Soil Resources in the Congo Basin: Their properties and constraints for food production

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Abstract.

The Congo basin, with a total area of about 3 822 000 km^2 and a population exceeding 90 million people, has generally lagged behind in agricultural development. The purpose of this paper is to describe the different soil types in the Congo basin, their major constraints, the actual utilization types, their management and the impact of land use on food production. Agriculture in countries of the Congo basin has a dualistic character, with on the one hand the traditional smallholder agriculture in forested areas based on shifting cultivation, with almost no use of external inputs and characterized by low productivity, and on the other hand, large commercial perennial crop plantations of oil palm, rubber, Robusta coffee and cocoa. To increase community resilience and to ensure food security, agriculture must move from shifting cultivation to permanent agriculture that relies on agroforestry practices, a good knowledge of the soils and the integrated land use management. However, in most countries, farm-level information and detailed soil maps are non-existent. When this is coupled to other socio-economic constraints, it provides one explanation for the lack of progress in ensuring food security. Proper utilization of soils is essential to sustainable agricultural production and economic development. In the Congo basin, 65 % of the population lives in rural areas and the majority is directly involved in agriculture. Food production requires suitable soils for crop cultivation, however suitable soils for agricultural production are limited in the Congo basin. Sustainable food production in the Congo basin can partly be attained if soil characteristics and constraints are well understood.
Key words: Congo basin, soil properties, soil constraints, food production

1. INTRODUCTION

Congo Basin forests support the livelihoods of more than 90 million people. Even today, a large portion of the population living in the Congo Basin forest is indigenous. In addition to those inhabitants, many others directly or indirectly rely on the forest for fuel, food, medicines, and other non-timber products. For the Congo Basin's population, the forest is a major source of food. The contribution of forests to food security is very often overlooked, but rural communities in the Basin get a significant portion of protein and fats in their diets.

Land use changes influence the fertility of the soil. Land use changes mostly focused on deforestation, cropland expansion, dry land degradation, urbanization, pasture expansion and agricultural intensification. In tropical regions, forest is cleared for the expansion of cropland, wood extraction or infrastructure expansion. Croplands expanded by 50% during the 20th century, from roughly 1200 million ha in 1900 to 1800 million ha in 1990. There are several interacting drivers for land cover change but the exponential growth in human population is important. Currently, 95% of the population growth takes place in tropical regions and soil fertility in tropical regions is affected by rapid land use changes. The effects of deforestation and grassland conversions as well as agricultural intensification have been fairly well-documented but the spatial and temporal effects of soil fertility change and its interaction with land use change remains to be investigated;

2. CONGO BASIN CHARACTERISTICS

Although agriculture is the main economic activity in the tropical regions, the proportion of cultivated land is virtually the same as in the temperate region: about 10 percent. There is a tremendous potential for expanding agricultural output in the tropics by bringing new lands into production with a reasonable degree of expected success. One of the factors presently limiting the utilization of tropical areas suited for crop production is inadequate knowledge of how to manage the highly weathered soils presently under rainforest or savanna vegetation.

The proper management of soils in the tropics Congo Basin is considered one of the critical components in the worldwide race between food production and population growth. In spite of the voluminous literature, comprehensive knowledge of the characteristics of soils in Congo Basin (the tropics) is still quite limited (Nachtergaele and Van Ranst, 2003). One of the reasons for this lack of integrated knowledge has been the development of strong local biases by full-time tropical soil scientists working only in a specific area or country. The lack of a common language has thus impeded the transfer of many important management findings from one area to another.

3. SOIL INFORMATION IN AFRICA

With the exception of a few countries such as Kenya, detailed information on the soil resource base is generally inadequate for most developmental purposes. In most countries, farm-level information and detailed soil maps are non-existent. When this is coupled to other socioeconomic constraints, including land titling and availability of capital for land management investments, it provides one explanation for the lack of progress in poverty alleviation and food security (Cleaver and Schreiber, 1994). Large gaps in soil information persist in many African countries.

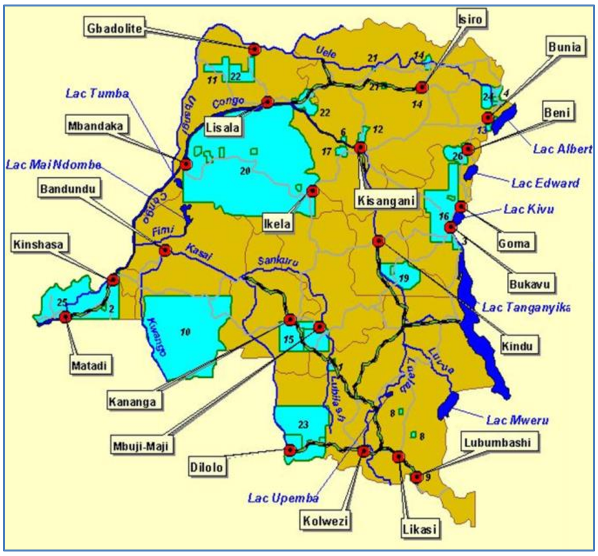
Table 1. National soil survey coverage in Africa (%) :

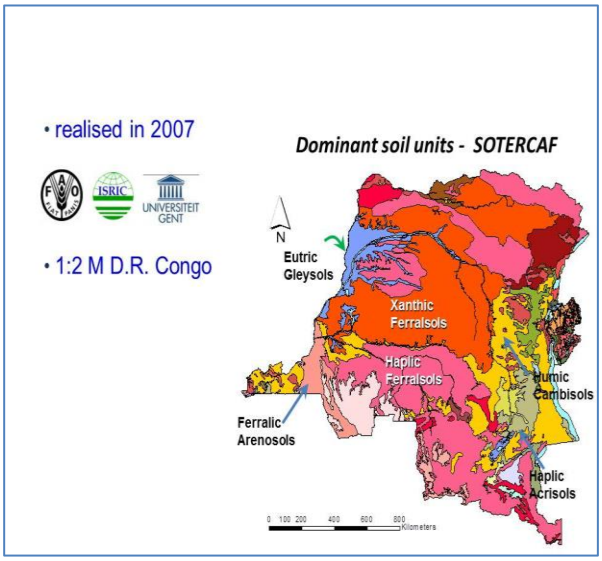
Country	Small scale 1:500,000 – 100,000	Medium scale 1:100,000 – 50,000	Large scale ≤ 1:25,000
Algeria	-	5	5
Benin	100	10	2
Botswana	40	5	-
Burkina Faso	100	25	-
Burundi	100	-	-
Cameroon	30	5	1
DR of Congo	10	5	-
Egypt	100	10	10
Gabon	30	-	-
Gamb ia	100	-	100
Ghana	95	-	-
Kenya	100	25	-
Mali	50	-	-
Morocco	-	40	20
Nigeria	70	35	-
Rwanda	100	100	-
South Africa	70	-	-
Swaziland	100	10	5
Tanzania	50	-	-
Togo	80	20	-
Uganda	100	-	-

HIGH DEMAND

In DRC for example, considerable attention was also given to soil and vegetation mapping. From 1945 till 1960, around 15% of the territory of Congo was mapped by the Belgian soil survey team of INEAC, at scales ranging from detailed (1:10.000) to reconnaissance level (1:200.000 – 1:500.000) (Sys,1960. The Belgian team working under INEAC developed their own legend for the soil maps – the I.N.E.A.C. soil Classification - the insights of which were at the base of diagnostic horizons adopted in Soil Taxonomy and in WRB to accommodate soils of the tropics. Besides the I.N.E.A.C. soil surveys, several other soil surveys were carried out after the independence by the Laboratory of Soil Science of the University of Gent at detailed level for agricultural purposes:

- Kaniama-Kasese (Katanga) : evaluation for maize
- Lubilashi (Katanga), Fiwa (Equator), Mushie Pentane (Bandundu) and Luiza (Oriental Kasai): evaluation for sugarcane
- Katale (North Kivu): evaluation for coffee





National coverage (16,5%)/1/200.000, 1/500.000

Figure 1. Mapped area

Figure 2. Soil map of DRC

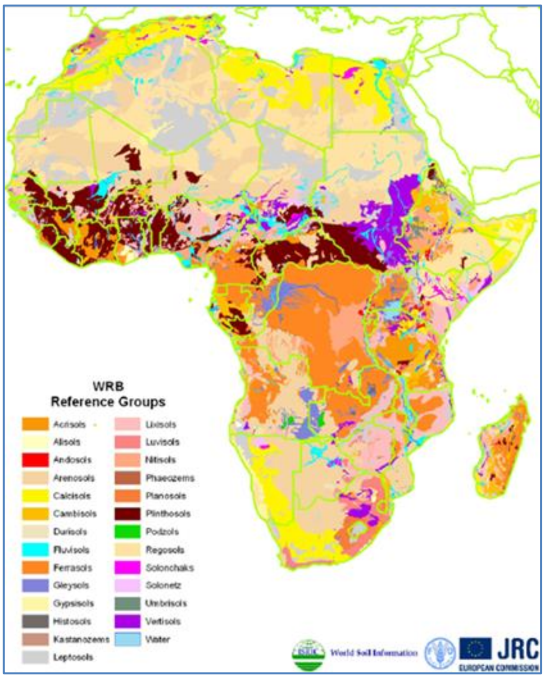
The Soil and Terrrain database of Central Africa (SOTERCAF, version 1.0) was compiled at scale 1:2 million for the Democratic Republic of Congo and at scale 1:1 million for Rwanda and Burundi. The SOTERCAF compilation has been a joint collaboration of the Soil Science Laboratory of the University of Ghent, Belgium and ISRIC - World Soil Information, Wageningen under contract with the Food and Agriculture Organisation of the United Nations. Further assistance is provided by the Department BIOT of the Hogeschool Gent, the Royal Museum for Central Africa (Tervuren) and data holders in the Democratic Republic Congo, Burundi and Rwanda. The project started in September 2005 by deriving physiographic units from SRTM grid data based on SOTER landform definitions. The database was completed in July 2006 after combining the physiographic layer with the lithology and soils layer. The border harmonization with the SOTERSAF database was finalized November 2006. (Van Engelen et al.2006)

According to SOTERCAF, the main FAO soil groups are Ferralsols, Acrisols, Cambisols, Arenosols, Gleysols, Histosols, Lixisols and Nitisols, covering some 99% of the region. The main soil units are haplic Ferralsols (FRh, about 29%), haplic Acrisols (ACh, ~23%), xanthic Ferralsols (FRx,~16%), umbric Ferralsols (~5%), eutric Gleysols (~4%), ferralic Cambisols (CMo, ~3%), haplic Lixisols (LXh, ~3%), ferralic Arenosols (ARo, ~2%) , dystric Cambisols (CMd, ~2%), rhodic Ferralsols (FRr, ~2%), and haplic Arenosols (ARh, ~2%); these units cover over 90% of CAF.

Two of the early efforts of compiling the soil resources of Africa, were those of Marbut (1923) and Shokalskaya (1944). These maps at a scale of 1:30 million are based on geology and phytogeography and had minimal field soil information. Many of the recent concepts of tropical weathering and soil formation originated in Africa during the colonial period (Ollier, 1959; King, 1962; Moss, 1968). In

1953 an Interafrican Pedological Service was created with its Administrative Headquarters at Yangambi, Belgian Congo (Zaire). The Council of this Service decided in 1955 to make a soil map of the continent which was eventually realized in 1964 (D'Hoore, 1964). This soil map and accompanying report was perhaps the last effort in Africa until the FAO-UNESCO Soil Map of the World was published a decade later (Eswaran et al. 1996).

The FAO soil map of Africa at a scale of 1: 5 million has over 6,000 polygons. The FAO soil unit designator for each polygon is systematically converted to WRB reference group and for this process, only the dominant unit in the association is considered



http://eusoils.jrc.ec.europa.eu/library/maps/africa_atlas/

Figure 3. Soil map of Africa (WRB reference groups)

4. MAJOR SOILS TYPES IN CONGO BASIN

From the study of the tropical environment, it is obvious that the soils of the tropics show considerable diversity as a result of major differences in moisture regime, lithology, and age, degree of weathering of parent materials, relief, and elevation above sea level (Van Wambeke 1989).

Figure 3 illustrates the distribution of soil Orders in Congo Basin.

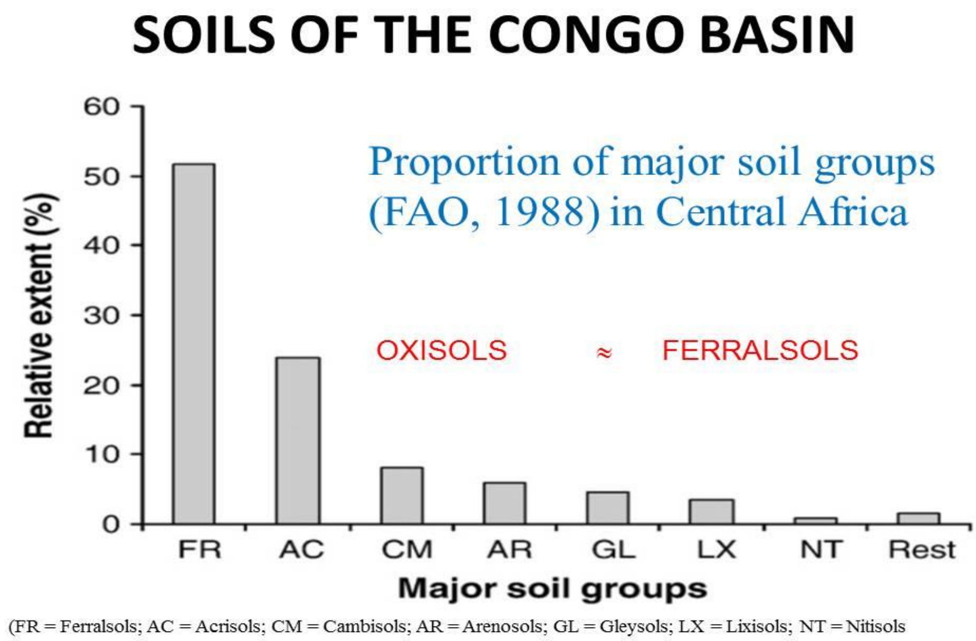
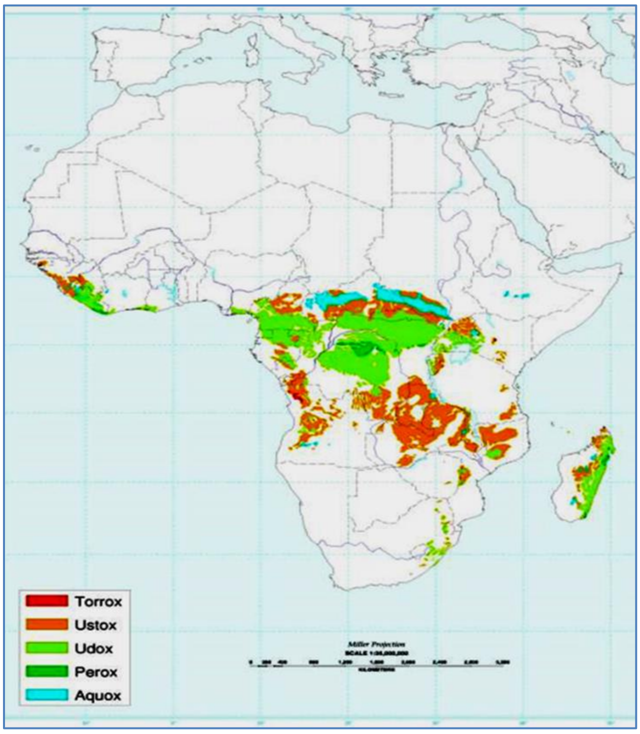


Figure 3. Major soil of the Congo Basin

Table 2. Major soils type in some country of Congo basin

	Central Africain Republic	**CONGO**	**CAMEROON**	**GABON**	**DR CONGO**
1	Xanthic Ferralsols	Rhodic Ferralsols	Xanthic Ferralsols	Xanthic Ferralsols	Xanthic Ferralsols
2	Rhodic Nitisols	Xanthic Ferralsols	Rhodic Ferralsols	Ferralic Arenosols	Rhodic Ferralsols
3	Humic Ferralsols	Eutric Gleysols	Rhodic Nitisols	Dystric Fluvisols	Ferralic Arenosols
4	Eutric Vertisols	Humic Cambisols	Dystric Gleysols	Dystric Gleysols	Eutric Gleysols
5	Eutric Gleysols		Eutric Gleysols	Rhodic Nitisols	Haplic Acrisols
6	Distric Regosols		Eutric Vertisols	Humic Cambisols	Ferralic Cambisols
7			Dystric Regosols		Haplic Nitisols

Figure 4. show the distribution of oxisols in Afica. The DR Congo bas the largest extent of oxisol.



Characteristics:

- red or yellow in colour
- old and strongly leached
- deep
- finely textured
- traces of weatherable minerals
- low activity clays
- no (<5%) recognizable rock structure
- gradual soil boundaries
- goot permeability to water and air
- easily trafficable (strong aggregation).
- weak macrostructure renders the soils prone to compaction
- but rapid recovered with appropriate tillage management
- strong cohesion of microaggregates
- complicates determination of particle size distribution

Figure 4. Distribution of oxisols in Africa

Figure 5. Oxisol profile

4.1. Physical properties

a. Particle size distribution

Texture of HWS (Highly weathered soisl) is closely related to the nature of the parent rock and may vary from sandy clay loam on sandstones and quartzites to heavy clay on shales and basic rocks.

Sandy loam and loamy sand occur normally on transported materials. A common characteristic is the low silt content.

b. Porosity and soil aggregation

Total porosity decreases slightly with depth (5 to 20 percent). This is due to a decrease of the macroporosity following the decrease in the organic matter content. Prolongated cultivation of annuals does not cause an important change of total pores but may be at the origin of a decrease of the macroporosity in the topsoil due to a decline in the organic matter content. This decrease in macroporosity may reduce root penetration. The stable microporosity can be explained by the formation of strong micro-aggregates (negatively charged clay surfaces combine with positively charged sesquioxide surfaces).

Micro-aggregation helps to explain the well-known fact that many HWS of the tropics have better physical properties than might be suggested by the high clay content

c. Soil-water relationship

Two type of moisture regimes: the continuously humid rainforest areas with udic moisture regime and the seasonally rainy tropics with ustic moisture regime.

All HWS have good permeability and high percolation rate. The average permeability of Tropical Oxisols was observed to be about 14 cm/h in the surface layers and 6.5 cm/h in the subsoil. Oxisols and other soils dominated by LAC have a low available water content compared with soils characterized by HAC. This may represent serious limitations especially under seasonally dry climates. An important feature is that under ustic climatic conditions annual crops have to start their growth cycle when the soil has little or no moisture reserve. Therefore crops are very sensitive to erratic rainfall and to drought stress.

4.2. Chemical properties

a. Organic Matter

Organic matter is the most important product of the forest and savannah vegetation. The amount of organic matter immobilized in a rainforest varies from 150 to 300 tonnes of dry material per hectare containing 1.5 to 2 tonnes of mineral salts.

The annual gain at the soil surface is estimated at about 15 tonnes dry material per hectare containing approximately 200 kg of nitrogen, 250 kg of mineral salts and 250 kg of silica.

The organic matter content of a soil under rainforest is about 110 tonnes per ha, which is 7 times more than the annual gain.

Organic matter is the most important product of the forest and savannah vegetation.

The amount of nutrients stored in soils of the Congo Basin is mainly related to the organic matter content and the production of organic matter by the vegetation (Table 3). Under natural vegetation, the development of the humiferous topsoil is a general expression of the soil fertility.

Soil organic C is predicted to decrease from 43 to 25 t/ha in 15 years, with continuing inputs of 2 t/ha instead of 11 t/ha of C per year. These levels correspond approximately to humid tropical conditions changing from forest cover to arable crop production. Loss of organic matter through oxidation when the soils are cultivated or through erosion reduces the ability to supply N, P and S for crops. Also it reduces the abiliy to retain cations in an available form (Van Ranst, 2004).

From the analytical point of view the organic matter content is best evaluated in the upper 15 cm :

- $> 2.5\%$ O.C : high
- 2.5-1.0% O.C : medium
- $< 1.0\%$ O.C : low

Organic matter (pH_0 around 3.5-4) develops negative charges that contribute to the cation retention of the soil. It has been estimated that the CEC of soils in the humid tropics is around 260 cmol(+) kg^{-1} C at pH 7 and 35 cmol(+)kg^{-1} C at pH 4.5.

Table3. Immobilization of mineral elements by a forest fallow at Yangambi (Sys, 1979

(Year)	Dry material (t/ha)	Immobilization of minerals (kg/ha)		
		N	P	K
2	20	190	22	160
5	112	570	32	420
8	153	580	35	670
18	173	700	108	820

b. Nitrogen

The nitrogen in soil organic matter (SOM) remains the most important source of nitrogen for crop production in the humid tropics. The annual addition of fresh organic matter is about 15 tonnes per ha under a tropical rainforest, but may vary, according to the development stage of secondary forest regrowth, from 3 to 15 tonnes.

Under savannah, the annual addition may vary from 0.5 to 1.5 tonnes per ha of dry material.

The annual decomposition rate of SOM varies from 2 to 5 percent (average 4%) under rainforest and is estimated at 1.2 percent under savannah. (Sys, 1979).

An annual legume crop in rotation may provide 10 to 70 kg/ha of nitrogen. A perennial legume crop, after two or more years, may furnish from 50 to 150 kg/ha of nitrogen to the crop that follows. Management and effect of cultivation have an important influence on the decomposition rate (Table 3).

c. Phosphorus

Total phosphorus has no practical importance but it is an indication of the degree of weathering. It has been stated that with increasing weathering the total P content of the soil decreases:

- Young soils : 2,000-3,000 ppm P
- Ultisols : around 500 ppm P
- Oxisols : around 200 ppm P (between 20 and 300 ppm)

– **Organic phosphorus**

Organic P can be mineralized during the breakdown of the organic matter and becomes easily available for uptake by plants. Therefore the ratio **C/P** or **N/P** or the organic matter is a good parameter for the availability of P. C/P should be around **100-120** and N/P around **10**. In strongly weathered tropical soils these ratios are respectively around 200-250 and 20-25.

Increasing the mineralization of organic matter, e.g. by liming, may therefore improve the yield of crops. On the other hand, maintaining organic matter by regular addition of organic material increases the availability of P for plants. It is obvious that organic P is especially important in areas where P fertilizers are not available.

Table 4. Effect of cultivation on decomposition rate of OM

(Year)	Dry material (t/ha)	Immobilization of minerals (kg/ha)		
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2	20	190	22	160
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18	173	700	108	820

- **Inorganic phosphorus**

Inorganic P is bound to Ca, Fe or Al, but the exact nature of these compounds is not very well known. In HWS, containing high amounts of free Fe and/or Al, the fraction of P which has not been leached out is included mostly inside these compounds

d. Effect of cultivation on decomposition rate of OM

Shifting cultivation occurs in almost half of the tropical world in both forested and savanna areas. These are usually the least developed areas, where farmers cut and burn a small area, plant several crops in the same field, and abandon the fields when native soil fertility, weeds, or other factors decrease yields. Shifting cultivation is most widespread in Congo Basin under udic and ustic regimes. It is also very common in the Amazon Basin, Central America, and the hill country of Southeast Asia and the Pacific (Table 4).

Table 5. Immobilization of mineral elements by a forest fallow at Yangambi (Congo)

CROP	Part	YIELD	Nutrients Kg/ha				
		T/ha	N	P	K	Ca	Mg
CORN	Grain	1	25	6	15	3	2
	Stover	1,5	15	3	18	4,5	3
	Total	2,5	40	9	33	7,5	5
	Grain	4	63	12	30	8	6
	Stover	4	37	6	38	10	8
	Total	8	10	18	68	18	14
	Grain	7	128	20	37	14	11
	Stover	7	72	14	93	17	13
	Total	14	200	34	130	30	24
RICE	Grain	1,5	35	7	10	1,4	0,3
	Straw	1,5	7	1	18	2,6	2,2
	Total	3	42	8	28	4	2,5
	Grain	8	1,6	32	20	4	1
	Straw	8	35	5	70	24	13
	Total	16	141	37	90	28	14
WHEAT	Grain	0,6	12	2,4	3	0,3	1
	Straw	1	3	0,8	14	2	2
	Total	1,6	15	3,2	17	2,3	3
	Grain	5	80	22	20	2,5	8
	Straw	5	38	5	60	10	10
	Total	10	118	27	80	12,5	18
SORGHUM	Grain	1	20	0,9	4	4	2,4
	Straw	1,2	6	0,4	2	4,6	3,2
	Total	2,2	26	1,3	6	8,6	5,6
	Grain	8	135	10	27	16	9,6
	Straw	8	65	4	13	18	12,8
	Total	16	200	14	40	34	22,4
MILLETS	Grain	1,1	17	5	59	-	-
CASSAVA	ROOTS	8	30	10	50	20	10
	ROOTS	16	64	21	100	41	21
	ROOTS	30	120	40	187	77	40
	Whole plant	59	64	19	176	102	26
	Roots	59	42	28	291	43	19
SWEET POTATOES	ROOTS	16,5	7,2	8	88	-	-

e. Effects of exchangeable Al

The amount of acidity which may be present in HWS strongly depends on the stage of evolution and the subsequently mineralogy, as well as on their ZPNC. The processes necessary to develop acidity are : accumulation of organic matter, breakdown of primary minerals and leaching of soluble constituents :

The effect of exchangeable Al is diverse:

1. Exchangeable Al affects the normal activity of the soil micro-organisms; in the first place Rhizobium is affected
2. Aluminium has also an effect on plant physiology. As all mineral elements, Al is indispensable for plant growth; in weak concentrations it has a benefic effect.
3. At the level of the cell membrane exchangeable Al presents antagonism with Ca and Cu and prevents these elements to penetrate the cells. On the other hand Al favours uptake of Mn and may therefore indirectly induce Mn toxicity stated in some tea plantations.
4. Resistance to Al depends on plant species: rubber, tea, cassava and rice are resistant; cotton, cocoa and tobacco are sensitive.

f. Trace elements

Trace elements are seldom limiting factors under extensive systems of agriculture in tropical areas where yields are low. However, with more intensive management the demand for micronutrients increases above the supply level of virgin soils. This is particularly true in acid soils under intensive cultivation and receiving large amounts of nitrogen and phosphorus.

5. SUITABILITY FOR CROP PRODUCTION

Soil properties, including soil climate, provide some preliminary information to address soil quality. Soil quality is used here to indicate the ability of the soil to perform its function of sustaining agriculture under the current low-input system of agriculture. Low-input implies that large-scale irrigation is absent, use of fertilizers, and pest and weed control is minimal, and soil management does not require high energy mechanized equipment. The low potential lands have several major constraints which are not easily corrected through management. The unsustainable class of lands are those which are considered to be fragile, easily degraded through management, and in general are not productive or do not respond well to management. They are generally highly erodible and generally require very high investments for any kind of agriculture

High potential lands are those with some minor limitations. The medium and low potential lands have major constraints for low-input agriculture. Resource poor farmers who live on these lands have high risks and generally, the probability of crop failure is high to very high. The constraints include surface soil crusting, impermeable layers, soil acidity and specifically subsoil acidity, and high risks water erosion.

The soil proprieties analysis and the evaluation provide a first assessment of crops suitabily.

Much of the land within the Congo basin is biophysically capable of supporting some type of sustainable agriculture system. Much of their sustainability is dependent on the extent of inputs to maintain soil quality. In many countries of Congo Basin, though application of costly inputs in order to achieve sustainability is not realistic, expansion of low-input agriculture systems on these soils is likely to result in soil degradation and loss of productivity. There is thus an urgent need to provide alternate options for a more equitable use of the soil resources until some form of capital intensive systems can be implemented. Food security is becoming or is already of paramount concern in many of the African nations. Traditional agriculture systems and declining 'aid' imports may not supply the needs of a region which has some of the highest birth rates (Kesseba, 1993. A declining resource base will eventually contribute to civil unrest due to uncertain food supplies;

As the population growth and the demand for suitable agricultural land increases, there is need for a planned assessment of agricultural potential in Africa. Thus, soil resources, especially using small scale regional maps and more detailed national and local assessments can provide better information for crop suitability. With socioeconomic and other data layers, realistic national assessments and appropriate strategic plans can be developed.

In this study eleven types of soils were taken as the basis for evaluation. Soils characteristics (table 6) and qualities of those soils were compared with crop requirement (Tables,7,8,9,10) of 5 major crops (maize, rice, banana, cassava, oil palm), grown under rainfed conditions in Congo basin. Estimates were made, at congo basin level, of the suitability of soil for rainfed crop production, for each crop, divided into five classes (tab ….) : very suitable (S), suitable (S1), moderately suitable (S2), marginal (S3), and not suitable (N). Except for S1 and N, all classes were subdivided in subclasses depending of the type of limitation (m= water limitation, n = nutrients limitation, h= relative humidity limitation, w= flooding, u= insolation, r=root depth limitation= erosion risk).

As a result, suitability classes have been defined that fall into the soil properties of fertility, depth, drainage, nutriment, acidity, moisture regime, temperature regime etc.. (Tab 11 Figure 6)

Table 6. Soil characteristics

Soil type	**pH**	**C (%)**	**N (%)**	**K**	**ca**	**CEC**	**Al**	**P (bray) ppm**	**Depth(cm)**	
Haplic Acrisol	5,2	0,87	0,6	0,1	1,2	8,2			>100	OR5
Xanthic Ferralsol	4,9	0,6	0,3	0,05	0,4	4,1	0,8	1,5	>100	Y4
Gleyic Arenosol	4,3	0,31	0,02	0,07	0,35	3,8	1,2	2,1	>100	Y5
Haplic Ferralsol	5,9	0,7	0,12	0,25	2,2	4,5			>100	NU8
Eutric regosol	4,7	0,8	0,2	0,1	1,9	3,1			=< 40	BP7

Haplic lixisol	5,9	1,8	0,2	0,5	5,3	6,7			>100	AL1
Eutric Cambisol	6,1	2,3	0,23	0,9	7,2	10,8			=< 60	NU11
Rhodic Ferralsol	5,7	0,25	0,03	0,09	0,9	3			>100	SU1
Haplic Arenosol	5,3	0,4	0,02	0,2	0,6	2,5			>100	SU8
Plintic Ferralsol	4,6	0,9	0,07	0,08	1,2	5			=<90	SU14
Gleyic Acrisol	5,9	0,22	0,06	0,12	3,5	5?8			>100(gleyic	OR1

Table 7. Banana requirement

Suitability class	S1		S2	S3	N
Water disponibility(%)	>90	95-85	85-75	75 - 55	<55
-CEC meq/l00g of soil	>10	10 - 8	8 - 6	<4	
-Ca meq/l00g of soil	>3.8	4 - 2.6	2.6 - 1.5	<1.4	
- Mg meq/l00g of soil	>0.9	0.9-0.6	0.6-0.4	<0.4	
- K meq/l00g of soil	>0.4	0.4-0.25	0.25-0.14	<0.14	
-pH	>5.8	5.8-5.5	5.5-5.2	5.2-4.5	<4.5
Organic matter	>1.5	1.5-1.2	1.2-0.6	<0.6	
Soil depth	>100	100-75	75-50	50-25	<25
Temperature Régime (Moy)	>25	25-7.2	22-20	20-18	<18
……………………….. (Min)	>20	20-12	18-16	16-14	<14

Table 8: Maize requirement

Suitability class	S1		S2	S3	N
Water disponibility(%)	>90	95-85	85-75	75-55	<55
-CEC meq/l00g of soil	>10	10 - 8	8-6	6-2	<2
-Ca meq/l00g of soil	>4	4-2.5	2.5-1.5	<1.5	
- Mg meq/l00g of soil	>1	1-0.6	0.6-0.4	<0.4	
- K meq/l00g of soil	>0.5	0.5-0.25	0.25-0.1	<0.1	
-pH	>5.8	5.8-5.5	5.5-5.2	<5.2	
Organic matter	>1.5	1.5-1.2	1.2-0.8	<0.8	
Soil depth	>100	100-75	75-50	50-20	<20
Temperature Régime (Moy)	>22	22-18	18-16	16-14	
……………………….. (Min)	16-18	18-20	>20		

Table 9: Rice requirement

Suitability class	S1	S2	S3	N

Water disponibility(%)	>85	85-75	75-60	60-45	<45
-CEC meq/l00g of soil	>10	10-8	8-4	<4	
-Ca meq/l00g of soil	>2.6	2.6-1.9	1.5-1.1	<1.1	
- Mg meq/l00g of soil	>0.6	0.6-0.5	0.4-0.3	<0.3	
- K meq/l00g of soil	>0.25	0.25-0.18	0.14-0.1	<0.1	
-pH	>5.5	5.5-5.3	5.3-5	<5	
Organic matter	>1.2	1.2-0.8	<0.8		
Soil dept	>120	120-90	90-50	50-20	<20
Temperature Régime (Moy)	24-31	31-38	38-42	42-45	<45
………………………….. (Min)			24-18	18-10	<10

Table 10. Cassava requirement

Suitability class	S1		S2	S3	N
Water disponibility(%)	>75	75-70	70-50	50-40	<40
-CEC meq/l00g de soil	>8	41402	<5		
-Ca meq/l00g of soil	>2.1	2.1-1.2	<1.2		
- Mg meq/l00g of soil	>0.5	0.5-0.29	<0.29		
- K meq/l00g of soil	>0.2	0.2-0.11	<0.11		
-pH	>5.5	5.5-5.2	5.2-4.5	<4.5	
Organic matter	>1.2	1.2-0.8	<0.8		
Soil depth	>100	100-75	75-50	50-30	<30
Temperature Régime (Moy)	>23	23-20	20-18	18-16	<16
………………………….. (Min)	>18	18-16	16-14	14-12	<12

Table 11. Soil suitability classes

Soil Name	Maize	Rice	Banana	cassava	Oil Palm	Coffee	
Haplic Acrisol							OR5
Xanthic Ferralsol	S3,nhu	S3,un	S3,n	S2,ne	S2,nu	S2, n	Y4
Gleyic Arenosol	N1,nwhu	S3,wnu	S3nw	N1,wn	S3wnu	S3wn	Y5
Haplic Ferralsol	S3,wn	S3,wu	S3wn	S3w	S2nw	S2w	NU8
Eutric regosol	S3nhur	S2/S3uwn	S3nw	S3wnu	S2nuw	S3wn	BP7
Haplic lixisol	S2/S3nh	S2/S3nu	S2n	S2n	S2nur	S2n	AL1
Eutric Cambisol	S2nhr	S3run	S2rn	S2r	S2rn	S2r	NU11
Rhodic Ferralsol	S3nh	S2/S3 nu	S3n	S2n	S3nw	S2n	SU1
Haplic Arenosol	S3nh	S2/S3nu	S3n	S2n	S2/S3nu	S2n	SU8
Plintic Ferralsol	S2/S3nc	S2un	S2n	S2n	S2/S3nu	S2n	SU14
Gleyic Acrisol	S3nhc	S3uer	S2rS2r	S2r	S2/S3ru	Sér	OR1

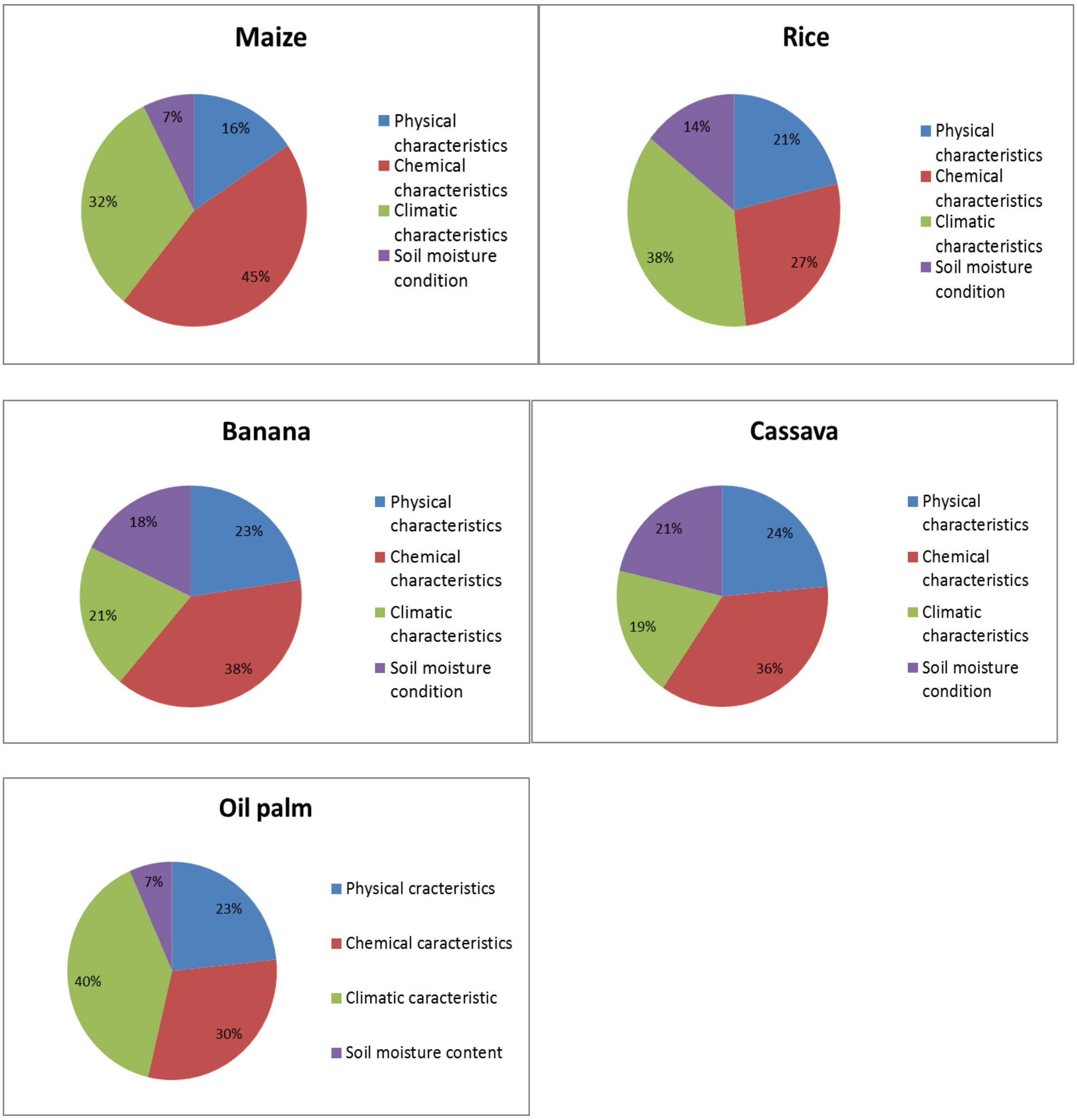
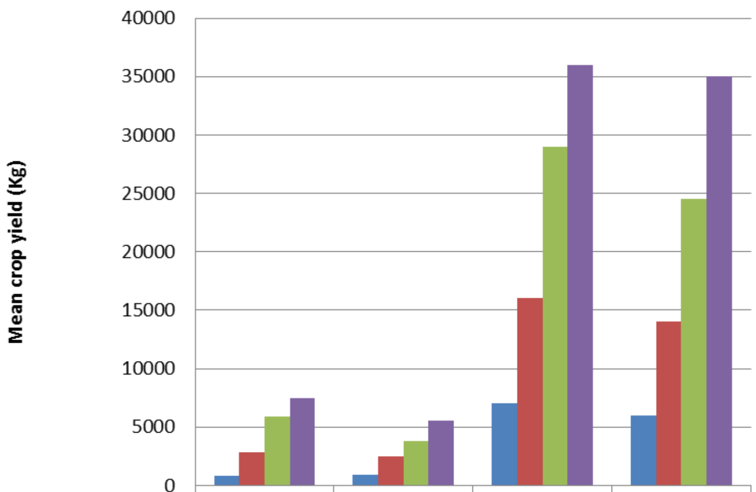


Figure 6. Influence of each group of characteristics on the suitability class



	Maize	Rice	Banana	Manihot
Traditional	850	900	7000	6000
Low improved	2800	2500	16000	14000
Improved	5900	3800	29000	24500
Potential yield	7500	5500	36000	35000

Figure 7. Estimated mean crop yield for different management level in Congo basin

Most of soils of Congo basin are considered as considered as moderate to marginal suitable, due to low fertility, height risk of erosion, moisture and temperature regimes. High content of Fe and Al oxides create the acidic soil property. Such soils fix high amounts of phosphates. With an inherently low soil quality, low-input agriculture can be equated to potential soil degradation. These are some of the priority areas for technical assistance and the implementation of appropriate soil management technologies.

6. MAJOR SOIL CONSTRAINTS IN CONGO BASIN

There are eleven inherent soil constraints for food production in Congo basin. The characteristic levels affecting soil fertility are summarized in Table 11

Congo basin soil limitations:

1. *Low cation exchange capacity:* low capacity to retain added nutrients.
2. *Aluminium toxicity:* strong acidity.
3. *High phosphorus fixation:* a high level of ferric oxides in the clay fraction.
4. *High decomposition rate of organic matter:* The nitrogen in soil organic matter (SOM) remains the most important source of nitrogen for crop production in the Congo Basin. Organic matter (pH_0 around 3.5-4) develops negative charges that contribute to the cation retention of the soil
5. *pH value less than 5,5 (high acidity)*
6. *Hydromorphy:* poor soil drainage.

7. *Soil-water relationship* : Oxisols and other soils dominated by LAC have a low available water content compared with soils characterized by HAC. This may represent serious limitations especially under seasonally dry climates
8. *Low silt content* (texture)
9. *Porosity* : Prolongated cultivation of annuals does not cause an important change of total pores but may be at the origin of a decrease of the macroporosity in the topsoil due to a decline in the organic matter content. This decrease in macroporosity may reduce root penetration.
10. *Shallowness:* rock or a rock-like horizon close to the soil surface.
11. *Erosion hazard:* a high risk of soil erosion, caused by steep slopes, or moderate slopes in association with erosion-prone soils.

Table 12. Characteristic levels affecting soil fertility

	Depth of Horizon			**Moisture conditions**			**Plant nutrients**			**Reaction**			**Organic Matter**		
	Maize	**Rice**	**Cassava**	**Maize**	**Rice**	**Cassava**	**Maize**	**Rice**	**Cassava**	**Maize**	**Rice**	**Cassava**	**Maize**	**Rice**	**Cassava**
Xanthic Ferralsol	L	L	L	L	L	L	H	H	H	H	H	H	H	H	H
Haplic Acrisol	L	L	L	L	L	L	H	H	H	H	M	M	H	H	H
Haplic Arenosol	L	L	L	L	L	L	H	H	H	H	H	H	H	H	H
Eutric Cambisol	L	L	L	L	L	L	H	H	H	H	M	M	H	H	H
Gleyic Acrisol	M	M	M	M	M	M	H	H	H	H	M	M	H	H	H

Legend
H = High
M = Medium
L= Low

AGRICULTURAL VALUE AND LAND USE

The Congo Basin is marked by a dominance of highly weathered soils (HWS), having an oxic or a kandic (argillic) horizon. According to Soil Taxonomy, Oxisols and Ultisols are the most common soil resource.

In their natural state, these HWS often maintain highly productive and diverse ecosystems that are dependent on efficient resource utilization. A characteristic of these systems is their reliance on SOM to cycle nutrients from the soil through the plant and hence back to the soil through plant debris. Soil organic matter (SOM) effectively acts as a slow release nutrient delivery system that mediates the cycling of nutrients and chemical attributes of soils. However, when these ecosystems are disturbed through continuous cultivation, the productivity of many HWS often declines rapidly due to a loss of SOM, accelerated soil acidification, and a reduction in the CEC thereby limiting the ability of the soil to hold basic cations (nutrients), which are rapidly lost through leaching.

It has however, been shown that intensive continuous cropping with annuals is possible with adequate use of fertilizers after annulation of the phosphorus fixation capacity and Al-saturation.

1. ROLE OF FALLOW IN SHIFTING CULTIVATION SYSTEMS

Shifting cultivation is by far the most widespread tropical soil management system.

The role of fallow in humid tropical areas is Regeneration of soil organic matter; Immobilization of mineral elements;and elimination of weeds.

2. FOREST FALLOW

The efficiency of a forest fallow depends mostly on its ability to create in a short time a vegetation which protects the soil against erosion. The regeneration of the soil in organic matter is quite rapid. A forest fallow is able to rebuilt the original organic matter level is about 10 years. The most essential function of the fallow, the accumulation of mineral elements in the the aerial parts of the plants, is also gradual but achieved in a later stage (Table 3).

The length of the fallow period depends on the quality of the soil and the fertility status at the moment the field was abandoned. In the Congo basin, 12-14 years fallow was necessary on a Hapludox to regenerate the soil after a 2-3 years rotation including maize, rice, cassava and bananas (Sys, 1979).

On better soils the length of fallow remains similar but the cropping period may be longer (5-6 years).

A major practical problem in the humid tropics is to find liming materials of sufficient fineness and purity. Fineness is crucial because of the reactivity.

The purpose of liming is primarily to neutralize the exchangeable Al, and this is normally accomplished by raising the pH to 5.5. When Mn toxicity is suspected, the pH should be raised to 6.0 (Mn is very soluble at pH values lower than 5.5. If this element is present in sufficient amounts, Mn toxicity can occur along with Al toxicity at pH values up to about 5.5 to 6.0). However, in order to increase the soil pH to 6, large inputs of lime are required which is inefficient because of the high buffering capacity in these HWS and may result in micronutrient deficiencies (Noble et al., 2000).

The well-established practice of liming to neutrality is not effective in most of the HWS of the tropics. More often than not, liming to pH 7 causes more harm than good. Most plants grow well within a pH range of 5.5-6.5 and therefore a liming programme should be aimed at maintaining the pH in this range (Bolan et al., 2003; Paul et al., 2003).

Kamprath (1971) reviewed the consequences of overliming in tropics are : yield reduction; soil structure deterioration; and decreased availability of phosphorus, boron, zinc and manganese.
Increasing the organic matter content is difficult to achieve under warm and humid conditions when the soil is regularly cultivated.
Even if increasing the actual CEC is not feasible, current levels of exchangeable cations should be closely monitored to ensure there is no further decline as a result of decreasing organic matter levels under increasing cropping intensity or diversification into more demanding crops.
In the tropical soil, the behavior of P fertilizers is very complex, because it is influenced by the solubility of different possible constituents and the pH.

CONCLUSION

As population for Congo basin increases and demand for food rises, there will be increasing demand for suitable agricultural land to provide the agricultural products. Farmers will have to decide if they are more concerned with short-term yields or long-term sustainability and soil management. Their decisions are very critical as recent research has shown that the conversion of tropical forests to sustainable agriculture may be detrimental to preventing global climate change.

In order to translate soil characteristics into agronomic constraints and land use suitability we need detailed information from soil maps. There are some substantial data limitations to the sources used. The reliability of some of the maps and data is known to be relatively low.

Soil degradation and in particular the decline of soil chemical fertility is major concern in relation to food production and the sustainable management of land of Congo Basin.

Conserving soil nutrients and organic matter are practices that must be followed if sustainable agriculture is to continue to meet increasing global demand

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