotton. The unit TC5 which occupies a flat topography, favorable to stagnation of rainwater, is managed as a garden and assigned to a wide range of crops (sorghum, maize, peanut, yam, sweet potatoes and various vegetable crops) in a general context of female and manual agriculture. In this case, crops are generally installed on boards or mounds (around 30 cm high), made to increase the volume of soil exploited by the roots of crops and also to mitigate the negative effects of any excess standing water (Figure 4).

When annual rainfall is less than 800 mm, gravelly soils on cuirass are exclusively used for breeding (units TC1 and TC3).

Agricultural techniques evolution and land use

Agricultural techniques evolution has an impact on gravelly soils use. In manual cultivation system, many farmers prefer gravelly soils where weed control, is relatively easy. In rural areas where mechanization with animal traction is widespread, the peasants are not interested in gravelly shallow soils and are driven to the plains and lowlands with deep soils, where they can easily practice conventional tillage (Figure 5). So, according to photographs interpretation, in Bélékoni watershed (120 km^2) for example, gravelly soils on

Figure 3. Groves scattered in herbaceous stratum in TC5 sites observed during the rainy season in Bagoé watershed, Sikasso region (a) I. Kassogué (b) T. Diallo.

Table 5. Current use of gravelly soils on Cuirass.

Rainfall and land use	Soil vegetation units				
	TC1	TC3	TC4	TC5	TC6
Annual rainfall (mm) of the reference station	250 – 550	550 - 800	800 - 1150	> 800	>1100
Breeding	(+)	(+)	(+)	(+)	(+)
So, Mi, Ma, Pe	(-)	(-)	(+)	(+)	(+)
Ri	(-)	(-)	(-)	(+)	(-)
Co	(-)	(-)	(+)	(-)	(+)

So = sorghum; Mi= millet; Ma = maize; Pe= peanut; Ri = rice; Co = cotton. (+) means Yes and (–) means No.

cuirass represented 62% of the cultivated area before 1960. Today this percentage is very low (inferior to 20%). With the development of mechanized agriculture, many village communities look gravelly soils as women landscapes. Indeed, these soils are occupied by many small plots, manually owned by women.

Environmental impacts of agricultural use of gravelly soils on cuirass

Problems arising from the cultivation of gravelly soils depend on topographic position, land use and agriculture techniques. Concerning soils of TC5, the problems are not perceptible enough. But after heavy rains, runoff and fine particles lost by erosion are possible. Cultivation of gravelly soils located on slope (TC4 and TC6), especially with the mechanization, can quickly lead to the disappearance of the dense tree cover. That is a major problem, because the presence of cuirass (not far of surface) and gravel does not allow recovery after cultural abandonment. Moreover, the slope (> 4%) is favorable to high runoff in Sudanian zone of West Africa and erosion of fine particles (clay and organic matter); it is a mass of sterile gravel that will be left on site. Many farmers give evidence of this rapid depletion of fine particles of gravelly soils.

DISCUSSION

Gravelly soils fundamental properties

Ferruginous gravels and blocks presence can be explained by the current degradation process affecting cuirass materials (parental materials of these soils), as described by Leprun (1977). The dominance of red in soil colour is due to the presence of iron oxides and the acidity seems a consequence of the large amounts of silica in the parental material.

The low agricultural quality of gravelly soils on cuirass is mainly explained by the low thickness of soil profile, its

(a) (b)

Figure 4. Mounds confectioned on TC5 for cropping in Bagoé watershed, Sikasso région (a) peanut plantation (photo T. Diallo); (b) sorghum and earth peas (photo I. Kassogué).

Figure 5. Conventional tillage on a deep soil in Bagoé watershed, Sikasso region (photo H.Sangaré).

high content in ferruginous gravel and the low water storage capacity.

Current land use and sensibility to degradation

In Mali, the widespread use of gravelly soils for breeding is justified by the existence of high forage availability. The cultivation of these soils in some situations is explained by low availability of land resources and strong pressure on the better one (deep soils). In a climate context characterized by an annual rainfall inferior to 800 mm, it is very likely that gravelly soils are cultivated in general, because growing of crops is highly uncertain (low rainfall and low water storage capacity of soils are serious constraints).

The high sensibility of gravel soils to degradation can be explained by:

i) the thickness of the soil over hardpan which is favourable to runoff;
ii) the low levels of stable macro-aggregates measured in these soils (Diallo et al., 2004). These authors reported that stable macro-aggregates rate is variable from 147 to 225 g/kg of gravelly soil against 560 to 630 g/kg of brown vertic soil located below.

Concerning soils of unit TC5, the physical degradation is not perceptible enough according to the flat topography; it is also not conductive to runoff.

RESEARCH NEEDS FOR A BETTER UTILIZATION OF CUIRASS ENVIRONMENT

Better utilization of ferruginous cuirass environment, occupying large areas in the Sudanian and Sahelian zones of Mali and elsewhere in West Africa, is necessary in the current context:

i) Generalization of land and ecosystems degradation;
ii) Necessity to improve food production for a growing population.

So, studies must be thorough in order to better enhance their impluvium function and their potential fodder.

Research needs for improving impluvium function of cuirass table

Today it is necessary to develop research in two directions:

i) Development of runoff harvesting from cuirass table and its stockage techniques on the landscape in upstream of rivers;
ii) Development of micro irrigation systems with the stocked water on the landscape.

Research needs for improving potential fodder of gravelly soils

Improvement of the potential fodder requires field experimentations in order to:

i) identify better herbaceous species according to their biomass productivity and their agrostological quality;
ii) identify better production and conservation techniques of fodder.

Conclusion

Agricultural use of cuirass lands faces real physical constraints (mainly thin material, heavy duty gravel and low water storage capacity) and has been identified by pedologists since long time. The techniques developed by some farmers (construction of boards and mounds) appear to be a significant alternative to improve soil depth and profitability of rainwater. However, pastoral potential of these lands appear significant. Globally, current management practices for cropping on gravelly soils are poor and contribute to acceleration of degradation process (particularly runoff) affecting all the toposequence. Better management systems have to be developed for better use of gravelly soils on cuirass and the concerned landscape in upstream of rivers. In this order, development of runoff harvesting from cuirass table and its stockage for complementary irrigation can be experimented in the local context. In other words, field experimentations are necessary to improve biomass (from herbaceous species) production and conservation for livestock use.

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Full Length Research Paper

Nutrient budget analysis under smallholder farming systems and implications on agricultural sustainability in degraded environments of semiarid central Tanzania

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Soil nutrient budget is one of the critical concerns in most farming systems, especially in degraded environments. This paper reveals a net nutrient removal from the agricultural system that resulted in negative budgets, particularly for N. Large variations existed between villages, with N budget ranging from -9.6 to -252.4 kg/ha/year, with a mean budget of -91.9 kg/ha/year. Various factors seem to have contributed to the negative budgets, including soil erosion, crop harvest and residue removals. The latter two contributed significantly less to nutrient losses compared to soil erosion. The main input sources for nutrients into the system were found to be manure, crop residues, atmospheric deposition and to a limited extent inorganic fertilisers. Manure application added into the soil about 13, 1.5, and 0.04 kg/ha/year of N, P and K respectively. Its use was, however, limited by the inadequate amounts available. Crop residues added about 3.9, 1.9 and 11 kg/ha/year of N, P and K respectively. The use of crop residues for nutrient recycling and soil maintenance is however, constrained by its competitive use for animal feed. Generally, this farming system seems to be characterised by negative nutrient budgets, limiting agricultural productivity and sustainability.

Key words: Nutrient budget, smallholder farming systems, degraded environments, agricultural sustainability, semiarid Tanzania.

INTRODUCTION

Farming in the tropical environments is largely on upland soils under rainfed agriculture. These soils easily degrade when subjected to over-exploitation, for example through cultivation (Kang, 1993). In the past the traditional bush and fallow system with short cropping cycles and long fallow periods allowed for regeneration of adequate soil productivity. The system was of high biological stability and sustained agricultural production for many generations. In recent years various socio-economic factors have caused the fallow periods to be shortened or abolished as observed in many parts of the tropics (Kang, 1993; Mohamed, 1989; Adesina, 1994; Scholes et al., 1994). The shortened fallow periods have resulted in increased soil degradation in farmlands, more weed infestation, declining crop yields, and reduced production of both food and cash crops. Increasing and sustaining food and cash crop production on these inherently erodible and low fertility tropical soils is an elusive goal.

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One of the reasons for low agricultural production is the gradual process of soil nutrient depletion in many of the sub-Saharan land-use systems (Smaling, 1993). Among the processes responsible for this nutrient depletion are soil erosion, crop harvesting, residue removals and leaching, phenomena that have received less public attention compared to aspects like erratic rainfall, crop failures, and civil wars which are directly related to famine and starvation (Smaling, 1993). The supply of nutrients dictates the productivity of land and dwindling soil fertility has become one of the major constraints to crop production, especially in sub-Saharan Africa (Smaling, 1993; CWFS, 1985). In most land-use systems, the amount of nutrients leaving the soil in crops, by leaching and erosion, is grossly exceeding the nutrient input to the system by natural processes such as atmospheric deposition and biological nitrogen fixation, or artificially by organic manure and mineral fertilisers (Smaling, 1993; CWFS, 1985). This has resulted into reduced land productivity and agricultural sustainability (Lynam and Herdt, 1989; Spenser and Swift, 1992; Rockström, 1997).

This paper analyses nutrient budgets in the Irangi Hills (Figure 1) located in Kondoa District, which forms an area commonly known as the Kondoa Eroded Area (KEA). It presents findings from three villages namely, Baura, Bolisa and Mafai. The main objective of the study was to determine the nutrient budget for the crop/livestock and soil management systems in the area. Specifically, the objectives were to determine input sources and pathways for nutrient loss, and to compute the difference between nutrient input and output into and from the agricultural system. The KEA is a badly degraded area in the hills where comprehensive land-rehabilitation activities have been tried out since the 1930s, including the eviction of grazing animals implemented in 1979. The studied villages are characterised by gullies as deep as 20 m.

The climate of the study area is semiarid with an average annual precipitation of 600 mm. The dry season normally lasts from June through October and the rainy season from November to May. The rainfall distribution pattern is influenced by elevation (Ngana, 1992). Mafai village, which is much higher in altitude (ranging from 1620 to 2010 m), compared to the other two villages (ranging from 1200 to 1545 m) is sub-humid, while Baura and Bolisa are semiarid. The long-term rainfall pattern for the study area shows that rainfall is highly variable between years and is also very erratic. Temperature varies from 16 to 23°C, the coolest period being in June and July.

MATERIALS AND METHODS

Laboratory analyses of soil, plant and farmyard manure samples

Plant samples (grain and stover) from major crops grown in the area were analysed for chemical nutrient content, mainly N, P, and K. The objective was to determine the amounts of these nutrients that are removed from the soil through crop harvest and residue removals, and that returned back into the soil by the residues retained in the farm. Farmyard manure was also analysed with the aim of establishing the amounts of same nutrients that it contributes to the soil when applied. Soil samples were collected from soil profiles dug to 1 to 1.5 m depth from representative locations for major soil groups identified by the farmers during transect walks. Soil profiles were described to at least 80 cm depth, according to the internationally accepted guidelines for soil-profile description (FAO, 1990). Visual observation showed no distinct horizons; as such samples were taken at specified depth ranges as described by (Hodgson, 1985) and (FAO, 1990), at 20 cm intervals, starting with the upper 0 to 20 cm. The soil samples were then analysed for particle-size distribution, pH, organic carbon, total nitrogen, extractable phosphorus, exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+), and cation exchange capacity (CEC), in order to obtain information important for estimating nutrient availability and soil productivity. This determination essentially aimed at estimating the inherent soil fertility status and, subsequently used the findings in computing the quantities of nutrients (N, P, and K) lost from the soil through soil erosion and other pathways.

Household interviews

Interviews were also conducted to 10% (147 households) of the village households so as to solicit information on crop yield and fertiliser application whose data were later used in computing the nutrient budget.

Inputs

Nutrient input to the agricultural system included inorganic fertilisers, farm yard manure, incorporation of crop residues and atmospheric deposition, as described in the following sections.

Inorganic fertilisers (Input 1)

Information on this input based on data obtained from household interviews conducted to the farmers on the type and quantities of fertilisers they used in the preceding growing seasons. The major inorganic fertilisers used by the respondent households were Calcium Ammonium Nitrate (CAN), Nitrogen-Phosphorus-Potassium (NPK), Sulphate of Ammonia (SA), UREA and Triple Supper Phosphate (TSP). However, the amounts of fertilisers used by respective households varied considerable.

Manure (Input 2)

The quantities of manure used by the farmers based on responses regarding the number of livestock units that are kept by the interviewed farmers. One livestock unit (250 kg live weight) requires a total of about 3000 kg of dry matter per year, of which about 40% is given out as manure (Mero et al., 1988). This gives an average of 1200 kg of manure being produced by one livestock unit in a year.

Crop residues (Input 3)

This refers to that portion of crop plants which is retained in the field after harvesting the main crop and later incorporated in the soil. Nutrients returned back into the soil through this pathway was determined by using the percentage nutrient content in the stover and the proportion of the total residue that is retained in the field. Responses from the survey in Mafai village indicated that of the

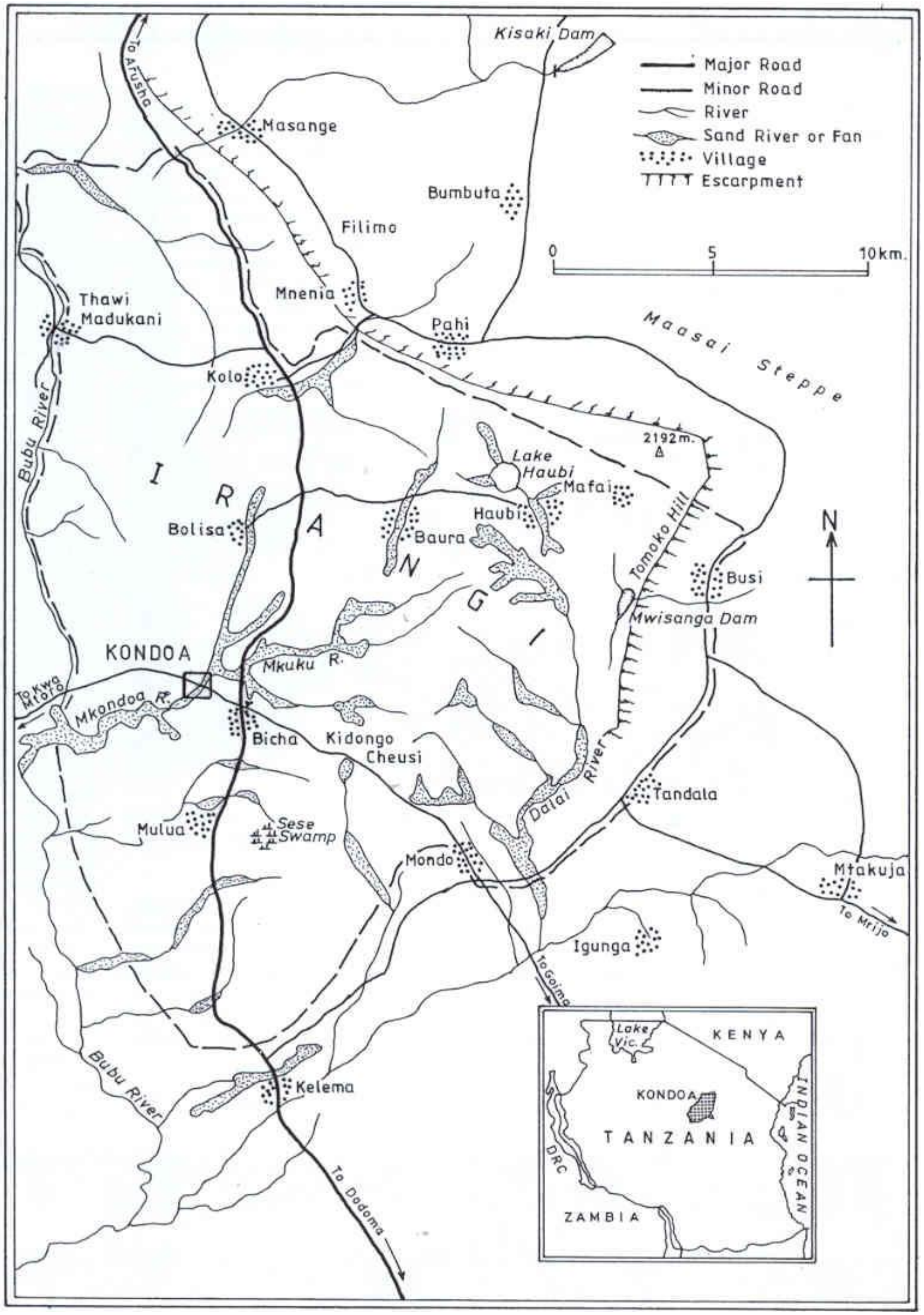

Figure 1. Map of the Irangi Hills. The mapped area forms the Kondoa Eroded Area (KEA), an area recognised for its severe soil erosion with extensive gullies. The insert shows the location of the KEA within Tanzania. Source: Kangalawe (2001).

Table 1. Land characteristics used in the calculation of soil loss by erosion in the survey villages.

Property	Mafai	Baura	Bolisa
Slope gradient in degrees (percent)	11 (20)	6 (10)	5 (8)
Slope length in metres	100	100	100
Rainfall factor (R)	200	200	200
Soil erodibility factor (K)	0.15	0.15	0.15
Slope length factor (L)	2.126	2.126	2.126
Slope steepness factor (S)	4.106	1.579	1.187
Crop cover factor (C)	*	*	*
Land management practice factor (P)	0.8	0.5	0.44

* Refer to Table 12 for crop cover factor (C).

total crop residue produced in the farm 55.4% is incorporated into the soil, 25.1% used as feed to livestock or other purposes and 19.5% is burnt. In Baura the corresponding values were 27, 25 and 48% respectively. Those for Bolisa village were 29.4, 44.4 and 26.2%. The residue yield per hectare was calculated based on harvest indices of the different crops.

Atmospheric deposition (Input 4)

Nutrient deposition from the atmosphere (wet and dry) was determined basing on the expressions below (Stoorvogel and Smaling, 1990; Smaling and Fresco, 1993).

$N = 0.14 * [\text{mean annual rainfall (mm)}]^{0.5}$
$P = 0.123 * [\text{mean annual rainfall (mm)}]^{0.5}$
$K = 0.092 * [\text{mean annual rainfall (mm)}]^{0.5}$

Where = N, P and K are kilograms of nitrogen, phosphorus and potassium deposited per hectare per year.

Outputs

Various pathways can be discerned regarding nutrient removal from the soil. The major pathways analysed during this study were nutrient removals (mainly N, P and K) from harvested crops plants, residue removals and loss through soil erosion. The determination of these nutrient output pathways from the farming system is described below. The landscape characteristics used to calculate soil and nutrient losses through erosion summarised in Table 1.

Harvested products (Output 1)

Nutrient output in harvested products was determined from crop harvest data reported by interviewed households. Crop yield data was then multiplied by the nutrient content in the product (e.g. grain, tubers and roots) so as to obtain the total amount of nutrients (N, P and K) that are removed from the soil through crop harvest.

Residue removals (Output 2)

The quantity of residue produced per unit area was determined based on the yield of harvested products and the respective harvest index for each crop. The term harvest index is used here referring to the proportion of the total crop biomass that is harvested. What remains is considered as residue. The total residue removal was derived from the interviews on the proportion taken away as animal feed, burnt or for other purposes. The amount of residue removed was multiplied by nutrient content in the residue to estimate the amounts of N, P and K taken away from the farming system.

Soil erosion (Output 3)

Nutrient loss in eroded soil material was determined by quantifying soil loss under the different crops grown in the area and later multiplying by the nutrient content in the soil samples. Quantities of soil loss by erosion were determined using the Universal Soil Loss Equation (USLE), that is, $A = R * K * L * S * C * P$. Where A = predicted soil loss in tonnes/hectare/year; R = rainfall factor (half the mean annual rainfall (Roose, 1976; Babu et al.,1978; FAO, 1979; Singh et al., 1981); K = soil erodibility factor; L = slope length factor; S = slope steepness factor; C = crop cover and management factor (shortly, crop cover); P = land management (erosion control) practice factor (Young, 1991; El-Swaify and Fownes, 1992). The values of L and S in the equation above were computed based on Smaling et al. (1993), while P was computed based on Wenner (1981) as follows.

$L = (d/22.13)^{0.5}$
$S = (0.43 + 0.30 * s + 0.043 * s^2)/6.613$
$P = 0.2 + 0.03 * s$

Where: d = slope length in meters; s = slope gradient in percent. Inherent soil fertility was then used to translate the soil loss into N, P and K losses. Soil erosion is a selective process, taking away nutrients and fine soil particles first. The eroded material is thus richer in nutrients than soil it originates from (Stocking, 1984; Gachene, 1987; Mnkeni, 1992). The amount by which the eroded material is richer in nutrients than the soil, from which it is taken, is referred to as the '*enrichment factor*'. The calculated nutrient loss in the above procedure was then multiplied by an enrichment factor of 2.

It should be noted that although leaching and denitrification are among the contributors to soil nutrient loss, they were not considered in this study because of the aridity of the climate in the study area. Due to low precipitation and high evapotranspiration of the area, no effective leaching or denitrification takes place (Young, 1991; FAO, 1978). As such, their role in nutrient loss from the surface soil layers in this area is considerably small.

RESULTS

Landscape and soil characteristics

Most of the soils in the study area are severely eroded

Table 2. Some characteristics from composite soils samples (0-20 cm depth) in the study area.

Soil characteristic	Mafai	Baura	Bolisa	Mean	NSS Classification
pH (H_2O)	4.80	5.20	5.40	5.10	Strongly acid
Total N (%)	0.29	0.07	0.08	0.14	Low
Available P (ppm)	4.20	7.20	3.20	4.87	Low
CEC me/100g	17.12	3.84	13.89	11.62	Low
Exchangeable K (me/100g)	0.61	0.61	0.52	0.58	Medium
Exchangeable Ca (me/100g)	4.39	1.83	2.74	2.99	Medium
Exchangeable Mg (me/100g)	1.61	0.40	1.20	1.07	High
Exchangeable Na (me/100g)	1.86	0.92	0.80	1.19	High
Organic carbon (%)	2.62	0.31	0.54	1.16	Low
Particle size distribution					
% Sand	54.83	80.27	69.20	68.10	na
% Silt	14.57	10.60	17.63	14.27	na
% Clay	30.60	9.13	13.17	17.63	na

na = not applicable; NSS = National Soil Service.

exposing the red argilic layer. A few exceptions exist in some sites in the conserved forest areas (e.g. in Mafai). Soils of this area are classified as ferric acrisols (Tosi et al., 1982), ferralic cambisols (Mowo et al., 1993) and luvisols (Payton et al., 1992). According to FAO/UNESCO (1974), the three soil types belong to the low erodibility class. The mean texture of the sampled soil profiles is medium, thus qualifying for the soil erodibility factor (K) of 0.15 in the USLE equation. Chemical soil analysis based on the top 20 cm soil layer because root systems of most annual crops grown in the area occupy this plough layer. Table 2 presents characteristics of this soil layer.

The organic carbon content ranged from low (0.31 and 0.54% in Baura and Bolisa) to high (2.62% in Mafai). The average for the three villages was classified as low (Table 2). The texture of the soils was sandy clay in Mafai, loamy sand in Baura and sandy loam in Bolisa. Based on the National Soil Service (NSS, 1994) classification, the soils in this area are strongly acid. However, the recorded pH values are higher than the critical pH value of 5 for a maize/sorghum, cowpea and cassava based cropping system of the area (Aune and Lal, 1995) and four for general plant and microbial growth (Logan, 1990). These soils also had low N, P, CEC and low to medium values of other exchangeable cations. These low figures suggest that soil fertility may be exhausted by continuous cultivation without adequate replacement.

Calculating inputs

Inorganic fertilisers (Input 1)

The inorganic fertilisers used in the studied villages were N-P-K (20:10:10), UREA (46% N), Sulphate of ammonia (SA-21% N), Calcium ammonium nitrate (CAN-26% N) and triple super phosphate (TSP-46% P_2O_5). Among the respondents who reported to have used inorganic fertilisers were 8.9% in Mafai village, while in Baura and Bolisa the percentages were 2.05 and 7.53% respectively. The remaining households did not use any fertiliser during the study period, and some had never ever used inorganic fertilisers before. The total amounts of N, P, and K nutrients applied through the use of these fertilisers are presented in Table 3. Considering the total area cultivated by respondents in these villages, it has been found that on average, the application of inorganic fertilisers on a hectare basis is about 2.60, 0.65 and 0.65 kg of nitrogen, phosphorus and potassium respectively (Figure 2).

Manure (Input 2)

Laboratory analysis for nutrients in farmyard manure indicated that the manure samples contained 1.56% N, 0.18% P and 0.005% K (on a dry matter basis). The N content of the manure samples compares well with the 1.3% reported by Smaling et al. (1993). However, the values for the other two nutrients, P and K are smaller. Smaling et al. (1993) used values as high as 0.5% for P and 1.6% for K. The availability and rate of manure application are influenced by the number of households keeping livestock and number of livestock units. Among the interviewed households only 40% are keeping livestock at present. The number of livestock units reported by these households was 42 in Mafai, 92 in Baura and 180 in Bolisa. These figures correspond to a total of 54.4, 110.4, and 216 tonnes of manure per year in Mafai, Baura and Bolisa respectively. Of all respondents,

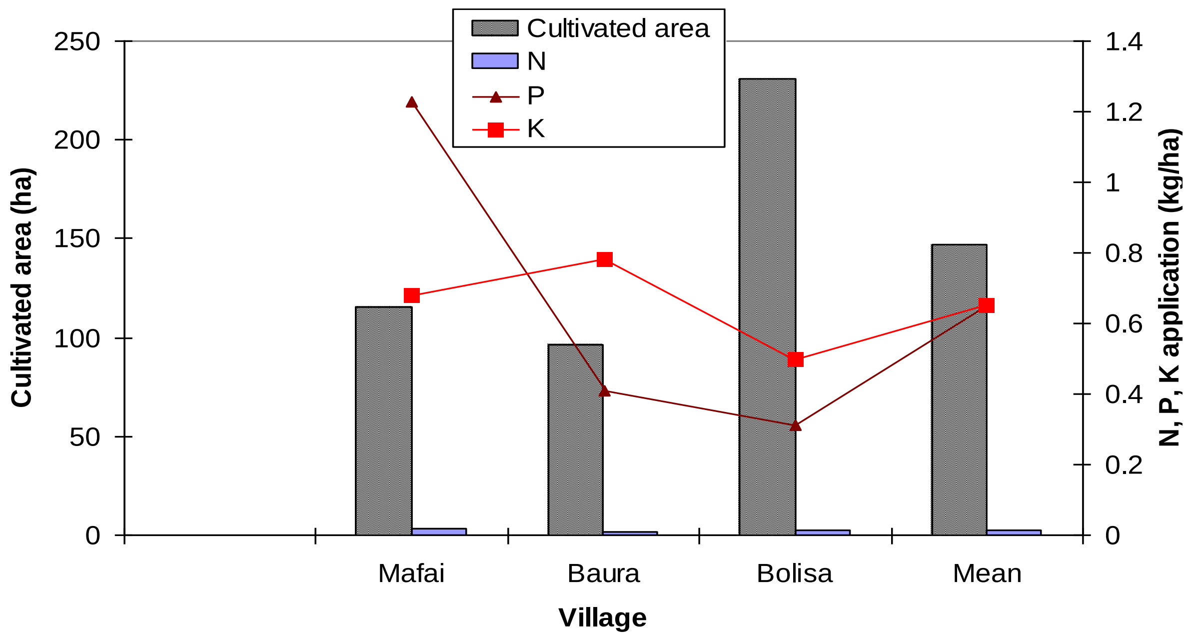

Figure 2. Area cultivated and average N, P and K application (kg/ha) from inorganic fertilisers.

67.32% had access to farmyard manure. It can be observed that the percentage of households using manure is larger than that of households keeping livestock. This disparity is due to the fact that the non-livestock keepers obtain some manure from relatives and/or neighbours who keep livestock. Among those using manure 37.4% are residents of Bolisa, whereas Mafai and Baura had 16.32 and 13.6% respectively. The average manure application rate for all respondent households have been found to be 1.5, 3.2, and 2.9 tonnes/household per year for Mafai, Baura and Bolisa, corresponding to an application rates are 0.44, 1.15 and 0.94 tonnes/ha/year respectively. The average application rate for the three villages is 0.84 tonnes/ha/year. Table 4 shows the application rates for various nutrients.

Crop residue additions (Input 3)

Determination of N, P and K nutrients added to the soil through crop residues was based on the percentages of crop residue retained in the field after harvesting the main crop and the nutrient concentration in the residues. The harvest indices (HI), area under each crop and amount of harvested product are presented in Table 5. For P and K the analysis included the percent of the total residue that was burned, because they are not removed from the arable land by burning (Smaling et al., 1993). The nutrient contents in the crop residues used in this computation are presented in Table 6. Figure 3 shows the total residue yield that was used in nutrient calculation for both inputs and outputs, whereas the quantities of residue-nutrients added into the soil by each crop are given in Table 7.

The largest N-input per hectare came from pigeon peas and sunflower stover which contributed 8.6 kg/ha each. Bean's residues ranked second in the quantity of N added per unit area, providing 3.4 kg/ha, followed by finger millet (3.3 kg/ha). Other crops with significant residue-N input were maize, cowpea, and sorghum (Table 7). The average N additions from all crop residue are 5.9 kg/ha in Mafai, 3.2 kg/ha in Baura and 2.7 kg/ha in Bolisa. Significant P additions per hectare were contributed by sunflower (8.6 kg) followed by cassava (2.2 kg) (Table 7). Lowest values are found in Irish and sweet potato because of the low inherent quantities of this nutrient in the residue. Pigeon peas residue provided the largest share of K additions from residues, amounting to 20.1 kg/ha, followed by maize (16.2 kg) and sunflower (15 kg/ha). The average K addition per hectare ranged between 8.3 and 13.9 kg with considerable variations between villages. Some of the crops such as beans, cowpeas and groundnuts had high nutrient concentrations in their residue, giving a high nutrient input per hectare.

However, because of the small farm areas they occupy, their contribution to total residue input has been relatively small (Table 6).

Atmospheric deposition (Input 4)

The mean annual rainfall for Kondoa district for the past 63 years (1931-1993) has been 643 mm (Mbegu, 1988;

Table 3. N, P and K nutrients (in kg) application from fertilisers by the surveyed households.

Village	Nitrogen (N)				Phosphorus (P)		Potassium (K)	All sources		
	CAN	NPK	SA	UREA	NPK	TSP	NPK	N	P	K
Mafai	39.0	190	120	69	41.4	100.2	78.9	418.0	141.6	78.9
Baura	0	180	0	0	39.2	0	74.7	180.0	39.2	74.7
Bolisa	0	280	0	253	61.0	10.0	116.2	533.0	71.0	116.2
Total	39.0	650	120	322	269.7	110.2	269.8	1131	251.9	269.8

Table 4. Area cultivated and average N, P and K application (kg/ha) from inorganic fertilisers.

Village	Cultivated area (ha)	N	P	K
Mafai	115.3	3.63	1.23	0.68
Baura	96.2	1.87	0.41	0.78
Bolisa	230.7	2.31	0.31	0.50
Mean	147.4	2.60	0.65	0.65

Table 5. Nutrient addition (kg/ha) from farmyard manure in the survey village.

Village	Farm area (ha)	FYM (kg/ha)	N	P	K
Mafai	115.3	437.12	6.82	0.77	0.022
Baura	96.2	1147.61	17.90	2.02	0.057
Bolisa	230.7	936.28	14.61	1.65	0.047
Mean	147.4	840.34	13.11	1.48	0.042

Table 6. Crop, harvest index (HI), cultivated area (ha) and yield of harvested product (kg/ha).

Crop	HI	Mafai		Baura		Bolisa		Total area cropped	Mean Yield/ha
		Area	Yield	Area	Yield	Area	Yield		
Maize	0.30	53.1	827	29.1	565	60.5	919	142.8	770
Sorghum	0.30	16.8	604	21.7	490	34.9	720	73.4	605
Pearl millet	0.30	0	0	23.1	413	55.0	727	78.1	569
Finger millet	0.30	26.3	786	11.5	497	33.7	439	71.5	574
Cowpeas	0.40	0	0	1.62	550	0.5	570	2.1	560
Beans	0.40	5.5	600	0.2	500	0.4	650	6.2	583
Pigeon peas	0.30	0.1	750	4.2	800	1.7	540	6.0	560
Groundnut	0.40	0	0	0	0	5.3	500	5.3	500
Cassava	0.70	0	0	0.9	3000	15.5	4100	16.4	3550
Sweet potato	0.85	6.6	3000	1.0	3000	1.3	3000	8.9	3000
Irish potato	0.73	3.7	2700	0	0	0	0	3.7	2700
Sunflower	0.30	1.6	600	2.8	520	21.9	750	26.3	623
Sugarcane	0.78	1.5	3500	0	0	0	0	1.5	3500
Total		115.3		96.2		230.7		442.2	

HI=harvest index (Agata, 1982; Cock, 1985; Victorio et al., 1986).

Ngana, 1990). Using the theoretical expressions for atmospheric depositions described above, the following results were obtained. The amount of N deposited in the study area is 3.55 kg/ha/year (that is, 0.14 * 25.36) and that of P is 3.119 kg/ha/year (that is, 0.123 * 25.36). The amount of K deposited from atmospheric sources is 2.333

Table 7. Nutrient content in harvested products and in residues (in percent).

Crop	Harvested product			Crop residue		
	N	P	K	N	P	K
Maize	1.48	0.28	0.24	0.30	0.09	1.34
Sorghum	1.06	0.34	0.34	0.30	0.07	1.15
Pearl millet	1.92	0.43	0.43	0.30	0.08	1.05
Finger millet	1.43	0.19	0.34	0.60	0.12	1.24
Cowpea	2.40	0.32	1.05	1.04	0.08	1.27
Beans	3.80	0.33	1.05	1.04	0.08	1.28
Pigeon pea	2.40	0.32	1.41	1.40	0.11	1.77
Groundnut	3.73	0.60	0.83	0.58	0.10	0.31
Cassava[1]	0.42	0.05	0.43	0.05	0.22	0.22
Sweet potato[1]	0.27	0.05	0.24	0.20	0.06	0.34
Irish potato[1]	0.34	0.05	0.41	0.20	0.06	0.34
Sunflower	3.89	0.32	0.52	1.98	0.59	1.03
Sugarcane[2]	0.61	0.09	1.47	0.31	0.12	1.15

Source: [1]Mnkeni (1992); [2]Smaling et al. (1993).

Table 8. Total crop residue yield (kg/ha) used in the nutrient input and output calculations.

Crop	Mafai	Baura	Bolisa	Mean
Maize	1930	1317	2143	1815
Sorghum	1410	1144	1679	1411
Pearl millet	na	963	1697	1329
Finger millet	1835	1160	1023	1339
Cowpeas	na	1155	975	1065
Beans	900	750	1005	885
Pigeon peas	2333	2030	1260	1597
Groundnut	na	na	750	750
Cassava	na	7000	9567	8283
Sweet potato	529	529	529	529
Irish potato	999	na	na	999
sunflower	1400	1213	1750	1454
sugarcane	778	na	na	778

na = not grown by the respondents during the period under study.

kg/ha/year (that is, 0.092 * 25.36). Similar findings for N deposition are reported for Northern Nigeria (Wilkes et al., 1984).

Calculating outputs

Nutrient removals in harvested products (Output 1)

Crop harvesting entails removal of nutrients from the arable land in the harvested products. The total quantity of the nutrients removed is a function of the area cultivated, yield per unit area and the nutrient content in the product. Grain is the major product harvested. Table 5 shows the land area that was grown with the different crops and yield of harvested products involved in the analysis, while Table 6 presented the nutrient content in the harvested products. The calculated overall average nutrient removals through harvested products from the respondents' crop fields were 14.0, 1.9 and 7.2 kg/ha for N, P and K respectively. At the village level, the nutrient removals were 14.7 kg N/ha in Mafai, 12.1 kg N/ha in Baura and 15.1 kg N/ha in Bolisa. Removals of P amounted to 2, 1.6 and 2.1 kg/ha respectively. In the same order, the values for K removed per hectare were 10.7, 5.2 and 5.7 kg (Table 8).

It can be seen from Table 8 that among the crops involved in the nutrient budget analysis, sunflower had

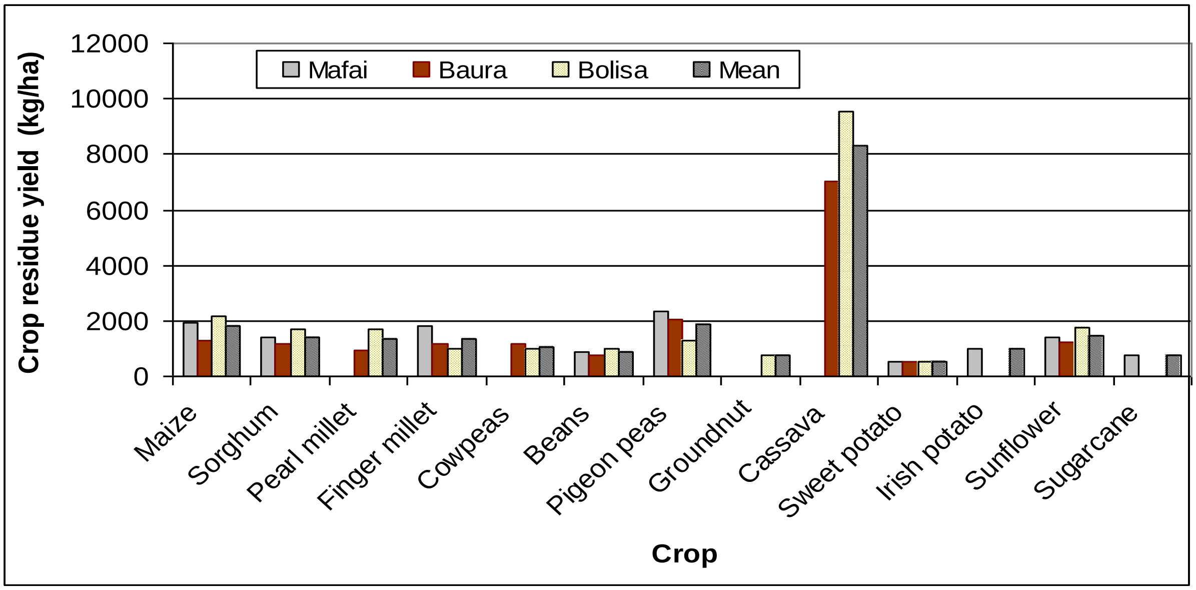

Figure 3. Total crop residue yield (kg/ha) used in the nutrient input and output calculations. Some crops were not grown by all the respondents during the period under study (e.g. cassava, cowpeas, groundnut, Irish potato, pearl millet, sugarcane), which raise their mean values.

the largest N removal (at a rate of 24.2 kg/ha), followed by beans (22.2 kg/ha), sugarcane (21.4 kg/ha) and groundnut (18.6 kg/ha). Lowest removals were observed under sorghum (6.4 kg/ha). This may be explained at least in part by the relatively low content of N in its (sorghum) grain compared to other cereals involved in the analysis (Table 5). The largest P removals were observed under sugarcane and groundnut that extracted from the soil 3.2 and 3.0 kg/ha respectively. Other crops with large removals were pearl millet (2.5 kg/ha) and pigeon peas (2.2 kg/ha). Lowest quantities of P were removed by finger millet grain at a rate of 1.1 kg/ha. Sugarcane featured highest in terms of extracting K from the soil (Table 8). However, because of the small area planted with this crop its total contribution to the overall nutrient loss through crop harvest was relatively small. Other crops removing large amounts of K from the arable land are cassava, Irish potato and Pigeon peas, taking away 15.3, 11.0 and 9.8 kg/ha respectively. The remaining crops had smaller rates of K nutrient extraction from the soil. The overall removals by these crops were however large because of the large land area they occupy, especially for cereals.

Crop residue removals (Output 2)

The removal of nutrients from the arable land in form of crop residues was calculated in a similar way as calculations for harvested products (Output 1). The calculation based on the proportion of the residue that is taken away from the arable land and the nutrient content in this residue. The average crop residue yield used in the analysis is presented in Figure 3. The proportion of crop residue considered here is that taken away as animal feed and for other purposes, which was 25.1% in Mafai, 25% in Baura and 44.4% in Bolisa. For nitrogen, the proportion of residue burned was also taken into consideration since N is lost by burning. The latter constituted 19.5, 48 and 26.2% of total residue in Mafai, Baura and Bolisa respectively. P and K are not taken away from the system by burning (Smaling et al., 1993). Quantities of nutrient removed through this pathway are given in Table 9. The average residue nutrient removal from the agricultural system was established to be 5.7, 0.4 and 4.3 kg K/ha. Baura and Bolisa villages featured high in the removal of nutrients (especially N) in crop residues (Table 9). The explanation to the observed trends is the larger proportion of the total residue that is taken away from the arable land by burning, for animal feed and other purposes. The two types of residue removals in Baura and Bolisa village accounted for 73% and nearly 71% of the residue produced in the farm respectively.

Regarding individual crops, sunflower, pigeon peas, cowpea and bean residues had the highest N removals (18.1 and 14.1 kg/ha respectively). Other crops removed relatively small quantities of N (Table 9). Cassava removed largest quantities of P (1.2 kg/ha), followed by finger millet (0.6 kg/ha), maize and Pigeon peas (0.5 kg/ha each). Other crop residue removals accounted for limited quantities, ranging from 0.1 to 0.4 kg P/ha. As for K, largest removals in crop residues were observed in pigeon peas whose residue removed 8.7 kg/ha. Maize was the next highest ranking crop in terms of removing K

Table 9. Nutrient addition (kg/ha) into the soil through incorporation of crop residues.

Crop[1]	Mafai			Baura			Bolisa			Mean values		
	N	P	K	N	P	K	N	P	K	N	P	K
Maize	3.2	1.3	19.3	1.1	0.9	13.2	1.9	1.0	16.0	2.1	1.1	16.2
Sorghum	2.3	0.7	12.1	0.9	0.6	9.9	1.5	0.7	10.7	1.6	0.7	10.9
Pearl millet	na	na	na	0.8	0.6	7.6	1.5	0.7	10.0	1.2	0.7	8.8
Finger millet	6.1	1.7	17.0	1.9	1.1	10.7	1.8	0.7	7.0	3.3	1.2	11.6
Cowpeas	na	na	na	2.3	0.5	7.9	2.6	0.4	6.0	2.5	0.5	8.5
Beans	5.2	0.5	8.6	2.1	0.5	7.2	3.0	0.4	6.9	3.4	0.5	7.6
Pigeon peas	13.5	1.4	23.2	7.0	1.5	24.8	5.2	0.8	12.4	8.6	1.2	20.1
Groundnut	na	na	na	na	na	na	1.3	0.4	1.3	1.3	0.4	1.3
Cassava	na	na	na	0.2	2.1	2.1	0.3	2.2	2.2	0.3	2.2	2.2
Sweet potato	0.6	0.2	1.3	0.3	0.2	1.3	0.3	0.2	1.0	0.4	0.2	1.2
Irish potato	1.1	0.4	2.5	na	na	na	na	na	na	1.1	0.4	2.5
sunflower	15.4	8.3	14.4	6.5	7.2	12.5	10.2	10.3	18.0	8.6	8.6	15.0
sugarcane	0	0.9	8.5	na	na	na	na	na	na	0	0.9	8.5
Total	5.9	1.7	11.9	3.2	2.3	13.9	2.7	1.6	8.3	3.9	1.9	11.4

[1]na = not grown by the respondents during the period under study.

(7.9 kg/ha) from the agricultural land.

Nutrient loss through soil erosion (Output 3)

The quantities of soil loss under each crop in respective villages were obtained by multiplying the factors in the USLE for each crop so as to get respective quantities of eroded soil material (Figure 4). Let us look at an example of maize crop in Mafai village and how soil loss from erosion was determined. The factors considered here are rainfall factor (R = 200), soil erodibility factor under ferric acrisols (K = 0.15), slope length factor on 100m slope (L = 2.126), slope gradient factor, with slope gradient of 20% (S = 4.11), and land management (erosion control) practice factor (P = 0.8). Multiplication of these factors gives a soil loss 83.8 tonnes/ha/year. The calculated average soil losses from cropland owned by the respondent households are 62.4, 16.5 and 11.2 tonnes/ha/year in Mafai, Baura and Bolisa respectively. The average soil loss on a hectare basis was highest under sunflower, maize, sorghum, finger millet and pigeon pea crop covers (Figure 4). The erosion loss was used in the determination of nutrient losses through erosion presented in Table 10. Soil erosion contributed greatest to the N loss. The calculated figures are in the magnitude of 253.0 kg/ha/year in Mafai, 17.8 kg/ha/year in Baura and 15.2 kg/ha/year in Bolisa.

Nutrient budgets

The term nutrient budget is used here to refer to the difference between total quantities of input to and outputs from the agricultural system. In all the three villages there were negative nitrogen budgets to the magnitudes of -252.4, -9.58 and -13.53 kg/ha/year in Mafai, Baura and Bolisa respectively (Table 11). Corresponding budgets for P were 4.16, 5.67 and 4.02 kg/ha/yr, while those for K were 0.07, 8.75 and -0.33 kg/ha/yr in the same order. The mean difference between the four inputs and three output factors for the three villages has indicated values of -91.85 kg N, 4.62 kg P, and 2.82 kg K/ha/yr. Among the four input factors, application of inorganic fertilisers has shown to play a small role as nutrient input source in the study area, contributing for only 2.6 kg N, 0.65 kg P and 0.65 kg K/ha/yr (Table 11), equivalent to 11.2, 9.1 and 4.5% of total N, P and K input to the system. Manure ranked highest as N input source, third as P source and fourth as K source, providing about 56.5, 20.8 and 0.3% of input N, P and K, in the same order. Incorporation of crop residues into the soil was the major contributor to K input and second as P and N source. Residues added into the system accounted for nearly 17.0, 26.3 and 79.0% of input N, P & K respectively. Atmospheric deposition contributed significant quantities of all the three elements, N, P, and K, ranking highest as input source for P, third N source and second K source, providing about 15.3, 43.8 and 16.2% of input N, P and K respectively (Table 11).

Removal of nutrients in eroded soil material has been found to be the major pathway for N losses. This was followed by nutrient removal in harvested products. Residue removals had the lowest contribution to the overall N losses (Tables 10 and 11). The mean values for the three output factors in the same order are 95.33, 13.97 and 5.73 kg/ha respectively. As for P and K budget, largest removals appeared to be in form of

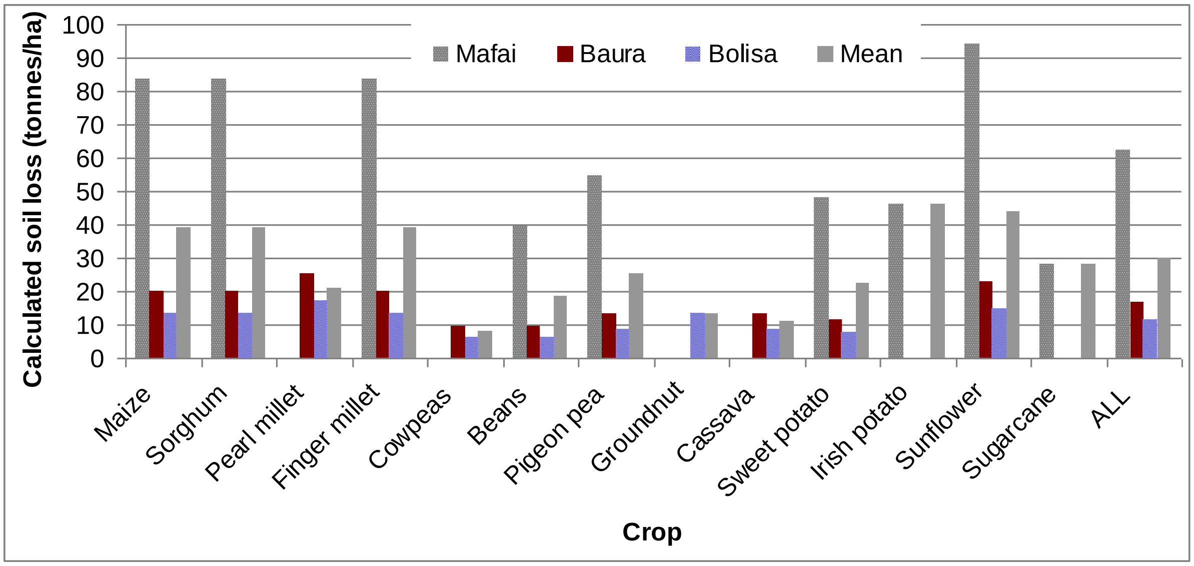

Figure 4. Calculated soil loss (tonnes/ha) by erosion under different crop covers. [1]For crop cover factor (C) refer to Smaling et al. (1993), Roose (1986) and Lewis (1987).

harvested products, withdrawing 2.0, 1.6 and 2.1 kg P/ha/yr, and 10.7, 5.2 and 5.7 kg K/ha/yr in Mafai, Baura and Bolisa respectively. The overall average P and K removals in harvested products were 1.90 and 7.2 kg/ha/yr, in that order (Table 11).

DISCUSSION

Landscape and soil features

The various landscape and soil characteristics presented in Table 2 reveal that in of the study villages the soil are generally of low organic carbon content. Such soils are characterised by low nutrient and water holding capacity which makes these soils of limited productivity compared to the sandy clay and loamy textures. The low N, P, CEC and low to medium values of other exchangeable cations that these soils had suggests that soil fertility may be exhausted by continuous cultivation without adequate nutrient replacement.

Major sources of soil nutrient inputs

The major sources of nutrient supply to the agricultural system were found to be inorganic fertilisers (Input 1), manure (Input 2), crop residue additions (Input 3) and atmospheric deposition (Input 4). Although no fertiliser recommendations exist for study area, the whole of Dodoma (Mowo et al., 1993), the quantities of inorganic fertiliser used by respondent farmers fall far below the recommended rates for other places in Tanzania. In areas with similar soil types and agro-climatic conditions such as Shinyanga, the recommended rates ranges from 12-80 kg N/ha and 10-27 kg P/ha (Tosi et al., 1982). Limited access to fertilisers and high prices were among the reasons put forward by farmers for the low fertiliser application rates. The low rates of soil nutrient replacement from inorganic fertilisers may lead to decreased crop productivity if other nutrient sources are also limiting.

Manure is another important sources of soil fertility I the study area. However, the average application rate for the three study villages was very low, ranging from 0.44 to 0.94 tonnes/ha/yr) with an average of about 0.84 tonnes/ha/year. The observed manure application rate falls far below the 5 tonnes per hectare recommended for a sorghum/millet based farming system of Dodoma region, and 7-10 tonnes/ha necessary to meet the requirements of most crops (Agata, 1982).

This situation indicates the inadequate supply of nutrients required to boost modest crop production. This nutrient application rates from manure does not compare favourably with rates applied elsewhere. In Kisii district is Kenya, for example, nutrient application rates from manure are as high as 24 kg N, 5 kg P, and 25 kg K/ha/year (Smaling and Fresco, 1993). The obvious explanation is low manure application rates in the study area attributed to the fact that only few households keep livestock.

Crop residue addition is another important source of the major soil nutrients, N, P and K. However, it contribution to the soil nutrients pool is influenced by the proportion of the plant material that is retained in the field as crop residue after harvesting the main crop and the quality (nutrient concentration) of the residues. The proportion of the crop removed from the field is referred

Table 10. Nutrient removals (kg/ha) in harvested products in the three villages.

Crop	Mafai			Baura			Bolisa			Mean		
	N	P	K	N	P	K	N	P	K	N	P	K
Maize	12.2	2.3	2.0	8.4	1.6	1.4	13.6	2.5	2.2	11.4	2.1	1.9
Sorghum	6.4	2.1	2.0	5.2	1.7	1.6	7.6	2.5	2.4	6.4	2.1	2.0
Pearl millet	na	na	na	7.9	1.8	1.8	14.0	3.1	3.1	11.0	2.5	2.5
Finger millet	11.2	1.5	2.6	7.1	0.9	1.7	6.3	0.8	1.5	8.2	1.1	1.9
Cowpeas	na	na	na	13.2	1.8	5.8	13.7	1.8	6.0	13.5	1.8	5.9
Beans	22.8	2.0	6.3	19.0	1.6	5.3	24.7	2.1	6.8	22.2	1.9	6.1
Pigeon peas	18.0	2.4	10.6	19.2	2.6	11.3	13.0	1.7	7.6	16.7	2.2	9.8
Groundnut	na	na	na	na	na	na	18.6	3.0	4.1	18.6	3.0	4.1
Cassava	na	na	na	12.5	1.4	12.9	17.1	1.9	17.6	14.8	1.7	15.3
Sweet potato	8.2	1.4	7.3	8.2	1.4	7.3	8.2	1.4	7.3	8.2	1.4	7.3
Irish potato	9.1	1.4	11.0	na	na	na	na	na	na	9.1	1.4	11.0
sunflower	23.3	1.9	3.1	20.2	1.6	2.7	29.2	2.4	3.9	24.2	2.0	3.2
sugarcane	21.4	3.2	51.5	na	na	na	na	na	na	21.4	3.2	51.5
All	14.7	2.0	10.7	12.1	1.6	5.2	15.1	2.1	5.7	14.0	1.9	7.2

Table 11. Nutrient loss (kg/ha) from agricultural land through removals of crop residues.

Crop	Mafai			Baura			Bolisa			Mean		
	N	P	K	N	P	K	N	P	K	N	P	K
Maize	2.6	0.4	6.5	2.9	0.3	4.4	4.5	0.8	12.7	3.3	0.5	7.9
Sorghum	1.9	0.2	4.1	2.5	0.2	3.3	3.6	0.5	8.6	2.7	0.3	5.3
Pearl millet	na	na	na	2.1	0.2	2.5	3.6	0.6	7.9	2.9	0.4	4.4
Finger millet	4.9	0.6	5.7	5.1	0.4	3.6	4.3	0.6	5.6	4.8	0.6	5.0
Cowpeas	na	na	na	6.3	0.2	2.6	6.3	0.3	4.8	6.3	0.3	3.7
Beans	4.2	0.2	2.9	5.7	0.2	2.4	7.2	0.3	5.5	5.9	0.2	3.6
Pigeon peas	10.9	0.5	7.8	19.0	0.5	8.3	12.4	0.6	9.9	14.1	0.5	8.7
Groundnut	na	na	na	na	na	na	3.1	0.3	1.0	3.1	0.3	1.0
Cassava	na	na	na	0.5	0.7	0.7	0.6	1.7	1.7	0.6	1.2	1.2
Sweet potato	0.5	0.1	0.5	0.8	0.1	0.4	0.7	0.1	0.8	0.7	0.1	0.6
Irish potato	0.9	0.2	0.9	na	na	na	na	na	na	0.9	0.2	0.9
sunflower	12.4	0	0	17.5	0	0	24.4	0	0	18.1	0	0
sugarcane	3.1	0	0	na	na	na	na	na	na	3.1	0	0
ALL	4.6	0.3	4.1	6.2	0.4	3.1	6.4	0.5	5.8	5.7	0.4	4.3

[1]Note: sugarcane and sunflower residues are burned, thus only N gets lost from the system. P and K are not removed (Smaling et al. 1993).

to as harvest indices (HI), as described by Agata (1982), Cock (1985) and Victorio et al. (1986). Harvest index depends on the genetic traits of the cultivar and the conditions of the environment, such as photoperiod, air temperature, solar radiation, water supply, and level nitrogen fertilisation (Mazurczyk et al., 2009). Findings presented in Table 5 revealed that the largest N-input per hectare came from pigeon peas and sunflower stover which contributed 8.6 kg/ha each. Bean's residues ranked second in the quantity of N added per unit area, providing for 3.4 kg/ha, followed by finger millet (3.3 kg/ha). These observations demonstrate that integration of leguminous crop plants in the farming system may partly help alleviate the soil fertility problems. Increased growing of these crops may enhance soil N-status taking advantage of their N-fixing properties. Pigeon peas residue also provided the largest share of K additions from residues, amounting to 20.1 kg/ha/year, followed by maize (16.2 kg) and sunflower (15 kg/ha). Although there were considerable variations between the villages regarding the nutrient input from crop residue additions, this source of soil nutrient appears to be particularly important given that many farmers cannot afford inorganic fertiliser, and have limited access to manure. Soil fertility improvement in the field would thus depend on careful management of crop residues. Atmospheric deposition (Input 4) is another source of nutrient input to the soil. However, since this input is dependent on the amount of rainfall, its contribution to the Kondoa environment is small due to the semiarid conditions. Similar findings were reported for Northern Nigeria (Wilkes et al., 1984).

Mechanisms for soil nutrient removals (outputs)

Three major outlets contribute to the net removals of soil nutrients from the agroecosystems, namely nutrient removals in harvested products (Output 1), crop residue removals (Output 2), and nutrient loss through soil erosion (Output 3). Crop harvesting entails removal of nutrients from the arable land in form of harvested products. The total quantity of the nutrients removed is a function of the area cultivated, yield per unit area and the nutrient content in the product. Grain is the major product harvested. Crops such as sunflower, beans, sugarcane, groundnut were found to be among the crops that had the largest N removal, at a rate of 24.2, 22.2, 21.4 and 18.6 kg/ha, respectively. Other crops removed large amounts of other nutrients, particularly K from the arable land. These included cassava, Irish potato and pigeon peas, taking away 15.3, 11.0 and 9.8 kg/ha respectively. The possible implication of the observed trends in nutrient removal through crop harvests is that continuous growing of these crops that extract large quantities of nutrients from the soil may lead to continuous deterioration of the soil if equal or larger quantities of nutrients are not replaced into the soil through the various input sources. The ultimate impact is continued soil degradation and lowered productivity of the land and limited future sustainability.

Regarding crop residue removals (Output 2), the larger proportion of the total residue appears to be that taken away from the arable land by burning and for animal feed. The two types of residue removals in Baura and Bolisa village accounted for 73% and nearly 71% of the residue produced in the farm respectively, and contributing to considerable removals as presented in crop residue removals (Output 2), accounting for 5.7 kg N/ha, 0.4 kg P/ha and 4.3 kg K/ha being removed from the agricultural system through crop residue removals. It has been established from this study that among the crops grown, maize, sorghum, finger millet and pearl millet straws removed the largest amounts of all N, P and K, partly because of the high nutrient concentration in their residues and in part because of the larger land area under these crops. Reducing the quantities of residues removed from the cropland would thus significantly help maintain the status of soil fertility in the existing farming system.

Figure 4 presented the quantities of eroded soil material by estimating the quantities of soil loss under each crop in respective villages. Respective quantities of eroded soil material were obtained multiplying the crop factors in the USLE. At village level, the calculated average soil losses from croplands owned by the respondent households were 62.4, 16.5 and 11.2 tonnes/ha/year in Mafai, Baura and Bolisa respectively; the highest soil loss being under sunflower, maize, sorghum, finger millet and pigeon pea crop covers. The figures for eroded soil material are slightly smaller than those reported for some parts of Dodoma region. In Mpwapwa for example, Christiansson (1981), reported yearly values as high as 105 tonnes/ha/yr (that is, 70 m^3/ha/year) under mixed native food crops in flat cultivation. In maize alone values of soil loss were 96.2 tonnes/ha/yr (that is, 64 m^3/ha/yr), while in sorghum and pearl millet it was 85.1 tonnes/ha (that is, 56.7 m^3/ha/yr) and 99 tonnes/ha/yr (that is, 66.6 m^3/ha/yr) respectively. Higher figures are also possible under similar rainfall conditions. In Kenya for example, figures recorded are as high as 350 tonnes/ha/year (Bekele and Thomas, 1992). In all the three villages erosion removed smaller quantities of both available P and exchangeable K. This may be explained by the fact that often the available P and exchangeable K in the soil are in smaller proportions compared to quantities of total N. Mafai village contributed a larger proportion, over 80% of the total nitrogen loss in eroded soil material (Table 10). This is attributed to the steeper slopes of the terrain in this village that resulted in larger values of both S and P factors in the USLE (Table 1) with a consequent effect of compounding the calculated soil loss compared to Baura and Bolisa. Another explanation to this observation is that Mafai soils are nearly four times richer in topsoil N than both Baura and Bolisa (Table 2). It is evident from Figure 4 and Table 10, and studies elsewhere (Christiansson, 1981) that land-use systems under cereal crops such as maize, finger millet and sorghum, and root and tuber crops (such as sweet and round potato) grown on steep slopes could be highly erosive, leading to large quantities of valuable nutrients being transported away in eroded materials, particularly if no sound soil conservation measures are practised.

Predominantly nutrient mining agricultural system

In all the three villages there were negative nitrogen budgets to the magnitudes of -252.4, -9.58 and -13.53 kg/ha/year in Mafai, Baura and Bolisa respectively (Table 11). Implicitly this gives reflections on the prevalence of a general nutrient mining from the cropping system in the study area, which leads to a net negative nutrient budget, particularly for N and marginal positive budgets for P and K. The removals of nutrients is from eroded soil material and nutrient removals in harvested products have been found to be the major pathway for N losses, accounting for 95.33 and 13.97 kg/ha respectively. As for P and K budget, largest removals appeared to be in form of harvested products. Thus careful management of these output pathways is likely to enhance soil fertility and

Table 12. Crop cover factors and the calculated soil loss (tonnes/ha) by erosion under different crop covers.

Crop	Cover factor[1]	Calculated soil loss by erosion			
		Mafai	Baura	Bolisa	Mean
Maize	0.4	83.8	20.1	13.3	39.1
Sorghum	0.4	83.8	20.1	13.3	39.1
Pearl millet	0.50	na	25.1	17.0	14.1
Finger millet	0.40	83.8	20.1	13.3	39.1
Cowpeas	0.19	na	9.7	6.3	5.3
Beans	0.19	39.5	9.7	6.3	18.5
Pigeon pea	0.26	54.6	13.1	8.7	25.5
Groundnut	0.40	na	na	13.3	4.4
Cassava	0.26	na	13.1	8.7	7.3
Sweet potato	0.23	48.0	11.6	7.6	22.4
Irish potato	0.22	46.1	na	na	15.4
Sunflower	0.45	94.1	22.7	15.0	43.9
Sugarcane	0.20	27.9	na	na	9.3
ALL	na	62.4	16.5	11.2	30.0

[1]Reference for crop cover factor (C) are found in Smaling et al. (1993), Roose (1986) and Lewis (1987).

Table 13. Nutrient loss (kg/ha) in eroded soil material under different cropping systems in the survey villages.

Crop	Mafai			Baura			Bolisa			Mean		
	N	P	K	N	P	K	N	P	K	N	P	K
Maize	486.0	0.70	0.10	28.2	0.28	0.02	21.2	0.08	0.02	178	0.36	0.17
Sorghum	486.0	0.70	0.10	28.2	0.28	0.02	21.2	0.08	0.02	178	0.36	0.17
Pearl millet	na	na	na	35.2	0.36	0.04	27.2	0.01	0.02	20.8	0.16	0.02
Finger millet	486.0	0.70	0.10	28.2	0.28	0.02	21.2	0.08	0.02	178	0.36	0.17
Cowpeas	na	na	na	13.6	0.14	0.02	10.0	0.04	0.01	7.8	0.06	0.01
Beans	229.2	0.34	0.04	13.6	0.14	0.02	10.0	0.04	0.01	84.2	0.18	0.02
Pigeon peas	316.6	0.46	0.06	18.4	0.18	0.02	14.0	0.06	0.01	116	0.24	0.03
Groundnut	na	na	na	na	na	na	21.2	0.08	0.02	7.1	0.02	0.01
Cassava	na	na	na	18.4	0.18	0.02	14.0	0.06	0.01	10.8	0.08	0.01
Sweet potato	278.4	0.40	0.06	16.2	0.16	0.02	12.2	0.04	0.01	102	0.20	0.03
Irish potato	275.4	0.38	0.06	na	na	na	na	na	na	91.8	0.13	0.02
sunflower	574.8	0.80	0.12	31.8	0.32	0.02	24.0	0.10	0.02	201	0.27	0.05
sugarcane	161.8	0.24	0.04	na	na	na	na	na	na	53.9	0.08	0.01
All	253.0	0.36	0.06	17.8	0.18	0.02	15.2	0.06	0.02	95.3	0.20	0.03

ensure the sustainability of agricultural system.

What is definitely worrying from the findings of this study is the large deficit of the most growth limiting nitrogen. The point of concern here is how long the nutrient resource base is going to sustain production given the present soil management system and extraction rates. Both P and K are in marginal positive nutrient budgets. Such marginal positive trends do not rule out the possibility of these nutrients becoming limiting in the near future, or in some parts of the landscape, especially if nutrient uptakes in harvested products, residue removals or erosion loss are not replenished by equal or larger quantities.

The use of inorganic fertilisers (Input 1) remains the major source of nutrient supplement into the soil (at least in the short-run) to offset the continuous depletion that has resulted into the observed negative nutrient budgets. No fertiliser recommendations exist for the study area, and for Dodoma region as a whole. However, based on the calculated nutrient budget, 5 bags (1 bag = 50 kg) of UREA (46%N) or 9 bags of N-P-K (20-10-10) compound fertiliser would be required to offset the calculated negative N-budget. Another approach to replenish fertility in the soil would be increased planting of leguminous

Table 14. Summary on nutrient input, output (in kg/ha/yr) and nutrient budget[1] from the different sources.

Source	Mafai			Baura			Bolisa			Mean		
	N	P	K	N	P	K	N	P	K	N	P	K
Input sources												
(1) Fertilisers	3.63	1.23	0.68	1.87	0.41	0.78	2.31	0.31	0.51	2.60	0.65	0.65
(2) Manure	6.82	0.77	0.02	17.90	2.02	0.06	14.61	1.65	0.05	13.1	1.48	0.04
(3) Crop residue	5.90	1.70	11.90	3.20	2.30	13.90	2.70	1.60	8.30	3.93	1.87	11.4
(4) Atmospheric deposition	3.55	3.12	2.33	3.55	3.12	2.33	3.55	3.12	2.33	3.55	3.12	2.33
Total input	19.90	6.82	14.93	26.52	7.85	17.07	23.17	6.68	11.19	23.18	7.12	14.4
Output sources												
(1)Harvested products	14.70	2.00	10.70	12.10	1.60	5.20	15.10	2.10	5.70	13.97	1.90	7.20
(2) Residue removals	4.60	0.30	4.10	6.20	0.40	3.10	6.40	0.50	5.80	5.73	0.40	4.33
(3) Erosion	253.0	0.36	0.06	17.80	0.18	0.02	15.20	0.06	0.02	95.33	0.20	0.03
Total output	272.30	2.66	14.86	36.10	2.18	8.32	36.70	2.66	11.52	115.03	2.50	11.6
Nutrient Budget	-252.40	4.16	0.07	-9.58	5.67	8.75	-13.53	4.02	-0.33	-91.85	4.62	2.82

[1]Nutrient budget = Total input - Total output in kg/ha/yr.

crops and tree species which fix nitrogen and add organic matter to the soil and reduce soil erosion. Leguminous trees incorporated in the farm are reported to fix up to 50 kg N/ha/yr and raise the productivity of semiarid soils (Mortimore, 1989). This can be adopted in areas with similar climatic conditions such as Kondoa. Trees incorporated in crop fields not only improve the fertility status of the soil but also reduces soil erosion through reduction of runoff (Young, 1991; Liniger, 1992).

Implication of the nutrient budget on agricultural sustainability

The agricultural system of the study area is characterised by declining crop productivity, mainly associated with negative balances for major nutrients like nitrogen. The amount of nutrients leaving the soil in harvested crops, by erosion and by residue removals, is grossly exceeding the nutrient input to the system by natural processes such as biological nitrogen fixation and atmospheric deposition, or artificially by organic manure and inorganic fertilisers.

Increasing and sustaining agricultural production in the inherently erodible and low fertility soils of the study area is a major challenge. This has resulted from among others factors, soil erosion and increased soil degradation in farmland, continuous harvesting without proportionate nutrient replenishment and residue removals.

One of the reasons for low agricultural production is the gradual process of soil nutrient depletion in many of the sub-Saharan land-use systems (CWFS, 1985; Smaling, 1993). Among the processes responsible for this nutrient depletion are soil erosion, crop harvesting, residue removals and leaching, phenomena that have received less public attention compared to aspects like crop failures due to erratic rainfall and climatic and non-climatic factors. The nutrient status of the soil dictates the productivity of land and dwindling soil fertility has become one of the major constraints to crop production, in the Kondoa area as well other parts of Tanzania and Africa in general. This has resulted into reduced agricultural sustainability (Lynam and Herdt, 1989; Spenser and Swift, 1992; Rockström, 1997). Thus, in order to ensure agricultural sustainability there is need to enhance the management of all the nutrient input pathways while minimising the nutrient output pathways.

Conclusions

It has been established in the foregoing discussion that the agricultural system in the study area faces extremely large nutrient deficit, particularly for N, as expressed by the enormous negative nutrient budgets. The major concern among the nutrient output factors from the agricultural land is soil erosion. This nutrient loss pathway accounted for more than 80% of the N losses in eroded material. Thus efforts to control erosion are necessary to reduce the amount of soil removed from the arable land, and as such help to halt the negative nutrient budget trends in the farming system. Increased effort on on-farm soil conservation is an important undertaking. Among the on-farm conservation strategies could be the increased incorporation of crop residues into the soil (Input 2). For ensured sustainability of the agricultural system protection of the land against soil erosion has to take a long-term perspective. In the short run, one of the important factors in the efforts to raise agricultural productivity is increased availability and application of inorganic fertilisers, especially under conditions of heavy population pressures and dwindling reserves of uncultivated arable land. Given the growing land pressure in the study area and elsewhere in the country and rising fertiliser prices, a subsidy on fertilisers is critical especially to the resource-poor farmers to ensure food security and soil productivity. However, further research has to be conducted on crop responses to fertilisers in this area so as to come out with more feasible recommendations bearing in mind the climatic and socio-economic conditions that prevail in the area.

Manure application (Input 2) provides nutrient and additional benefits such as increased water storage and nutrient retention in the soil. However, since not all households have got access to farmyard manure following expulsion of livestock from the area in the late 1970s, increased use of this input is unlikely to be achieved in the short-run. Present average manure application rate has been observed to be far below the recommended rates for the sorghum, pearl millet, and maize based farming system of study area. Such low rates pose a particular challenge given shortages of inorganic fertilisers. Incorporation of crop residues into the soil would, apart from contributing significantly to the maintenance of high nutrient levels in the soil, is also necessary to provide surface cover to the ground that is required so as to reduce surface runoff and control soil loss by erosion. Other conservation efforts such as including agroforestry trees in croplands and making contour ridges to control soil erosion need to be encouraged. Finally, a well-planned long term conservation strategy becomes an absolute necessity if agricultural productivity is to be made sustainable under such fragile semiarid environments.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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