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Nature and management of soils in West and Central Africa : A review to inform farming systems research and development in the region

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About CORAF/WECARD

The West and Central African Council for Agricultural Research and Development (CORAF/WECARD) is one of the four sub-regional organizations that constitute the Forum for Agricultural Research in Africa (FARA). The mission of CORAF/WECARD is *Sustainable improvements to the competitiveness, productivity and markets of the agricultural system in West and Central Africa by meeting the key demands of the sub-regional research system as expressed by target groups*. CORAF/WECARD is currently composed of 22 National Agricultural Research Systems (NARS) of the following countries in West and Central Africa (WCA): Benin, Burkina Faso, Cameroon, Cape-Verde, Central African Republic, Chad, Congo, Côte d'Ivoire, the Democratic Republic of Congo, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo. These countries cover a total area of over 11.5 million square kilometres, with a population of over 318 million, 70 % of whom depend directly on agriculture for their livelihoods.

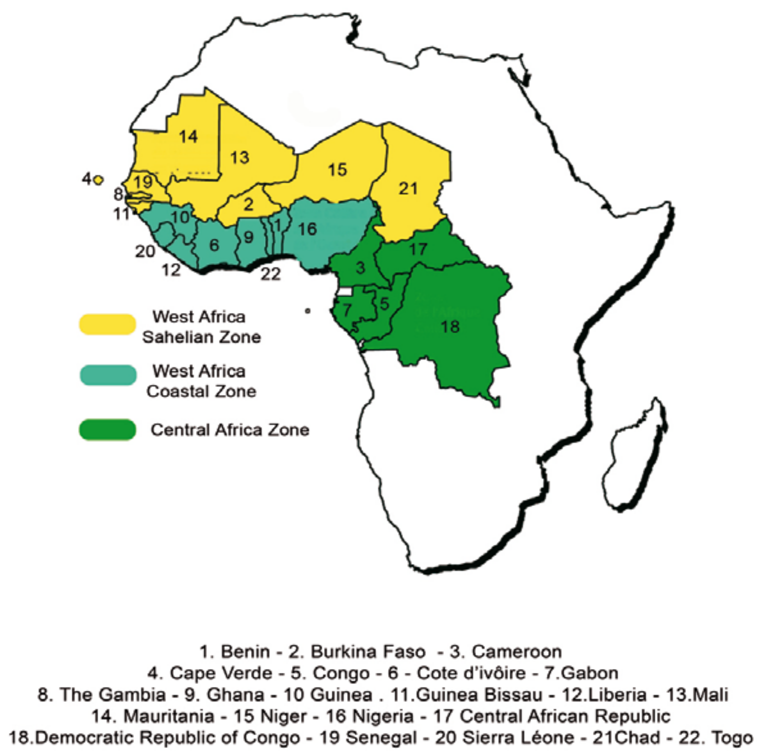

Figure 1. Map of Africa showing zones of CORAF/WECARD

The CORAF/WECARD secretariat is based in Dakar, Senegal. CORAF/WECARD has revitalised its approach to tackling the region's agricultural challenges by using a commissioned report prepared by the International Food Policy Research Institute (IFPRI). This report lists priorities for the region based on commodities and thematic areas. Through an intensive participatory process involving a cross section of relevant stakeholders it has developed new Strategic Plan (2007-2016) and, subsequently, an Operational Plan (2008 – 2013) defining its research direction and partnerships. CORAF/WECARD also targets the building of partnerships with relevant regional institutions and the private sector of economies across the sub-region.

CORAF/WECARD's vision is *A sustainable reduction in poverty and food insecurity in West and Central Africa through an increase in agricultural led economic growth and sustainable improvement of key aspects of the agricultural research system* with a strong alignment and commitment to the overall goal of the Comprehensive African Agricultural Development Programme (CAADP) of the New Partnership for Africa's Development (NEPAD).

Contents

Acronyms

CAADP	Comprehensive African Agricultural Development Programme
CEC	Cation Exchange Capacity
C/N	Carbon/Nitrogen ratio
CORAF/WECARD	Conseil Ouest et centre Africain pour la Recherche et le Development Agricoles/West and Central African Council for Agricultural Research and Development
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ECOWAS	Economic Community of West African States
FAO	Food and Agricultural organization
GEF	Global Environmental Facility
IFPRI	International Food Policy Research Institute
ISFM	Integrated Soil Fertility Management
LADA	Land Degradation Assessment in Drylands
GLASOD	Global Assessment of the Status of Human Induced Soil Degradation
IFDC	International Fertilizer Development Centre
ISRIC	World Soil Information
IPCC	Intergovernmental Panel on Climate Change
IUSS	Internal Union of Soil Sciences
NARS	National Agricultural Research System
NEPAD	New Partnership for Africa's Development
NPIC	National Photographic Interpretation Centre
PR	Phosphate Rock
RARC	Rokupr Agricultural Research Centre
SSA	Sub-Saharan Africa
UNESCO	United Nations Educational, Science and Cultural Organization
UNEP	United Nations Environmental Programme
USDA	United States Department of Agriculture
WCA	West and Central Africa
WRB	World Reference Base for Soil Resources
WISE	World Inventory of Soil Emissions

SUMMARY

The World Reference Base for Soil Resources (WRB) has 32 soil groups, about 14 of which occur in West and Central Africa. Good knowledge of the soils of the West and Central Africa region - including their physical, chemical and biological characteristics, state of degradation, geographic distribution, and available management technologies is required for their sustainable use. Determining baseline information about the natural environment of CORAF/WECARD member countries is critical to inform and improve farming practices and to enable production alternatives to be compared. The general objective of this review is to provide an up-to-date account of the state of soils in West and Central Africa. In addition a review of soil management techniques and options are explored with implementation examples from across the region, particular emphasis is given to the semi-arid and sub-humid regions.

A range of improved soil management technologies/approaches and best-bets (with very good chances of adoption and impact on livelihoods) are available for soils of West and Central Africa and are explored in this review. Some of the technologies are adaptations or improvements of indigenous systems. The available technologies are aimed, to differing extents, at improving/maintaining soil health, with a view towards increasing agricultural productivity, alleviating poverty and improving food security while protecting the environment. Integrated Soil Fertility Management is now the most widely accepted approach for managing these soils. Examples of best-bets for agro-ecologies, landscapes and soil types are given. Adjustments of recommendations to suit local biophysical and socioeconomic circumstances, through adaptive research and engagement with farmers, will be required. Special management practices are outlined for problem Gleysols, Vertisols, Solonchalks, Solonetzs and Thionic Fluvents. Soil amendments should be used to correct P fixation in Nitosols and Ferralsols.

This review also explores broader land degradation issues specific to West and Central Africa. The causes of land degradation are biophysical, socioeconomic, and political and they are interrelated. The effects on land degradation of population growth, insecure land tenure, political instability and climate change are now being recognized. Policy scenarios concerning economic development and environmental protection predict significant degradation of croplands unless protection of the environment is integrated in policy formulation. Good progress is being made in the development of global and regional land degradation databases, but serious efforts are required for the updating of national soil resource inventories (which serve as inputs for the databases).

Databases such as the Harmonized World Soil Database are becoming available but there is insufficient reliable data on the extent, severity and trend of land/soil degradation in Africa for rigorous analysis of soil degradation, planning and remedial actions. However, there are some well known cases of soil degradation in a number of countries in West Africa, especially in the highly populated regions of the Sahelian and Savannah zones where continuous cultivation with inappropriate soil management practices have depleted the soils of nutrients. Examples are the Peanut Basin of Senegal, the Mossi Plateau of Burkina Faso and the millet growing areas of northern Nigeria around Kano and the Terre de Barre in the west coast of Benin and Togo.

Almost all countries in Africa are susceptible to desertification but the Sahelian countries at the southern fringe of the Sahara desert are particularly vulnerable, with pockets of very high risk areas. High intensities of soil erosion by wind and water take place mainly in the semi-arid and sub-humid areas. The soils of Central Africa are mainly ferralitic and relatively well structured with less susceptibility to water erosion, unless severely mismanaged for agriculture. Within the CORAF/WECARD zone, there is an increasing severity and extent of land degradation from the humid zones of the Congo and Zambesi basins (24% to 29% of land degraded) up to a high 78% to 86% of land degraded in the dry areas of the Niger and Lake Chad basins.

Cases of nutrient depletion (mining) of poor soils, as a form of soil degradation, have been estimated through nutrient balance studies. In some areas of the semi-arid, arid and Sudano-Sahelian areas, where the soils are very poor but intensively cultivated with low levels of fertilizers, nutrient losses are high and range from 60 to100kg/ha of $N + P_2O_5 + K_2O$ annually. Central African soils experience moderate losses of 30 to 60kg/ha $N + P_2O_5 + K_2O$ annually. Losses are highly variable in the Savannah and Forest zones of West Africa.

In going forward, it is vital to acknowledge that decisions about land use and management practices adopted by people on the land is essential to establish the nature and extent of degradation. The latter is, more often than not, influenced by socioeconomic and cultural factors as well. A number of research and development activities to encourage sustainable management of soils and better adoption of improved technologies need to be undertaken by the National Agricultural Research Systems (NARS) and integrated into research projects where appropriate. The CORAF/WECARD Natural Resources Management programme's scoping study validated by relevant stakeholders in the region has outlined the three research and development themes: i) Sustainable management of land and water and adaptation to climate change; ii) Sustainable intensification and diversification of agriculture and iii) Socioeconomics and policy research on natural resource management. These themes provide a guide for research and development initiatives of the NARS aimed at positively contributing towards the sustainable management of the soil resources of West and Central Africa.

INTRODUCTION

The CORAF/WECARD mandate region covers the West and Central Africa sub-region with a membership of National Agricultural Research Systems of 22 countries located in the Sahelian, Central Africa and West Africa coastal zones (Figure 1). The farming system in the Sahelian zone is largely agropastoral, in the Central Africa zone it is Agrosylvicultural, and in the West Africa Coastal zone it is Agrosylvopastoral. Indigenous systems of soil management predominate and are characterized by in-situ burning of vegetation, bush fallow rotations, crop rotations, intercropping, minimum tillage, little crop residue addition, and very little use of external inputs such as mineral fertilizers. Use of livestock manure in the Sahelian and Savannah zones is a major soil management practice.

The low level of use of improved technologies in these agroecological zones contributes to the low productivity and growth in the agricultural sector of West and Central African countries. The Economic Community of West African States (ECOWAS) has drawn attention to the fact that increase in production in West Africa has been due to increases in cultivated area (230%) rather than yields (42%), a fact which has serious consequences for the fragile ecosystem of the region (ECOWAS, 2008). It is widely acknowledged (Liniger et al., 2011), that there is a need for increasing productivity to keep pace with demand while avoiding deterioration in the natural resources. Thus one of the most important aspects of sustainable land/soil management is the merger of concerns for agriculture and the environment through the twin objectives of (a) increasing productivity, particularly of safe and healthy food and (b) maintaining long term productivity of ecosystem functions.

Good knowledge of the soils of the West and Central Africa region-including their physical, chemical and biological characteristics, state of degradation, geographic distribution, and available management technologies is required for their sustainable use and the design and testing of improved technologies, transfer of technology as well as for sub-regional policy formulation. Rhodes et al. (2010) in a CORAF/WECARD-sponsored scoping study of the natural resource endowments of West and Central Africa identified broad socioeconomic and biophysical constraints and opportunities for increasing agricultural productivity and protecting the environment. They reported that compared to the forest zone, the semi-arid and sub-humid zones were more at risk to land degradation.

The general objective of this review is to provide up-to-date knowledge of the state of soils in West and Central Africa and their management with particular emphasis on the semi-arid and sub-humid regions. It is expected that the outputs of the review will inform the design of appropriate research interventions by CORAF/WECARD and its partners with the aim of improving livelihoods in the sub-region.

The specific objectives were to:

- Identify major soil types and their properties across the region
- Illustrate the distribution of the major soil types
- Identify the nature, extent and causes of soil degradation in the region
- Outline soil management options
- Demarcate major soil management recommendation domains based on soil type

1.0 SOIL TYPES AND DISTRIBUTION

1.1 Agro-ecological distribution

The World Reference Base for Soil Resources (WRB) has 32 soil groups (FAO, 2006) some of which occur in West and Central Africa. Deckers (1993) and Bationo et al. (2006) outlined the typical distribution in terms of agroecology. In the semi-arid zone, Lixisols and Arenosols are dominant, followed by Vertisols. Lixisols form a belt in West Africa between the Arenosols and Acrisols. Arenosols extend from northern Senegal through Mauritania, central Mali, and southern Niger to Chad. Niger and Chad have large areas of arid tropical Vertisols, but Vertisols occur in several countries in the CORAF/WECARD Sahelian, West African coastal and Central African countries. Solonchaks and Solonetzs occur in patches in this zone, especially in connection with poorly managed irrigation projects.

The most common soils in the sub-humid zone are Ferralsols and Lixisols but Acrisols, Arenosols and Nitosols also occur. Acrisols are found in southern Guinea, most of Côte d'Ivoire, southern Ghana, Togo, Benin, Nigeria and central Cameroon. In the humid zone, Ferralsols and Acrisols are the most frequent while Arenosols, Nitosols and Lixisols are less so. Ferralsols occur widely in Sierra Leone and Liberia in West Africa and in the Democratic Republic of Congo, Central African Republic and Cameroon in Central Africa. Nitosols mainly occur in eastern Democratic Republic of Congo. Fluvisols and Gleysols occur in all agroecological zones.

1.2 Landscape distribution

In addition to agroecological zone, the distribution of soils is a function of landscape and other factors such as parent material. The sequence of the main landscape components of inland valleys in West Africa are crests, upper, middle and lower slopes, valley fringes, colluvial footslopes and, lastly, valley bottoms. Windmeijer and Andriesse (1993) described the distribution of the soil groups in an area of West Africa with a growing period of 90 days or more. For rain-fed agriculture, the length of the growing period is calculated as the period when soil temperature exceeds the minimum for crop growth and moisture is available within the soil rooting zone. The inventory area covered the following countries or parts of them: Senegal, Gambia, Guinea Bissau, Guinea, Mali, Sierra Leone, Liberia, Côte d'Ivoire, Burkina Faso, Ghana, Togo, Benin, Nigeria, and Cameroon. They reported that soils of the uplands (crests and slopes) are mainly Ferralsols, Acrisols and Lixisols. The latter are the major soils in the northern and central parts of the inventory area (southern Senegal, Gambia, parts of Guinea Bissau, southern Mali, Burkina Faso, northern, central and eastern Ghana, Togo, Benin, and western, central and northern Nigeria).

Other soils of the uplands are Nitosols in the coastal terraces and aggradational plains of western Gambia and south western Senegal, Arenosols, in the northern parts, and Vertisols in Togo, Benin, Mali, Burkina Faso, Nigeria and Cameroon. Less frequent are Cambisols and Leptosols on strongly eroded valley side slopes. Soils of the Colluvial Footslopes and Valley fringes are Cambisols, Leptosols, Gleysols, Lixisols and Arenosols. The major soils in the bottomlands are Gleysols and Fluvisols (Windmeijer and Andriesse, 1993).

1.3 Soil mapping

Soil maps show the extent and distribution of soil types in any given geographical area. The modern trend in mapping is the development of web-accessible interactive maps, which facilitate computer-based analysis of the underlying data and prediction of changes in soil properties. Small scale maps at global and continental levels and larger scale maps at national level are available for West and Central Africa. The scale of a soil map is a major determinant of the uses to which a map can be utilised (Table 1).

Table 1 Scales of soil surveys and implications

Kind of Survey or Map and Level of Intensity	Range of Scales	Typical Scale	Area Represented by 1cm^2 on Map	Mean Distance Between Field Observations at 1 per cm^2	Mapping Units	Examples of Purposes
Exploratory surveys and compilations	1:1,000,000 and smaller		100 km^2 and less		Taxonomic soil classes of high categories e.g. brown earths, luvisols, mollisols,, sol ferrugineux	Display, national atlases, teaching; background for survey preparation
Reconnaissance	1:500,000 to 1:120,000	1:250,000	6.25 km^2	2.5km	Land systems or other landform-soil units, combining great soil groups	Resource inventory at national or regional levels; national land use planning, tentative project location
Semi detailed	1:100,000 to 1:30,000	1:50,000	25.00 ha	500m	Associations, series; landform-soil units combining associations and series	Project feasibility studies; regional land use planning
Detailed	1:25,000 to 1:10,000	1:25,000 1:20,000 1:10,000	6.25 ha 5.00 ha 1.00 ha	250m 200m 100m	Series, phases, some associations and complexes	Agricultural advisory work, project planning, irrigation surveys, some management and periurban surveys
Intensive	Larger than 1:10,000	1:5000	0.25ha	50m	Series, phases of series, individual soil properties	Management, periurban and urban surveys, invariably special –purpose

Source: Dent and Young (1981)

With reference to Table 1, a range of maps is available which can be utilised by research and development workers. Figure 2 shows soil types of sub-saharan Africa. The Harmonized World Soil Database linked through G.I.S to the small scale 1:5,000,000 FAO-UNESCO world soil map (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012) is interactive and can be accessed at http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116.

There are digital soil maps of Africa produced by the Africa Soil Information Service (URL http://africasoils.net). D'Hoore's soil map of West Africa (D'Hoore, 1964) at a scale of 1:5,000,000 is one of the earliest among the few attempts to produce sub-regional maps for Africa. It is, however, based on a system of classification that has been superseded by the FAO-UNESCO system. Maps of individual African countries at 1:500,000 or a larger scale are available at the URL http://eusoils.jrc.ec.europa.eu/esdb_archive/EuDASM/Africa/indexes/map.htm, but in many cases they are rather old (Rhodes et al. 2010). They may consist of a number of sheets covering various geographic regions within a country and are therefore voluminous. Maps at scales larger than 1:500,000 are available within CORAF/WECARD member States especially for specific research/development projects.

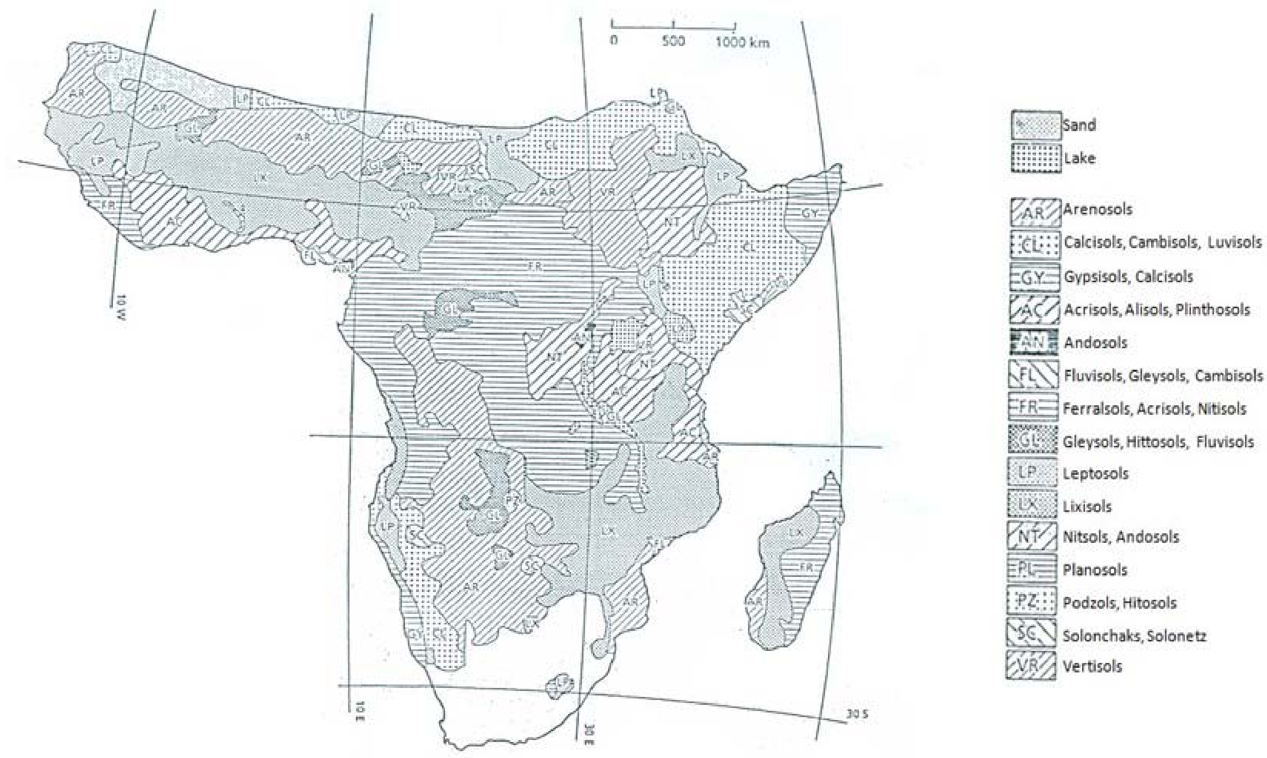

Figure 2 Soil map of sub-Saharan Africa

1.4 Soil groups and constraints on agricultural production

The classification, physical and chemical properties and limitations of the soil groups in the region have been described below (Driessen et al., 2001; FAO 2006):

1.4.1 Acrisols

Acrisols correlate with several subgroups of Alfisols and Ultisols of the USDA system of classification, and with *Sols ferralitiques fortement ou moyennement de'sature's* of the French system. These are acidic, highly weathered soils (but less weathered than the ferralsols) with accumulation of low activity clay in an argic subsurface horizon with low base saturation. They are found mainly on old land surfaces with hilly or undulating topography with wet monsoonal climate. Acrisols under a protective forest cover have a porous surface. If cleared, the topsoil degrades and slakes to form hard surface crusts that inhibit the infiltration of rain leading to soil erosion. Microstructure is weak, nutrient levels low and aluminium toxicity and phosphate retention are common.

1.4.2 Arenosols

Arenosols generally correlate with Psamments and Psammaquents of the USDA system; the *Classe des Sols mineraux bruts and Classe des Sols peu e'volue's* of the French classification system. They are sandy soils with available water (storage) capacity as low as 3 to 4%. Arenosols are permeable to water and infiltration of water varies between 2.5 to 25 cm/hr. Sealing and crusting in the Sahelian zone however result in reduced infiltration and high run off. They have relatively high bulk density usually between 1.5 to 1.7 kg/dm^3.They usually lack structure, are non sticky and non plastic when wet and loose when dry. A cemented or indurated layer may occur in the subsoil. Organic carbon content is normally less than 1% and effective cation exchange capacity less than 4 cmol/kg. In dry areas the soils are moderately leached and therefore have satisfactory levels of base saturation and pH. Macro and micro nutrient deficiencies are common.

1.4.3 Cambisols

Most of these soils are classified as Inceptisols in the USDA system and *Sols brun* in the French system. They are weakly developed soils with at least the beginnings of horizon differentiation in the subsoil evident from changes in structure, colour and clay content. Cambisols in the humid tropics are low in nutrient status but still higher Ferralsols and Acrisols. Cambisols in alluvial flood plains make for relatively good agricultural lands, but do not do the same on steep slopes.

1.4.4 Ferralsols

They are equivalent to the oxisols of the USDA system and *Sols ferralitiques* of the French system. These are the leached and deeply weathered red or yellow soils of the humid tropics. They occur typically in level to undulating land of Pleistocene age or older. They have stable microaggregates, good porosity, permeability and infiltration. The chemical fertility of these soils, whose clay fraction is dominated by low activity clays (kaolinte) and oxides of iron and aluminium, is poor for crop production. Soil pH is low, base saturation low and effective cation exchange capacity is only 3 to 4 cmol/kg. There is high retention by the soil colloids of applied phosphate leading to reduction in its immediate availability to crops.

1.4.5 Fluvisols

They are equivalent to Fluvents in the USDA Taxonomy and *Sols mine'raux bruts d'apport alluvial ou* colluvial or *Sols peu e'volue's non climatiques d'apport alluvial ou colluvial* in the French system of classification. They are relatively young soils. A special type of Fluvisol is the Thionic Fluvisol which is subject to the development of extreme soil acidity. Fluvisols are wet in all or part of the profile because of stagnating groundwater and/or flood water from rivers and tides. Terraces are better drained than the active flood plain (due primarily to the latter's low landscape position). Wet clays and silt soils that have lost little water since deposition are soft and 'unripe' and have low 'bearing capacity'/trafficability. Chemical fertility is relatively good but salinity in coastal areas can be a constraint on crop production. Thionic Fluvisols consist of potential acid sulphate soils and the latter have very low pH (less than 3.5) because of the oxidation of pyrite (FeS_2): $FeS_2 + 7/2\ O_2 + H_2O = Fe^{2+} + 2SO_4^{2-} + 2H^+$. Ferrous iron toxicity for rice also becomes a problem.

1.4.6 Gleysols

Gleysols correlate with the 'Aqu' suborders of Entisols, Inceptisols and Mollisols of the USDA system. They are found in depressions and low lying landscape positions with shallow groundwater. They are wetland soils that unless drained are saturated with groundwater long enough to develop a characteristic gleyic colour pattern, that is, reddish, brownish, or yellowish colours at ped surfaces and/or in the upper soil layers, in combination with grayish/bluish colours inside peds and/or deeper in the soil. Gleysols are saturated with water for prolonged periods, resulting in poor soil structure (especially when puddled). Soil textures are finer than in uplands but in some areas, erosion of coarse material, including boulders from uplands, lowers the quality of the lowland soils. Gleysols have low redox potentials and have large amounts of ferrous iron, relatively high organic matter content, base saturation and pH and available nutrients compared to adjacent upland areas. There is a narrow range of soil microflora and survival of soil fauna is poor compared to well-drained soils.

1.4.7 Leptosols

Leptosols correlate with Lithosols of the USDA system of classification. They are very shallow soils over rock as well as deeper soils that are very gravelly or stony. They generally occur on lands of medium to high altitude with strongly dissected topography where erosion has removed the top of the soil profile.

1.4.8 Lixisols

They correlate with the oxic subgroups of Alfisols of the USDA system and *Sols ferralitiques faiblement de'sature's appauvris* and *Sols ferrugineux tropicaux lessive's* of the French system. Lixisols are highly weathered soils with an argic subsurface horizon with low activity clay and moderate to high base saturation. They occur in areas with pronounced dry seasons on old erosional depositional surfaces. Most Lixisols are well drained. They have a strong structure but slaking and surface crusts are still problems. The level of available nutrients is low but their chemical fertility is higher than Ferralsols and Acrisols because of higher base saturation and pH and the absence of severe aluminium toxicity.

1.4.9 Nitosols

They correlate with kandic groups of Alfisols and Ultisols of the USDA system and *Sols fersialitiques or ferrisols* of the French system. Nitosols are deep, well drained, red tropical soils, highly weathered but more productive for agriculture than other red tropical soils. Their consistency is hard when dry, ranging from very friable to firm when moist and sticky and plastic when wet. Gravel and stones are rare but fine iron-manganese concretions may be present. Cation exchange capacity and phosphate retention capacity are relatively high.

1.4.10 Plinthosols

These soils were called “Groundwater laterites” (Jones and Wild,1975) and correlate with Plinthaquox of the USDA system and *Sols gris late'ritiques* of the French system. Plinthosols contain plinthite which is an iron-rich, humus-poor mixture of kaolinite clay with quartz and other constituents that change irreversibly to a hardpan or to irregular aggregates on exposure to repeated wetting and drying. They are formed in level to gently sloping areas with a fluctuating water table. The soils are described as petroplinthic when plinthite is exposed to the surface in the form of a continuous hard ironstone, for example, on erosion surfaces that are above the present drainage base. They are referred to as skeletic when there is a layer of hardened plinthite concretions, occurring mostly in colluvial or alluvial deposits. Soft plinthite is associated mainly with the rain forests and bottomlands while hard plinthite (petroplinthic or skeletic) is more common in the Savannahs. Most have low cation exchange capacity and base saturation and high iron and/or aluminium content.

1.4.11 Regosols

Regosols is a taxonomic group containing all soils that cannot fit into any of the Reference Soil Groups. They correlate with Entisols of the USDA System and *Sols peu e'volue's regosoliques d'e'rosion* or *Sols mine'raux bruts d'apport e'olien ou volcanique* of the French system. The great variation amongst Regosols makes it very difficult to give a generalized account of their properties and management. In the arid and semi-arid areas they may be of high base saturation but are prone to erosion, have low water holding capacity, as well as surface crusts which impede emergence of seedlings and infiltration of rain.

1.4.12 Solonchaks

Solonchaks have high concentrations of soluble salts at some time in the year. They are sometimes referred to as 'salt affected' soils. They are formed in arid and semi-arid regions, notably in seasonally or permanently waterlogged areas and in poorly managed irrigation projects. They also occur in coastal areas in all climatic zones. Solonchaks that dry out during part of the year are structurally strong; at the onset of rain they are deflocculated, especially if the salts contain sodium and or magnesium compounds. Electrical conductivity of saturation extracts (ECe) of Solonchaks is in excess of 15dS/m at 25^{o}C at some time of the year or more than 8dS/m if the soil pH (H_2O, 1:1) is greater than 8.5 (alkaline carbonate soils) or less than 3.5 (acid sulphate soils).

1.4.13 Solonetzs

They correlate with Natrustalfs, Natrustolls, Natrixeralfs, Natragids or Nadurargids of the USDA system and *Sols sodiques a' horizon B* and *Solonetz solodise'* of the French system. Solonetzs are soils with a dense, strongly structured clay illuviation horizon with a high proportion of adsorbed sodium and/or magnesium. They are commonly termed 'alkali' or 'sodic soils'. Solonetzs may occur predominantly in areas with dry season and annual precipitation of not more than 400 to 500 mm in flat lands with impeded vertical and lateral drainage. They can also occur when irrigated land is not properly drained. Most Solonetzs are very hard in the dry season and sticky when wet. Solonetzs that contain free sodium carbonate have pH greater than 8.5. Too much sodium is toxic to most plants and disturbs the uptake of essential elements. Excess sodium inhibits percolation of water and root growth.

1.4.14 Vertisols

Vertisols (also called Vertisols in the USDA Taxonomy) are dark coloured, churning heavy clay soils with a high proportion of swelling 2:1 lattice clays. They form deep, wide cracks from the surface downwards when dry. They have a very hard consistency when dry and are plastic and sticky when wet. They are friable only over a narrow range of moisture content and tillage is difficult except for a short period during the transition from the rainy to the dry season. Their physical properties are greatly influenced by soluble salts and/or adsorbed sodium. Infiltration of water in dry, cracked vertisols with surface mulch or fine tilth is initially rapid; however, once the surface soil is thoroughly wetted and the cracks closed the rate of water infiltration drops to almost zero. Most vertisols have high base saturation and cation exchange capacity and are weakly acid to weakly alkaline in reaction. Most vertisols of the Savannah of West Africa contain 0.5 to 2% organic carbon, and low to moderate levels of total nitrogen, available phosphorus and potassium (Jones and Wild, 1975). Annex 1 outlines key constraints for each soil group and the agroecologies in which the soil groups are most frequent.

1.5 Variation in soil properties with agroecology, topography and country

Annexes 2 and 3 show quantitative properties relevant to soil management and the constraints on increased agricultural production in terms of topographical and agroecological units (Windmeijer and Andriesse, 1993) and for the CORAF/WECARD zones and countries (FAO, 2011).

Soil organic carbon is lower in the drier agroecological zones as compared to the wetter ones. On the other hand, soil pH and base saturation are higher in the drier areas where leaching of bases is less. The FAO data was based on small scale maps and inventories and does not distinguish between arable or non-arable lands, that is, the data presented is for aggregated land areas. It was thus intended to be used as a preliminary assessment of potential development strategies or potential for soil management technology transfer.

The data shows the following: percentage of land area with low CEC is least in the West Africa Coastal zone. The reason for this is not evident; this zone contains a range of agroecologies from humid forests to savannahs, underscoring the need for more location-specific data on CEC. The percentage of country land area with soils of toxic aluminium levels (exchange complex dominated by aluminium) decreases in the following order: Central Africa zone > West Africa Coastal zone > Sahelian zone, which correlates with the relatively higher pH and base saturation of soils of the Sahelian zone. Aluminium toxicity is reported for only two out of seven countries in the Sahelian zone. The proportion of country land area with soils of high P fixation is highest in Central Africa, where Ferralsols and Nitosols are common. Percentage of saline soils decreases in the order Sahelian > West Africa Coastal > Central Africa; among the Central African countries salinity is reported only for Gabon. Sodicity is fairly common outside Central Africa with sodic soils in 8 out of 16 countries in two zones. Compared to the other countries, Burkina Faso and Chad in the Sahelian zone and Nigeria in the West Africa Coastal zone have the highest proportion of their land area under sodic soils.

1.6 Soil databases

Detailed information on the soil resources of Sub-Saharan Africa is stored in databases and contributes to scientific knowledge for planning sustainable agricultural expansion and policy formulation on land use. The Harmonized World Soil Database has three blocks of data: general information on soil mapping unit composition, phases and physical and chemical characteristics on the 0 to 30 cm and 30 to 100 cm depths. It is composed of international data sets held by the National Conservation Service of the USA, FAO and ISRIC and complemented by regional and national data bases where available. Special computer programmes are required to fully exploit the databases containing 1799 profiles from Africa. Twenty eight soil groupings are used to display the main soil types using the HWSD Viewer. The most recent updates can be found on the HWSD website: http://www.iiasa.ac.at/Research/LUC/External-world-soil-database/HTML. Since its inception in 1966, ISRIC has prepared a number of national, continental and global soil profile databases and specialized geo-referenced soil and terrain databases. They are: ISRIC Soil Information System/World Soil Information (ISIS); World Inventory of Soil Emission (WISE); and SOTER-World Soils and Terrain Digital Databases (FAO, 2011).

The Soil and Terrain Database (SOTER) programme implemented by ISRIC, FAO and UNEP under the aegis of the International Union of Soil Sciences (IUSS) in collaboration with national institutions is aimed at developing a global SOTER on a scale of 1:5,000,000, containing digitized map units and their attributes in standardized formats. SOTER is a hierarchical system in which the higher level of classification is based on morphometric land form criteria and altitude levels. The units are subdivided on the basis of form, topography and dimensions. The lower level is open-ended and provides the structure for further subdivision on the basis of geology and soils (FAO, 1995). SOTER has compiled a soil and terrain database for Central Africa (SOTERCAF) as part of the ongoing activity to update the world's baseline information on natural resources. It includes a database for the Democratic Republic of Congo on a scale of 1:2,000,000 with a total of 144 SOTER units. SOTER also has data for Senegal and the Gambia. The SOTER-GIS files are presented in Arcinfo@ format as coverage and export files with geographic coordinates in decimal degrees and with WGS84. SOTER attribute data is stored in a relational database system in MS Access@ format (see http//www.fao/org/nr/land/pubs/digital-media-series/en). Metadata of ISRIC datasets may be accessed through ISRIC GEONETWORKS as well as the WDC Portal at GCMD-NASA (available at www.isric.org). FAO publishes on its website TERRASTAT a compilation of information on land and soil properties estimated from small scale maps. The database has, however, not been updated. Data obtained from the site is shown in Annex 3.

There is an urgent need to implement a comprehensive programme of surveys and to evaluate soils systematically, at national and sub national levels. It is only on the basis of national data that valid, sub-regional, regional and international comparisons can be made (FAO, 2000). Concerning sub-national levels, it should be kept in mind that variability in nutrient stocks at individual plot, farm and village levels can differ considerably; the variability can be due to differences in soil texture, land use history and microclimate. Farmers exploit this variability in the pursuit of food security objectives by matching cropping systems to soil properties and in the allocation of resources (Prudentio,1993; Rhodes et al., 1996; Schlecht et al., 2006).

2. LAND/SOIL DEGRADATION

In discussing the issue of land/soil degradation in this section, reference will be made to the situation in West and Central Africa but where there is lack of data at the sub-regional level, information will be taken from broad estimates made at the SSA continental level. There are numerous terms and definitions concerning the degradation of the environment that are a source of confusion. Some overlapping terms used are soil degradation, land degradation and desertification. The word 'land' refers to an ecosystem comprising land, landscape, terrain, vegetation, and water. Soil degradation is therefore part and parcel of land degradation. Desertification should be used to refer to land degradation in arid, semi-arid and dry sub-humid areas due to anthropic activities and climatic variations (UNEP, 1993; Darkoh, 1995; Reich et al., 2001).

The agricultural environment in most of West and Central Africa is harsh. The land surface is generally very old (Precambrian, over 600 million years), consist of sand and alluvial deposits (Pleistocene, less than 2 million years), and many of the materials of present day soils have undergone more than one cycle of pedogenesis. Basic primary rocks are rare. Physical and chemical soil properties are therefore inherently poor. Climate change and poor management aggravates the situation. Soil degradation, a part of land degradation, remains an important global issue because of its adverse impact on agricultural productivity, the environment and its effect on food security and the quality of life.

2.1 Nature of land/soil degradation

Land degradation is the loss of production capacity of land in terms of loss of soil fertility, soil biodiversity and degradation of natural resources (FAO, 2002). It can be considered in terms of the loss of actual or potential productivity or utility as a result of natural or anthropogenic factors; it is the decline in land/soil quality[6] or reduction in its productivity. In the context of productivity, land degradation results from a mismatch between land quality and land use (Beinroth et al., 1994). Mechanisms that initiate land degradation are physical, chemical and biological processes (Lal, 1994; Eswaran et al., 2001). Important among the **physical processes** involved are a decline in soil structure leading to crusting, compaction, erosion, and reduced infiltration.

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[6] Soil quality or health is defined (Eswaran et al. 1997; Brady and Weil, 1999) as the ability of the soil to perform its functions in a sustainable manner. The functions of soil are to serve as (1) medium to promote the growth of plants and animals including humans, while regulating the flow of water in the environment (2) an environmental buffer that assimilates and degrades environmentally hazardous compounds and (3) as a factor in enhancing the health of plants and animals including humans.

Significant **chemical processes** include soil acidification, leaching, salinization, decrease in cation exchange capacity, nutrient depletion, pollution from industrial wastes and excessive or inappropriate use of pesticides and fertilizers. **Biological processes** include reduction in total and biomass carbon, decline in soil organic matter and decline in land biodiversity. The latter integrates important concerns related to eutrophication of surface water, contamination of groundwater and emission of green house gases from terrestrial/aquatic ecosystems to the atmosphere. The main contributing processes to soil fertility decline are:

- Decline in organic matter and soil biological activity
- Degradation of soil structure and other physical properties
- Reduction in availability of major nutrients and micronutrients
- Increase in toxicity of aluminium due to acidification and of ferrous iron due to soil reduction
- Soil erosion

2.2 Extent and rate of land/soil degradation

There are difficulties in the quantitative estimation of the extent, severity and trend of land degradation in Africa. Apart from insufficient data (Thiombiano and Tourino-Soto, 2007), the available data is confounded by the different processes of land degradation. Some landscape units are affected by more than one process and there is a probability of double counting. Also, a wide range of methods are used for assessment of land degradation (Lal et al., 1997; Vlek et al., 2008) and data generated by different methods may not be comparable.

Vlek et al. (2008) reported consistent and significant land degradation over the last twenty years of the past century that amounted to 10% of the Sub-Saharan land area as observed from space by tracking the greenness of the vegetation signal. It is widely accepted that high intensities of soil erosion by wind and water take place mainly in the semi-arid and sub-humid areas of SSA. Soils of Central Africa are mainly ferralitic and are well structured with less susceptibility to water erosion, unless very poorly managed for agriculture. Thiombiano and Tourino-Soto (2007) used the FAO map of problem soils (Nachtergaele, 1997), human impact, livestock impact and forest cover to estimate land degradation in various agroecologies of Africa. They showed that there was an increasing extent of land degradation from the humid zones of the Congo and Zambesi basins (24% to 29% of land degraded) up to a high 78% to 86% of land degraded in dry areas of the Niger and Lake Chad basins. Figure 3 shows the state of land degradation in the world, including Africa. However, some overexploited soils in the forest zone were also highly degraded. They suggested that soil loss by erosion accounted for the pattern, on the basis of results of several field studies, which showed that soil loss was ten times higher in the semi-arid zone as compared to humid zone.

There are some well known cases and research-based evidence of soil degradation in a number of countries in West Africa. This is especially the case in the highly populated regions of the Sahelian and Savannah zones where continuous cultivation with inappropriate soil management practices such as low use of mineral fertilizers and organic materials have exhausted the soils of nutrients. Examples are the Peanut Basin of Senegal, (Charreau,1972; cited by Pieri,1983 and Crasswell et al., 2004); the Mossi Plateau of Burkina Faso, on the millet growing areas (Broekhuyse,1983) from which many farmers had to migrate to the sub-humid regions of the coastal areas of Benin, Ghana, and Côte d'Ivoire (where the soils were better), northern Nigeria around Kano (Smith,1994) and the Terre de Barre on the west coast of Benin and Togo (Thiombiano and Tourino-Sato, 2007).

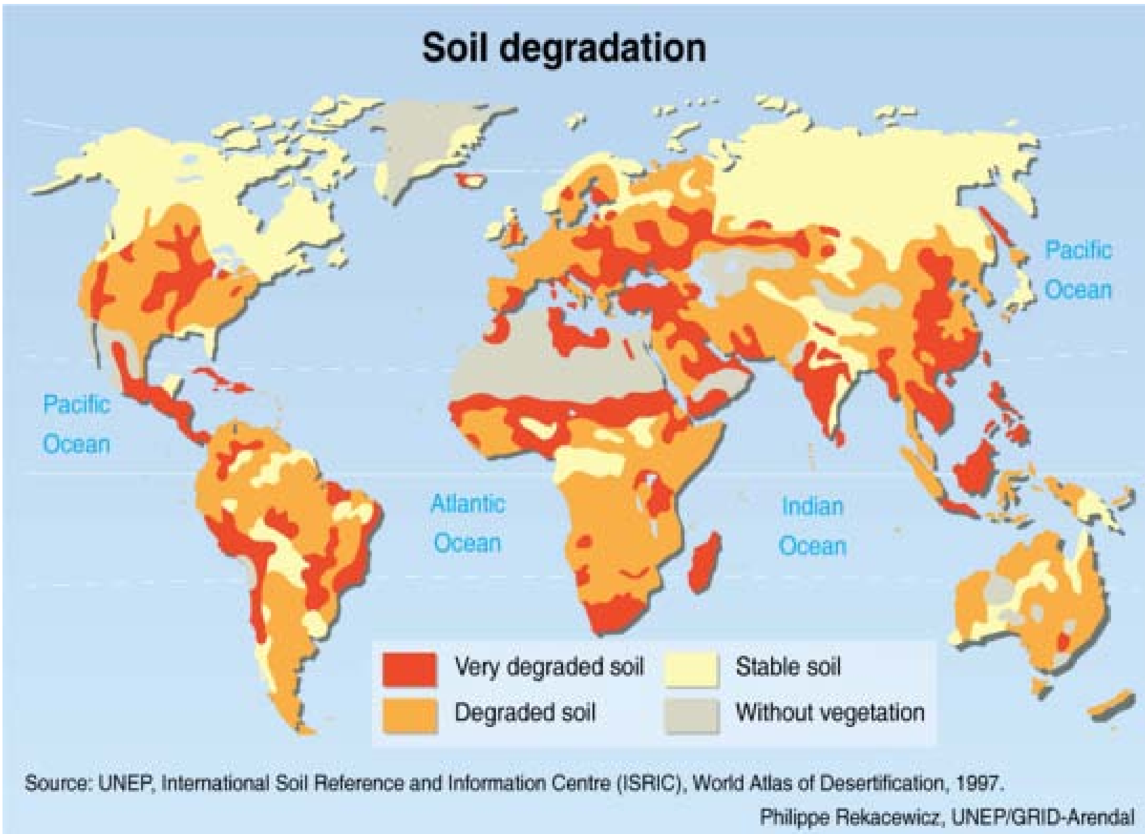

Figure 3. State of land degradation in the world, including Africa

At Sefa, Senegal, in the Savannah zone and Samaru, Nigeria (also in the Savannah zone) there was a decline of 25% to 40% respectively (compared to that under natural vegetation) of soil organic matter after 15 to 20 years of continuous cropping. At Sefa but not at Samaru, organic matter levels appeared to have stabilized. The annual removal of crop residues at Samura probably accounted for the continued decline (Jones and Wild, 1975). Brams (1971) for alluvial soils (Fluvisols) and upland soils (Ferralsols) at Njala in the forest regrowth agroecology of Sierra Leone reported that, following mechanical land clearing with bulldozers, five years of continuous cropping, even with fertilizer use and return of crop residues reduced organic matter content by 50% as compared to the initial levels under bush/shrubs. The rate of loss was sharply reduced after three years and appeared to have started levelling out by the fifth year. In general, activities and processes responsible for loss of soil organic matter during continuous cropping of the fragile soils included the removal of topsoil by bulldozers during land clearing, soil loss by erosion, removal of crop residues, low use of mineral fertilizers and organic materials and mineralization of soil organic matter.

Soil nutrient depletion (soil mining) in arable lands as a form of soil degradation has been estimated through nutrient balance studies. The estimated additions of nutrients are mineral fertilizers, animal manures, deposition from rain and dust, biological nitrogen fixation and sedimentation. The estimated losses are nutrients in harvested products, crop residue removal, leachates, gaseous emission, and soil erosion. Stoorvogel and Smaling (1990) estimated nutrient losses for the period 1982 to 1984 for 35 crops in 38 Sub-Saharan countries. According to their findings, many countries had losses above 24 kg nutrients/ha (10 kg N + 4 kg P_2O_5 + 10 kg K_2O) annually for arable lands (Table 2), and the predicted loss was 48 kg nutrients/ha per year in 2000.

Table 2 Classes of nutrient loss

Class	N (kg/ha/yr)	P_2O_5 (kg/ha/yr)	K_2O (kg/ha/yr)
Low	<10	<4	<10
Moderate	10-20	4-7	10-20
High	21-40	8-15	21-40

Source: Stoorvogel and Smaling (1990)

Figure 4 shows estimates of soil nutrient loss in Africa, including the CORAF/WECARD countries: Chad, Guinea, Mali, Mauritania, Central African Republic and Congo Brazzaville were classified as having a low nutrient loss rate. Benin, Burkina Faso, Cameroon, Gabon, Gambia, Liberia, Niger, Senegal, Sierra Leone and Togo had moderate rates and Côte d'Ivoire, Ghana and Nigeria had high rates. The fact that Nigeria is relatively densely populated and agriculture is relatively intensive in Côte d'Ivoire and Ghana may explain these findings.

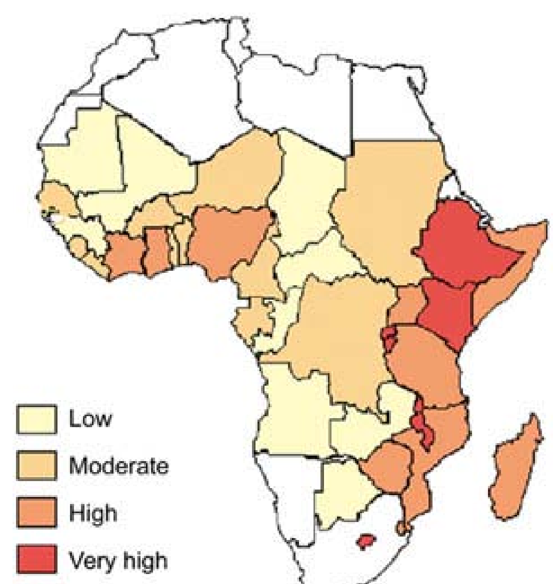

Figure 4 Nutrient depletion rate in sub-Saharan Africa, 1983.
http://www.fao.org/docrep/006/y5066e/y5066e06.htm

Van der Pol (1992) and Stoorvogel et al. (1993), showed that nutrient loss has been serious in densely populated areas in Mali, Nigeria, Ghana, Côte d'Ivoire and Chad where agriculture was intensive and less than 30% of the land per annum was allowed to revert to fallow. Schlecht et al. (2006) however believed that these estimates were pessimistic. Breman (1994) also reported that about 50% of the grazing lands in the Sahel, located on Arenosols with very low fertility, are affected by high nutrient loss rates.

More recent analysis (Craswell et al., 2004) also showed nutrient losses in areas of the semi-arid, arid and Sudano-Sahelian that were most densely populated, and the average nutrient loss ranged from 60 to 100kg/ha of N + P_2O_5 + K_2O annually. These high losses were probably due to the fact that highly weathered shallow soils of low water retention capacity were being subjected to intensive cultivation with little to no fertilizer use. They also reported that the loss was moderate in Central Africa (30 to 60 kg/ha N + P_2O_5 + K_2O annually). Losses were highly variable in the sub-humid Savannah and humid forest of West Africa.

The uncritical use of nutrient balance sheets has been criticized (Dreschel, 1999). The expression of the extent of land degradation on a country basis may hide hot-spots within countries or sub-regions that require urgent attention. Assessment of soil degradation on a watershed or community level, although more expensive would be more practical and useful. Rhodes et al. (1996) reported on how variability in soil nutrient stocks at the macro, meso and micro levels in West African farms has to be given due consideration in soil management practices.

2.2.1 Vulnerability of lands to desertification

Depending on their inherent characteristics and the climate, lands vary from highly resistant or stable to those that are vulnerable and extremely sensitive to degradation. Extreme sensitivity to degradation processes may refer to the whole land, a particular degradation process or a property. Stable lands do not necessarily resist change. They are in a stable, steady condition in relation to the new environment. Under stress, fragile lands degrade to a new steady state and the altered state may be unfavourable to plant growth and less capable of performing environmental regulatory functions (Eswaran et al., 2001; Reich et al., 2001).

Reich et al. (2001) estimated the vulnerability of lands in SSA to desertification on the basis of variability of rainfall, soil depth, soil resilience and soil classification. They reported that excluding deserts, which occupy 46% of the land mass, about 25% of the land in Africa is prone to water erosion and 22% to wind erosion. Practically every country of West and Central Africa is susceptible to desertification (Table 3) but the Sahelian countries on the southern fringe of the Sahara desert are particularly vulnerable, with pockets of very high risk areas for agriculture. For example, only about 19% of Niger is non-desert and of this, 17% belongs to the high and very high vulnerability classes. For Mali, the corresponding values are 33% and 22%, respectively.

Table 3. Assessment of lands vulnerable to desertification in Africa

Country		Vulnerability(% of total)				Other Lands (% of total)	
	Total Area (1000km^2)	Low	Moderate	High	Very high	Dry	Humid
Benin	110	5.44	63.13	31.43			
Burkina Faso	273	11.62	37.82	45.34	4.64	0.59	
Cameroon	469	31.49	12.75	6.30	0.86		48.60
Cen.Afr.Rep.	622	61.42	23.31	10.03			5.24
Chad	1,251	3.25	7.42	24.20	7.24	57.89	
Congo, Rep.	341	18.40	7.39	0.58	0.09		73.54
Congo, Dem.Rep.	2,287	28.56	6.13	1.05			64.26
Côte d'Ivoire	318	16.44	63.27	0.03			20.25
Gabon	257	42.81	6.33	0.81	0.53		49.51
Gambia	10	1.07	11.18	82.92	4.83		
Ghana	230	7.47	48.78	15.15	1.04		27.57
Guinea	245	15.15	73.22	0.43			11.20
Guinea Bissau	28	15.39	83.72	0.24	0.65		
Liberia	96	0.78	2.78	1.30	1.81		93.33
Mali	1,220	1.36	9.55	17.73	4.22	67.15	
Niger	1,266	1.31		8.66	8.58	81.44	
Nigeria	910	6.53	56.24	28.59	3.23	0.39	5.02
Senegal	192	5.49	21.25	46.46	19.46	7.35	
Sierra Leone	71	64.98	15.98	1.44	1.10		16.50
Togo	54	17.69	60.79	21.30			0.22

Source: Adapted from Reich et al. (2001)

2.3 Causes of land/soil degradation

There are direct and indirect causes of land/soil degradation (FAO, 2001; UNEP, 2006). The direct causes are deforestation; overgrazing and overcutting; shifting cultivation; mismanagement of soil and water resources including use of marginal lands, poor or no soil and water conservation and improper crop rotation; improper use of fertilizers, mismanagement of irrigation schemes and over-pumping of groundwater. The indirect causes are socioeconomic and political: poor farmers' ill health which does not allow them to put as much effort as they would like into managing their lands; insecure land tenure; little or no land-use planning; poor markets; poor institutional support; poverty; political instability and wars.

A vicious cycle is in effect (Figure 5); poor subsistence farmers who are short of land and cannot afford inputs over-exploit what lands they have and degrade them in the process, leading to low productivity and more poverty. Poor soil management practices contribute to soil erosion, reduced carbon sequestration, emission of green house gases and loss of biodiversity (Figure 6).

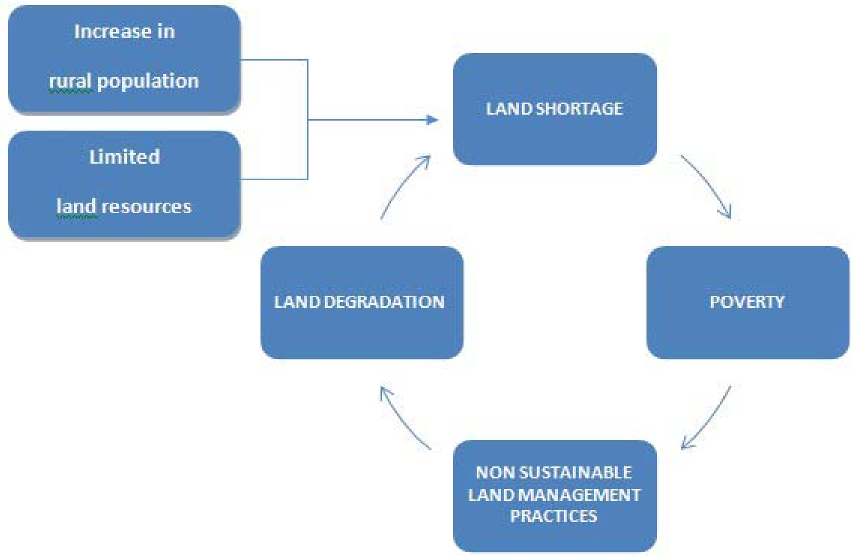

Fig 5 Causal nexus among land resources, population, poverty and land degradation
Source: FAO (2001)

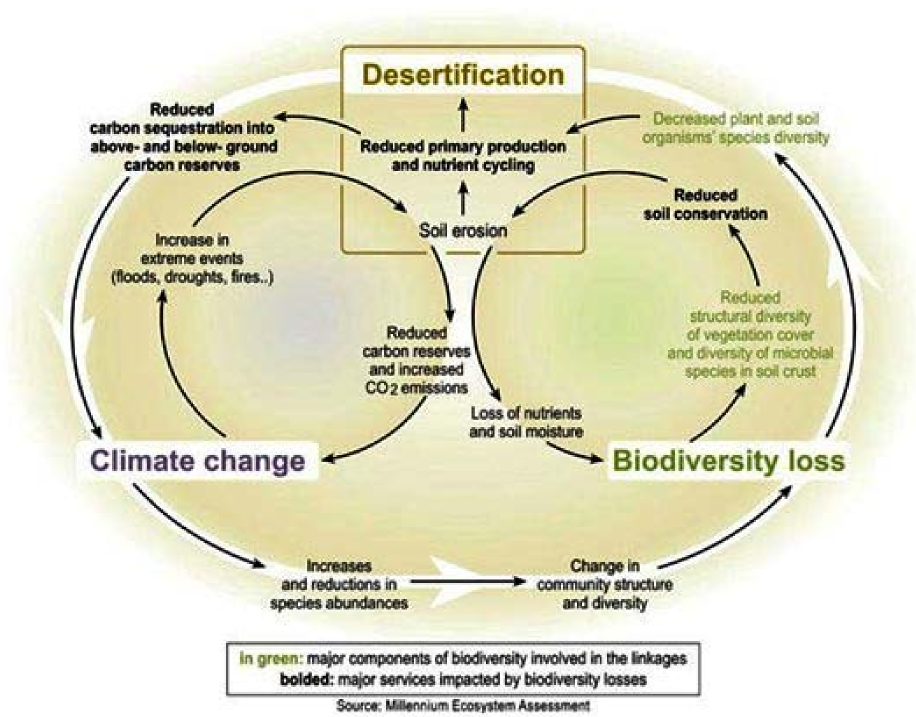

Figure 6 Linkages between climate change, desertification and biodiversity loss

Furthermore, some of the causes of land and soil degradation have been highlighted by the FAO (2001) and UNEP (2006) and are outlined in the following section:

2.3.1 Deforestation

Trees may be completely cut down for timber or cut back as part of shifting cultivation (bush fallow rotation).When sufficient land is not available for cultivation, the cropping period is extended at the expense of the bush fallow rest period. Trees are gradually destroyed as the period under fallow reduces and when land is abandoned regeneration of the natural vegetation takes place over a much longer period or not at all.

The regrowth of trees and shrubs after clearing for cultivation is much slower in semi-arid regions as compared to the humid regions. A larger area than that cultivated in the humid zone is usually a must in order to maintain subsistence for the family. Labour constraints subsequently make mechanical cultivation necessary. However, mechanical cultivation requires that most tree stumps be removed and so re-establishment of a vegetative cover of trees and shrubs is a slower process and the land degrades. The annual burning of vegetation in semi-arid and more humid areas in order to clear land for cropping severely reduces the return of organic matter to the soil and it becomes poorer in terms of physical, chemical and biological properties (structure, water retention, organic carbon, biodiversity, etc).

Shortage of land for agriculture forces people to seek more land in forest areas and they are more concerned with their survival than in ensuring that their farming methods are sustainable. Deforestation is both the cause and the symptom of the deteriorating productivity as the problem is cyclical: intensive land use - induced by the need to produce more - causes soil degradation and lower crop yields, which demand, in turn, that more land is cleared for cultivation.

2.3.2 Overgrazing

Livestock play a major role in the food production system in the semi-arid and sub-humid regions of West Africa and their numbers often increase as the human population increases. Grasslands, however, have a limited number of livestock they can support (carrying capacity), which is related to the amount of vegetation produced and the availability of water supplies. When livestock production increases in an uncontrolled manner, the pressure on grazing areas leads to a loss of edible vegetation and dominance of shrub species and further desertification. As the area of cultivated land increases the best soils are chosen for cropping and so the productivity of the remaining pastures declines. Around watering holes, the plant cover may be destroyed and soils compacted by trampling of animals, leading to increase in runoff water. However, manure dropped in these areas may enrich the soil locally.

In most sub-humid and semi-arid areas, much of the grazing land is burnt annually during the dry season to remove the old and coarse vegetation and encourage the growth of young and more nutritious grasses for livestock. Burning, however, causes the loss of carbon in vegetation as CO_2 and the loss of soil organic matter, resulting in degradation of the soil. In addition, burning exposes the soil to the erosive forces of the wind during the dry season and of the rain at the end of the dry season.

2.3.3 Land tenure

Traditional land rights in many countries in SSA derive from communal arrangements, however the ways in which these are enforced differ across countries. As pressure on the land increases, it becomes fragmented and overexploited. Application of the traditional land rights system becomes more difficult as pressures develop to ensure formal ownership of existing cultivated land. Communal wooded areas have also been degraded as the extraction of firewood for cooking and poles for building intensifies with increase in human population.

Grazing land is also regarded as communal property. As the size of the community grows, the number of livestock on the grazing land increases, which results, ultimately, in land degradation. Pressure from the government, local authorities and development organizations to reduce livestock numbers is usually resisted because of the social and economic value of livestock. Women in particular are vulnerable to the consequences of the increase in land pressure. Under normal circumstances they are marginalized with regards to access and ownership of agricultural lands even though their role in food production is indispensable.

Recommended changes in management practices to improve agricultural productivity involve inputs where the benefits may take several years to accrue. Land users who do not have security of tenure are therefore reluctant to make the required investments, even with government support. Solving the problems associated with communal ownership is difficult. A permanent land title encourages investment in land but it may lead to the emergence of land markets and inequalities in income distribution becoming acute; poor households are forced to sell land and then migrate and join the unemployed in the major cities, contributing to social and political instability. Land titling requires an accurate and detailed land survey and the maintenance of records of land sales and hence requires institutional capacity building and funding to implement.

2.3.4 Political instability

Armed conflicts in West and Central Africa are a serious threat to the sustainable management of natural resources (UNEP, 2006)**.** Liberia, Sierra Leone, Congo Republic, Democratic Republic of Congo, Chad and more recently Côte d'Ivoire have experienced civil wars lasting a number of years (sometimes over 10 years) leading to displacement of people from their original locations. Lands left behind by their owners normally do not receive the same level of protection from strangers who may be temporarily occupying such land,leaving at the end of the war. Such temporary occupiers of land are not usually keen to take the trouble required for proper utilization of the land, therefore causing land degradation through deforestation and inappropriate farming practices.

2.3.5 Population growth

Population growth results in an increased demand for food, water, and fuel and increased demands often translate into overexploitation of natural resources. This phenomenon is prevalent in situations of high levels of poverty which characterize West and Central Africa. Table 5 shows dramatic projected increases in the populations of West and Central Africa. The relationship between population density and land degradation is, however, not simple. Vlek et al. (2008) showed that within degraded areas in SSA, a large proportion of affected areas are thinly populated irrespective of rainfall, suggesting that they are marginal and have a limited carrying capacity. Degraded areas with high population densities were also identified, some of which have high agricultural potential where urgent attention is needed in order to contain degradation.

Table 4 Population projections (millions) for West and Central Africa

Sub-region	1980	1990	2000	2010	2020
Central Africa	54	74	98	127	164
West Africa	132	178	234	278	344

Source: UNEP (2006)

2.4 Projections of land degradation

2.41 Climate change

The sub-region is faced with bio-physical constraints such as droughts, soil acidity, nutrient depletion and degraded soils which impinge on agricultural development. The threats of climate change could prove to be most challenging to an already over-stretched sub-regional production system (CORAF/WECARD, 2007). Nicholson (2001) pointed out that the most significant climatic change that has occurred in Africa is a long term reduction in rainfall in the semi-arid regions of West Africa. She shows that while most of the African region has been affected by increased aridity, particularly since the 1980s, the change has been greatest over parts of the Sahel (20 to 40% between the periods 1931 – 1960 and 1968 – 1997). Climate projections for Africa presented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) include a likely average temperature increase of 1.5 to 4° C in this century, which is higher than the global average.

Climate change may result in reduced rainfall or extreme rainfall events and increased temperatures leading to reduction in vegetative cover and aggravated water and wind erosion. Climate change may adversely affect biodiversity and exacerbate desertification because of increased evapo-transpiration and likely decrease in rainfall in dry lands (Millennium Ecosystem Assessment, 2005). The major predicted impact of expected climate change is an increase in the frequency and severity of droughts (IPCC, 1995; Thornton et al., 2009; IPCC, 2007; Parry et al., 2007). This should lead to the episodic die-off of woody vegetation, which will increase the fire-fuel load. Because human populations in the semi-arid region depend mainly on pastoralism, human responses are likely to include increasing the distribution and security of surface water for livestock. This is likely to weaken the grass layer and increase soi1 crusting, with acceleration of desertification (Sivakumar and Valentin, 1997). While all people and ecosystems are vulnerable to climate variability and change, the impacts are location specific. They depend on the nature of climate change and variability, the speed of the change, sensitivity of the area and the adaptive capacity of its people and ecosystems (FAO, 2009b).

2.4.2 Scenarios for economic development and environmental protection

UNEP (2006) described four scenarios that may result from different policy choices at the regional and sub-regional levels regarding economic development and environmental protection. They are the Market Forces Scenario, the Policy Reform Scenario, the Fortress World Scenario and the Great Transition Scenario.

In the Market Forces Scenario the economy is increasingly privatized and governments gradually withdraw from their roles as principal actors in development. Market forces control the allocation of resources and the distribution of the benefits of growth. Government provides the enabling environment for economic growth while the private sector provides the impetus for the growth. The Policy Reform Scenario is rather similar to the Market Forces, but there is an acknowledgement of the need to address the negative consequences of market forces being in full control through actions by both government and civil society. In other words, policies and programmes are put in place to counter serious negative social and environmental impacts.

The Fortress Scenario posits that elites have access to resources for economic growth and monopolize them for their own good at the expense of the majority. The Fortress Scenario in Africa may result from (a) conflicts centred on religion and ethnicity or (b) collapse of world economic, social and political systems.

The Great Transition Scenario takes the view that neither the Market Forces nor Policy Reform Scenarios are adequate to address the damages caused by economic growth on the environment. It sees the need for the evolution of a new development paradigm in which sustainability of the environment is not compromised.

Figure 7 shows the projected degradation of croplands in West and Central Africa up to 2025 for the four policy scenarios (UNEP, 2006).The results of the scenarios are derived from analysis of driving forces such as demographics, health, economics, social issues, culture, technology, governance, peace and conflict. According to the model, degradation of croplands is likely to be most pronounced under Market Forces and Fortress scenarios, and least under the Great Transition scenario. It is important to realize that the predictions of this model have not been tested and the underlying theories and assumptions require scrutiny.

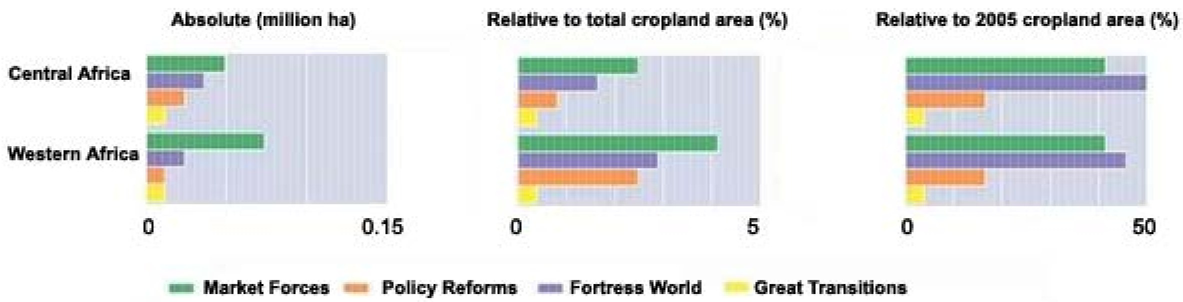

Figure 7. Projections to 2025 of degradation of croplands in West and Central Africa under different development theory scenarios. Source: UNEP (2006)

2.5 Information systems on land/soil degradation

To harmonize land degradation information, the Global Environmental Facility (GEF), funded the Land Degradation Assessment in Drylands (LADA) project implemented by UNEP and executed by the FAO. A major objective of the project is to assess and quantify the nature, extent, severity and impact of land degradation on ecosystems in drylands (Dijkshoorn et al., 2008; FAO/UNEP/GEF, 2010). Senegal is one of six countries participating in the project, the others being outside West and Central Africa. The project has developed standardized protocol for land degradation assessment from landscape to national scales. The LADA approach recognizes soil health as one of the Ecosystem Goods and Services affected by natural and human induced pressures.

The natural pressures of relevance to West and Central Africa with respect to soils are ferrallitization, salinization, sodification, steep slope, high rainfall intensity, low resistance to erosion, low land cover and low nutrient stock. The human induced pressures are increased mechanization, overstocking, poor land management, high use of chemical inputs and irrigation. The degradation processes are compaction, natural (problem soils) water erosion, nutrient mining, pollution, and salinization. The Africa Soil Information Service URL http://africasoils.net has a soils database and a mission of setting baselines for monitoring changes and providing options for soil and land management. An online low resolution Global Land Degradation Information System URL http://lprapp11.fao.org:8080/glad_res/ is under construction. In close collaboration with FAO, ISRIC has coordinated the development of a database on global soil degradation status-GLASOD (Global Assessment of the Status of Human Induced Soil Degradation). This will facilitate the exchange of information between stakeholders and policy formulation to mitigate land degradation at country, sub-regional and regional levels.

3.0 SOIL MANAGEMENT OPTIONS AND RECOMMENDATION DOMAINS

Soil management involves any kind of manipulation of soil properties, including cultivation done either in the interest of soil conservation or improved crop yields. A range of improved soil management technologies/approaches and best-bets are available for soils of West and Central Africa (Lal, 1983; Mokwunye et al., 1996; Bationo et al.,1996; Schlecht et al., 2006; FAO, 2006; MAHRH, 2008; MED, 2010). Best-bets are selected technologies that, according to 'expert opinion', have good chances of adoption and a positive impact on livelihoods. Some of them, for example green manuring and Zai pits, are adaptations or improvements on indigenous systems. However, adoption of these improved technologies by farmers is generally low. It is in this context that Schlecht et al. (2006) discussed the opportunities and limitations of models for ex-ante assessment of the suitability of new technologies at various scales that could lead to improved adoption rates by farmers. They proposed a conceptual framework for an agro-economic modelling approach for technology evaluation which takes into consideration the perspectives of farmers and researchers.

Liniger et al. (2011) recently compiled a number of best-bets, together with the biophysical/ socioeconomic circumstances at which they are targeted; these are focused on in this section of the review. They are aimed, to differing extents, at improving/maintaining soil chemical and physical fertility, arresting or minimizing degradation in terms of declining soil organic matter content, nutrient loss; toxicities, compaction, sealing and crusting; poor infiltration of rain, and loss of topsoil by erosion. Their primary goal is to increase agricultural productivity, alleviate poverty and improve food security while protecting the environment.

3.1 Integrated Soil Fertility Management (ISFM)

This approach involves combining different soil fertility technologies with soil and water conservation. It is based on the principles of maximizing use of organic materials, minimizing loss of nutrients and judicious use of mineral fertilizers. Soil and water conservation is treated under a separate heading in this section for the sake of emphasis. ISFM technologies include use of animal manure, crop residues, green manuring, composting, application of ground phosphate rocks, integration of nitrogen fixing crops into the cropping system, seed priming, tillage and water harvesting. There are two main groups of technologies regarding nutrient management: (i) those which **add** nutrients to farmlands, for example mineral fertilization and nitrogen fixing systems and (ii) those which **save** nutrients from being lost, for example crop residue restitution and soil erosion control (Rhodes et al., 1996; Bationo et al., 1996). Some best-bet component soil fertility technologies of ISFM are as follows:

3.1.1 Mineral fertilization

This is the practice of using inorganic materials that occur naturally (such as muriate of potash) or are synthesized, for example - urea to supply essential elements to crops. FAO (1989) reported positive responses to NPK fertilizers in several countries in Africa from trials and demonstrations conducted from 1961 to 1986. Yanngen et al. (1998) reported maximum value/cost ratio of 26, 18 and 4 for maize, sorghum and irrigated rice respectively in West Africa. On the basis of evidence of crop response to fertilizers, the Africa Fertilizer Summit of 2006 in Abuja, Nigeria (IFDC/NEPAD/OAU, 2007) resolved to promote an increase in the level of use of fertilizers to an average of at least 50kg of nutrients per hectare. The most commonly used fertilizers in West and Central Africa are straight and compound fertilizers that supply one or more of the major nutrients (N, P, K, Ca, and S). Use of micronutrient carriers is rare. Fertilizers can be recommended for any nutrient-deficient soil type in the Sahelian, Coastal and Central Africa zones. Losses from leaching and erosion tend to be greatest on sloping lands, coarse textured soils and soils with compact subsoils. Important soil degradation risks associated with the use of fertilizers in West and Central Africa are soil acidification and the accelerated depletion of nutrients not contained in the fertilizers.

The socioeconomic determinants of the successful use of mineral fertilizers are availability, affordability and markets for crop produce. Small amounts of fertilizers as micro-dosing in the field or as seed treatment are being promoted to encourage use by resource-poor farmers. Very old blanket fertilizer recommendations (not tuned to specific soil groups or fields) in many counties in West and Central Africa, and the absence of subsidized soil testing facilities for farmers also function as limitations to increased fertilizer use efficiency and adoption of mineral fertilizers by farmers.

1.1.2 Use of Phosphate Rock (PR)

Phosphate rocks (PR) occur in several countries in West and Central Africa, but some are reactive while others are not. McClellan and Northholt (1985) reported the presence of PR in all CORAF/WECARD member countries except Gambia, Guinea, Cape Verde, Côte d'Ivoire, and Sierra Leone in West Africa and Chad in Central Africa. The agronomic effectiveness of PR depends on its mineralogical and chemical composition and on soil and plant factors. Ground reactive phosphate rock corrects P deficiency, does not acidify the soil and has a strong residual value. Tahoua and PARC-W phosphate rock from Niger, Tilemsi from Mali, Kodjari from Burkina Faso and Hahotoe from Togo have been successfully tested in field trials (Sedogo et al., 1991, Bationo et al., 1992). The agronomic effectiveness of PR is improved by composting it with organic materials (Lompo, 1995; MAHRH, 2008), but Vanlauwe and Giller (2006) believe that the short term effectiveness of PR is not improved this way. PR is most useful for soils where P is the most limiting nutrient, in areas with relatively high rainfall and acid soils, for wet land rice?? and when mixed with organic materials. Constraints on its adoption include its dusty (powdery) nature, content of only one primary macronutrient and its slow reactivity. Some phosphate rocks have a high content of undesirable heavy metals.

3.1.3 Seed Priming and Microfertilization

Seed priming consists of soaking seeds of crops (rice, sorghum, cowpea, groundnut, sesame) in water for 8 to 18 hours (depending upon the crop) and drying the seeds prior to planting. It should be carried out after a shower sufficient for sowing when the rains have stabilized. It results in improved germination, establishment and rooting leading to better crop growth and yields (Harris, 2006; Liniger, 2011). Priming upland rice seeds with water can give yield increases of 15 to 25% and about 30% if priming is with zinc micronutrient solution (RARC, 2011).

Micro fertilization consists of applying very small amounts of compound fertilizers, for example 16:16:16 NPK or diammonium phosphate per planting station, equivalent to 3 to 8 kg fertilizer/ha. Yield increases of 34 to 52% for millet and 48 to 67% for sorghum by microfertilization have been reported in field trials in Mali (Aune et al., 2007). Tabo et al. (2006) reported that application of 4kg P/ha (one third of the recommended rate) increased yields of millet and sorghum in Burkina Faso, Mali, and Niger by 43% to 120%. On average, yield increases of up to 50% can be expected if microfertilization is combined with seed priming. Microfertilization has been mechanized in Mali. The technology is applicable across the Sahelian to the Forest zone for soils of low fertility and on flat to gentle slopes on small farms of 2 to 20 ha. Market orientation is mixed (subsistence and commercial). A major problem is that complete dependence on microfertilization will induce nutrient depletion and soil degradation.

3.1.4 Green Manuring

Green manuring is the growing of herbaceous plants for the express purpose of application to the soil surface or incorporation for the benefit of a food crop. Green manuring in West and Central Africa has taken several forms. The green manure plant may be sown into the food crop at varying intervals after the latter has emerged and incorporated before the planting of the next crop - a practice known as undersowing. Plant materials may be cut from outside the cropped plot and brought to the plot for application, as in the ‘cut and carry agroforestry system’. In lowland rice production, the water fern Azolla species (which grows in association with the N fixing *Anabaena azolla*) has been used by the Rice Research Station, Rokupr, in Sierra Leone for green manuring.

Liniger et al. (2011) proposed the production of green manure using *Tithona diversifolia* in Cameroon as a best-bet for soil fertility management. Hedges of this plant grow along roadsides or farm boundaries. Its biomass has a high nitrogen and phosphorus content and decomposes quickly after application. Fresh leaves and stems are cut, chopped and applied on cropland after the first ridging. The material is spread over the half-made ridge at the rate of 2 kg/m^2 and then covered with 5 to 10 cm of soil to finish the ridge. Sowing of seeds is done not sooner than a week later. Maize yield increases of at least 50% have been recorded. *Tithona* can also be applied as mulch six to eight weeks after planting. The technology is targeted mainly at the sub-humid to humid zone (1500 to 3000 mm rain), soils of medium fertility, slope of up to 30% and small size farms (1 to 5 hectares). Market orientation is mainly subsistence but caters to some amount of commercial production. A limitation of green manuring is that, except when the green manure is a leguminous crop and can fix nitrogen, it does not **add** nutrients to soils at the plot level. Rather it helps to **save** nutrients from being lost from the farming system. If the green manure crop is from a soil of poor fertility, its quality will be low and its contribution to soil fertility therefore also low.

3.1.5 Composting

Composting is the process of producing partially decomposed organic materials from materials high in carbon such as maize or rice straw mixed with small amounts of additives of higher nitrogen content such as excreta from farm animals, or mineral fertilizers. Composting narrows the C/N ratio of the materials and the nitrogen contained becomes more easily available to crops. FAO (2003) described a number of on-farm composting options. A method used successfully in Burkina Faso in conjunction with the Zai technique (Liniger et al., 2011) is as follows: pits 3 m x 1.5 m and 20 cm deep are dug in the dry season. After harvesting, layers of chopped crop residues, animal dung and ash are heaped as they become available up to 1.5 m high and watered. The pile is covered with straw and left to heat up and decompose. After 15 to 20 days the compost is turned over into a second pile and watered again. This is repeated up to three times or as long as water is available. Composts can also be produced in pits of up to 1 m depth; in this situation, the pit captures water.

The compost may be applied immediately to irrigated vegetable gardens or kept in dry shaded places for the next season's cereal, like sorghum. Concerning the latter, one handful of compost is mixed with soil in each planting hole (Zai); the compost conserves water and supplies nutrients to the crop but the immediate value of the compost is in its water holding capacity. Composting in general is applicable in the Sahelian, Coastal and Forest zone for smallholder farming on soils of poor fertility occurring in the region, provided water and labour are available. It is targeted at farm sizes of less than 1 to 2 ha. Market orientation is mainly subsistence but in urban and peri-urban areas composting is suitable for commercial vegetable production. Composting mainly **saves** certain nutrients from being lost from the farming system.

3.2 Conservation of water, soils and plant cover

These technologies fall into two major groups (mechanical and biological) and include ditch trenches, Zai, half moons, anti erosive earth dikes, stone bunds, minimum tillage, scarification, subsoiling, ploughing, mounding, and crop residue return. They have been described by several authors including Lal (1983), MAHRH (2008) and Liniger (2011). Constraints in conservation agriculture in smallholder agriculture are the competing use of crop residues, increased labour demand for weeding, lack of access to and use of external inputs (Giller et al., 2009).

3.2.1 Anti-erosive ditches

Ditches are constructed at the top of the slope and at the bottom perpendicular to the slope. The ditches are dug to channel run-off towards natural exits. The ditches also allow vegetation between the two trenches to benefit from a good provision of water.

3.2.2 Zai (Tassa)

The traditional method consists of digging tiny pits 10 cm in diameter and 5 m deep with hoes to break the surface crust during the dry season (Figure 8). The Harmattan wind transports sand and organic material into the pits. The improved technology involves digging bigger pits 20 to 50 cm in diameter and 10 to 25 cm deep to store more rainfall and runoff. Animal manure added after the first rains complement the work of the wind and make nutrients more easily available to crops (Reij et al., 1996).

Use of Zai has permitted doubling of millet yields in Niger. Mechanical digging of the pits to reduce the drudgery of manual digging is an improvement made in Burkina Faso. This is a technology used on the Arenosols of the Sahelian zone and on the ferruginous soils of the Savannah, particularly for the restoration of lands that are degraded. It is recommended by Liniger et al. (2011) as a best-bet water harvesting technique from work done in Niger, where it is sometimes used in combination with stone lines along the contour to further increase infiltration and reduce soil erosion and siltation of the pits. It is applicable to small scale farmers on 2 to 5 hectares, mostly subsistence, but also partly mixed (subsistence and commercial).

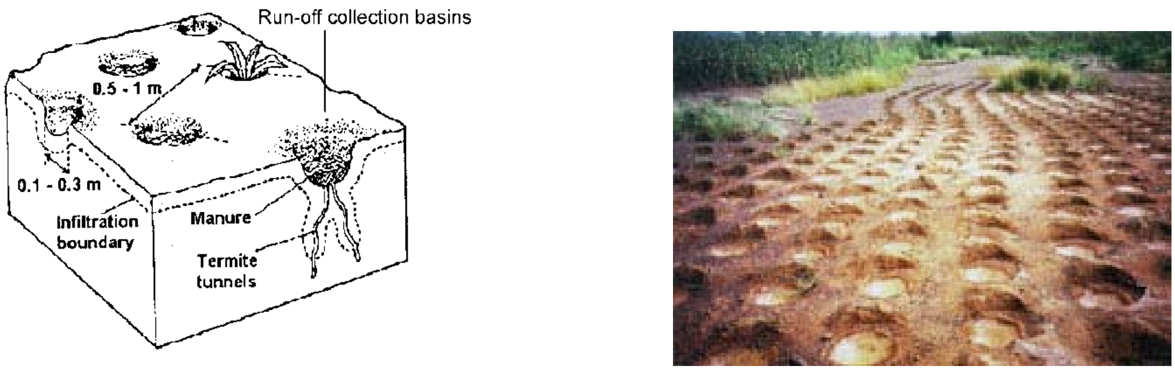

Figure 8 Zai in Niger
Source: FAO(1995; 1998)

3.2.3 Half moons

This is a technology (Figures 9 and 10) also applied on the Arenosols of the Sahelian zone and the ferruginous soils in the Savannah. It consists of semicircular structures (15 to 20 cm deep) with the remaining soil arranged as a contour bund on the curved side with a diameter of 3 to 4 m. The structure normally lasts 3 to 4 years but can last up to 10 years if improved through good preparation right from the start and reinforcement with stone bunds. It was applied originally on cultivated land but later adapted to the glacis (marginal lands or barren lands without vegetation and with lateritic soils). Its main benefit is that it maximizes water storage. The main problem with it is that its construction is tedious, especially on stony soils, and indeed more labour-intensive than the Zai. Waterlogging can occur on impermeable soils after frequent rains. It is applicable to the same situations as Zai.

Figure 9 Half moons in Niger
Source: FAO(1995)

Figure 10. Planted half moons
Source: FAO/R. Zougmore(2009)

3.2.4 Minimum tillage and direct seed planting

The essential elements of conservation agriculture are minimum soil disturbance, permanent soil cover, and crop rotation. In the promoted minimum tillage and direct planting system (Figure 11), land is prepared by slashing the original vegetation and allowing regrowth up to a height of 30 cm. A glyphosate-based herbicide is sprayed on the vegetation and the residue is left on the soil surface. Seven to ten days later, maize is planted with the aid of planting sticks or a jab planter, directly in rows through the mulch. The mulch increases stored water, reduces erosion, helps to control weeds and improves soil fertility in subsequent seasons after the residue has decomposed. The benefits of minimum tillage and mulching have been well documented for soils in south western Nigeria (Lal,1981) The technology described is promoted in Ghana, and is applicable to the sub-humid zone on well drained soils of medium to high fertility on smallholder farms of 1 to 5 hectares. It can be used for both subsistence and commercial systems.

Figure 11 Minimum tillage in Ghana

Source: Liniger et al./WOCAT/Souroudiaye Adjimon(2011)

3.2.5 Scarification/Subsoiling/Mounding/Ridging

Although minimum tillage is recommended as a soil conservation measure, there are special circumstances when it is necessary to mechanically disturb the top and/or subsoil in order to improve soil physical properties (MAHRH, 2008).This may involve:

(a) Scarification in a superficial way with prongs, either manually or with animal traction to improve the tilth of the top soil

(b) Tillage to break the crust and improve infiltration and reduce runoff

(c) Subsoiling with equipment to break up compacted subsoil and improve rooting

(d) Soil mounding and ridging.

The last technique is widely practiced in West and Central Africa for soil and water conservation, improvement of soil drainage and aeration and improvement of the soil rooting volume, especially in the cultivation of cereals and root and tuber crops. Subsoiling is applicable to degraded lands and soil mounding and ridging applies to non degraded and degraded lands in all agroecological zones. An important constraint is that farmers lack the specialized equipment required for subsoiling.

3.2.6 Cross slope barriers - Anti erosive bunds and Stone lines, Vegetative strips

Cross slope barriers (Figure 12) are measures for reducing runoff speed on sloping land thereby conserving soil and water. Anti erosive soil bunds on the ferruginous soils of Burkina Faso take the form of strips of soil measuring 80 cm to 1 m at the base and tapering upwards to 30 to 50 cm (MAHRH, 2008). The bunds retain water and facilitate infiltration. They are particularly useful in situations where construction of stone works is difficult (lack of stones, long distance from stone sites, transportation problems). Earth bunds are not suitable for very wet areas unless graded, as they can be washed away.

Figure 12. Contour bunds in Niger

Source: FAO(1995)

Stone lines (Figure 13) slow down the speed of runoff water, improve infiltration of water and permit the sedimentation of sand, finely textured materials and organic materials in the Soudano Sahelian zone (Hien et al., 1996). They are widely used in the Sahelian and Savannah zones of Mali, Burkina Faso and Niger. Yield increases of up to 20 to 30% have been reported in Burkina Faso.

Figure 13 Stone Lines in Niger
Source: Liniger et al.(2011)

Vegetative barriers: Seedlings of Aloe Vera, a drought tolerant plant well-known for its medicinal value, are sown along contour lines at 30 to 50 cm between plants spaced between rows of 6 to 10 m depending on the slope. The hedgerows (Figure 14) stabilize the soil by improving infiltration, soil structure and moisture content. On slopes steeper than 30% the hedgerows are often combined with stone walls, 40 to 50 cm wide and 80 to 90 cm high. Crops are planted between the hedges. It is applicable mainly on shallow loamy soils with medium fertility, medium drainage and good water holding capacity, slopes of 30-60%, smallholder farms (mainly subsistence), on leased, individual or family land. The technology is well known in Cape Verde and is applicable in the semi-arid and sub-humid zones. Vegetative strips are most effective in moist areas.

Figure 14 Vegetative barrier, Cape Verde
Source: Liniger et al./Jacques Tavares(2011)

In general, cross slope barriers are applicable on gentle to steep slopes in the semi-arid, sub-humid and humid zones. However, though they are used for control of erosion, water conservation and harvesting in the semi-arid zone, in the humid and sub-humid zones their main use is in the control of soil erosion. They are not suitable for very shallow and sandy soils. The cost of establishment in Burkina Faso, in decreasing order, is stone lines<earth bunds<vegetative barrier. They are applicable mainly to smallholder subsistence farming and areas where there is security of land tenure. Constraints on adoption include labour requirement, loss of land for production and availability of stones.

Crop Residues/Mulching: This involves utilization of vegetal material in the form of branches of shrubs/crop residues (such as stalks of maize, millet, sorghum) as mulch of about 2 cm thick equivalent to 3 to 6 t/ha, to cover the soil surface. On Lixisols of the semi-arid and sub-humid zones, they stimulate termite activity leading to breaking up of the soil crust. The result is an improvement in porosity and infiltration of water (Zombre et al., 1999; Mando et al., 1999; Mando and Stroosnijder, 1999).

Crop rotations: Crop rotations involving legumes are considered as a form of soil and water conservation (MAHRH, 2008) because of the following benefits (a) an improvement in soil structure and fertility; monocultures pose a risk of reducing soil fertility because the same layer of soil is exploited every year by the same crop (b) reduction in weed infestation (c) reduction in pest and disease infestation because the cycles of pest and diseases specific to a crop are broken by another crop. There are indications that crop rotations may facilitate the control of Striga, the parasitic weed. Biological soil and water conservation are applicable to all agroecologies.

3.3 Agroforestry

Agroforestry refers to land use systems and practices in which woody perennials are deliberately integrated with agricultural crops and/or livestock for a range of benefits and services. The integration can be spatial (crops with trees) or temporal (improved fallows, rotations). Agroforestry technologies include the traditional bush fallow rotation, improved fallows, farming with trees on contours, perimeter fencing with trees, shelter belts, multi-storey cropping, relay cropping, parkland systems, home gardens and fodder banks (Young, 1997; Huxley, 1999).

Agroforestry systems provide a favourable microclimate, permanent cover, improved soil organic matter content and biological activities, improved soil structure, increased infiltration of water, improved nutrient cycling and improved soil fertility. Agroforestry has the potential to improve land productivity and reverse land degradation. In general, agroforestry systems are applicable to the Sahelian, Coastal and Forest zone but some practices are more applicable to certain ecologies. For example, low rainfall areas require low tree densities and high rainfall areas higher densities. Multistorey systems are more suitable for the sub-humid to humid zone because of the higher water requirements. Competition for nutrients and water is most constraining in the Sahelian zone (Bremen and Kessler, 1995). Some best-bets are:

3.3.1 Shelter belts

Belts of leguminous trees (for example *Cassia siamea* or *Cassia spectabilis*, *Albizzia procera*, *Leucaena leucocephala)* or shrubs like *Cajanus cajan*, and *Erythrina variegate* are planted between fields of annual crops such as maize. The belts provide a favourable microclimate and protection against wind erosion, soil moisture loss and physical damage. The trees are usually planted perpendicular to the direction of the wind. Pruning of the crowns and roots may be required to avoid too much competition with crops and to provide fuel wood. The technology is promoted in Togo (Figure 15); it is applicable in the Sahel and sub-humid zones, on soils of medium to good drainage, sandy to loamy texture, medium soil organic matter content on slopes of 2 to 5%, small holder subsistence and commercial farming. The drawbacks include the areas lost for crop production and initial high labour requirements.

Figure 15. Shelter belts in Togo; Source: Liniger et al./Idrissou Bouraima(2011)

3.3.2 Farmer managed natural regeneration

Instead of slashing and burning trees, the sprouts of stumps of deep rooting species such as *Faiderbia albida*, *Piliostigma reticulatum*, and *Guiera senegalensis* are managed for greater soil efficiency. For the establishment of this system, 50 to 100 stumps/ha are selected for regrowth during the dry season. The tallest and straightest branches are selected and the side branches pruned to about half the height of the stem. Excess shoots are removed and the cut leaves left on the surface of the soil where they reduce erosion and are eaten by termites. Any unwanted new stems and side branches are pruned every 2 to 6 months and the prunings serve as firewood. Maintenance consists of cutting one stem per tree each year and letting another grow in its place. Once the stems chosen for growth are more than 2 metres high, they are pruned up to two thirds. The prunings serve as firewood.

The technology is promoted in Niger and it is applicable in the semi-arid zone on shallow soils of low fertility, on fairly level land under smallholder conditions. It is suitable for both subsistence and commercial production. Constraints on adoption include the scarce presence of tree stumps, therefore requiring the sowing of seeds of indigenous species to facilitate initial tree establishment.

3.3.3 Parklands.

Parklands (Figure 16) are the traditional systems where valuable trees are protected and cared for on croplands and grazing lands. The usual tree species are baobab (*Adansonia digitaria*), tamarind (*Tamarinda indica*), *Faidherbia albida*, shea nut or karite'(*Vitellaria paradoxa)* and ne're' (*Parkia biglobosa*).

A favourable microclimate is created below the trees and soil organic matter increases from the litter fall, prunings and root decomposition. *Faidherbia albida* sheds its leaves at the start of the rainy season, facilitating soil improvement. Pruning of branches may be done to improve light for crops and the felling of very large trees may be necessary from time to time. The technology is mainly applicable in the Sahelian zone on sandy loam regosols, fairly level terrain, smallholder farming (1 to 5 hectares), subsistence and commercial farming. Constraints are the scarcity of seedlings, inadequate soil moisture and the damage to seedlings by livestock.

Figure 16. *Faidherbia albida* in a Parkland in Burkina Faso;
Source: Liniger et al./William Critchley(2011)

3.4 Integrated crop-livestock management

Crop-livestock integration is an important practice in the CORAF/WECARD region. In this system, the waste products from one component serve as resources for the other. Manure from livestock improves soil fertility and thereby crop production while crop residues serve as feed for livestock. The system is mainly applicable in the semi-arid and sub-humid zones. Some best-bets include night corralling, rotational fertilization, and smallstock manure production.

3.4.1 Night corralling

Cattle, sheep and goats are corralled at night on the cropland during the dry season. Corrals are moved to a new spot within the field every 4-5 nights to ensure fairly uniform spread of manure over the field. A 250 kg cow can deposit about 1 kg of manure (dry matter basis) per night. To cover 1 ha with 2.5 t of manure 15 cows would therefore need to be corralled for 167 nights; seventy small ruminants for 178 nights would produce the same amount of manure. Night corralling is promoted in Niger; it is applicable in the Sahelian zone, on gentle slopes, sandy shallow soils of low fertility, land holdings of 10 to 13 hectares, subsistence and commercial production. Constraints are related to the high level of organization it demands, cash to invest in poles, high labour investment in the first year, and difficulty of revitalizing trust with transhumant pastoral groups.

3.4.2 Rotational fertilization.

Agropastoralists relocate with their livestock at 2 to 3 year intervals to degraded lands previously under crop cultivation where they put up temporary dwellings. Livestock are corralled or tethered in the rehabilitation area overnight and they feed on crop residues and emerging grasses. Dung dropped within the areas is spread over the fields. When the agropastoralists move elsewhere the treated areas are used for the cultivation of millet and legumes.

The success of the technology has led to field fertilization contracts between agropastoralists and sedentary farmers. The technology is promoted in Niger. It is applicable in the semi-arid zone on sandy soil of poor fertility, on land sizes of 1 to 2 hectares per household on both subsistence and commercial farms. Constraints on adoption include high investment costs in timber and poles for infrastructure and an initial high labour input. Cutting of woodlands for building materials degrades the natural vegetation.

3.4.3 Small stock manure production

A 1 to 2 m deep and 3 to 4 m diameter pit is excavated, shaping it into one to three circular terraces (0.5 m high, 0.5 m wide) which serve as a resting area for small ruminants. The pit is enclosed by a stone wall, a minimum of 0.5 m from the pit (Figure 17). The terrace risers are plastered or reinforced with stones; especially if the soil is loose to avoid damage caused by trampling animals. A roof is built to partly cover the pit and a bedding of straw is placed within. The structure serves as shelter for the animals to avoid uncontrolled grazing/browsing during the cropping season. Manure produced in the pit is removed and spread over the fields at the start of each cropping season. The technology is promoted in Togo and is applicable to the sub-humid zone on soils of good drainage, low soil organic matter, gentle slope (0 to 5%), small farms of 1 to 2 hectares and subsistence/commercial production. Constraints include high labour requirement for establishment, air pollution by the smelly manure, and danger to children if the pit is located in residential areas.

Figure 17. Small stock manure production in Togo

Source: Liniger et al./Idrisou Bouraima(2011)

3.4.4 Best-bets and soil types

Some reference has been made in various parts of Section 3 to the biophysical and socioeconomic circumstances to which the best-bets are targeted (recommendation domains). Annexes 4a to 4f link best-bets to the agroecologies, landscape positions and soil types on which they are applicable. However, adjustments (for example) in methods, time and rates of application to suit local biophysical and socioeconomic circumstances, through adaptive research and engagement with farmers, would be required. Integrated soil fertility management is appropriate for all soil types. Special management practices are outlined for Gleysols, Vertisols, Solonchalks, Solonetzs and Thionic Fluvents. Soil amendments should be used to correct P fixation in Nitosols and Ferralsols. Soils on lands highly susceptible to degradation, for example steep slopes, should not be cropped annually but should be left under natural vegetation or permanent tree crops, or terraced (if feasible).

4.0 WAY FORWARD

Information on the soil types of West and Central Africa, their distribution, characteristics and major limitations for agriculture are available in various databases, however access to and integration of data remain a challenge to practitioners in the region. It is certain that the soils are being degraded but information on the extent and rate of soil degradation is limited. The causes of degradation are known but not widely publicized to all stakeholders. Some of the information on soils and soil degradation is accessible from international databases kept by the FAO, ISRIC and their associates. Technologies developed to improve agricultural production are available but the rate of adoption by smallholder farmers is low. In going forward, it is vital to acknowledge that decisions about land use and management practices adopted by people on the land is essential to establish the nature and extent of degradation. The latter is, more often than not, influenced by socioeconomic and cultural factors as well.

A number of research and development activities to encourage sustainable management of soils and better adoption of improved technologies need to be undertaken by the NARS and integrated into research projects where appropriate. CORAF/WECARD has outlined three research and development themes that provide guidance to the NARS: These are:

1. Sustainable management of land and water and adaptation to climate change
2. Sustainable intensification and diversification of agriculture
3. Socioeconomics and policy research on natural resource management.

These three themes are elements of CORAF/WECARD's Natural Resources Management Programme and outline specific areas of research where further work is needed for the WCA region:

- Adaptive participatory trials to fine-tune the recommended options to biophysical (including soil types) and socioeconomic circumstances
- Field inventories at the country level on soil resources and database development
- Land tenure and access as related to soil degradation
- Climate change and soil degradation
- Dynamics of population density, soil fertility management, input and output markets
- Agroeconomic modelling of ex-ante evaluation of integrated soil fertility management technologies taking into consideration farmers' and researchers' perspectives
- Monitoring soil degradation and developing mitigation measures

Concerning development, action is required on:

- Outscaling and upscaling of proven soil management technological options to groups of soils and farmers with similar biophysical and socioeconomic circumstances
- Capacity building of NARS staff in the use of modern tools for assessing and mapping soil degradation and evaluating integrated soil fertility management options. Such tools would include Geographic Information Systems, Global Positioning Systems, and Decision Support Systems, access to and ability to input into databases to improve data quality and quantity.

In addition to these, national governments and the international donor community should provide strong support for soil management research and development and sensitization/education campaigns of stakeholders on the need for sustainably managing the soils and other natural resources of West and Central Africa.

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ANNEXES

Annex 1. Summary of key constraints for soil groups and agroecologies

Soil Group	Agroecology	Constraints
Acrisols	Sahel,Savannah,Forest	Weak microstructure, low nutrient status, acidity, Al toxicity, P fixation, low nutrient storage capacity, surface crusts
Arenosols	Sahel,Savannah	Low coherence, low nutrient storage capacity, very low available water holding capacity(AWHC), susceptibility to erosion
Ferralsols	Forest	
Fluvisols	Sahel,Savannah,Forest	Extreme acidity of thionic fluvisols, salinity in coastal areas, poor trafficability of unripe fluvisols, wetness
Gleysols	Sahel,Savanna,Forest	Waterlogging
Leptosols	Savannah	Shallowness and or stoniness, low water holding capacity, high vulnerability to erosion
Lixisols	Savannah	Low nutrient status, low nutrient storage capacity, surface crusts
Nitosols	Forest	High P fixation
Plinthosols	Savannah,Forest	Hard pans, stoniness, low nutrient storage capacity, high aluminium and iron content
Regosols	Sahel	Low nutrient storage capacity, susceptibility to erosion
Solonetzs	Sahel	Alkalinity, high sodium concentration, hard and sticky
Solonchalks	Sahel	Salt affected
Vertisols	Sahel,Savannah	Poor physical properties and hydrology, narrow moisture range for cultivation, susceptibility to water logging

Annex 2. Soil chemical characteristics of topographic sequences in West Africa

Physio-Graphy	Agroecol Zone	Rock Type	Depth (cm)	pH (1:2.5) H_2O	KCL	C (%)	N (%)	CEC (cmol/kg)	Base Sat. (%)	P (mg/kg) P-Bray 1	P-total
Uplands	Equatorial Forest Zone	Basic	0-20	5.9	3.6	2.04	0.160	9.58	36	n.d.	198
			20-50	5.6	3.7	0.76	0.074	6.37	26	n.d.	138
		Acid	0-20	5.3	4.3	2.45	0.160	8.81	21	12.07	628
			20-50	5.1	4.2	1.54	0.103	8.63	16	6.57	644
	Guinea Savannah Zone	Basic	0-20	6.4	5.5	1.42	0.114	11.14	78	n.d.	514
			20-50	6.0	5.1	0.64	0.058	9.87	59	n.d.	333
		Acid	0-20	5.7	5.1	1.17	0.139	6.25	60	2.38	392
			20-50	5.5	4.9	0.68	0.079	5.55	42	0.80	390
		Sedim	0-20	5.4	4.1	1.04	0.036	3.95	69	3.41	196
			20-50	5.2	3.9	0.61	0.031	4.28	51	1.85	106
	Sudan Savannah Zone	Basic	0-20	6.4	5.0	0.58	0.056	10.68	69	1.82	305
			20-50	6.4	5.0	0.47	0.052	12.16	69	0.70	330
		Acid	0-20	6.8	5.4	0.33	0.049	9.31	93	n.d.	287
			20-50	7.1	5.3	0.43	0.061	8.67	90	n.d.	285
		Sedim	0-20	6.2	5.1	0.68	0.051	7.34	66	n.d.	159
			20-50	5.9	4.4	0.42	0.034	5.10	33	n.d.	113
Foot-Slopes	Equatorial Forest Zone	Basic	0-20	6.2	3.9	1.71	0.077	13.04	48	n.d.	117
			20-50	7.5	3.9	0.26	0.021	10.99	46	n.d.	129
		Acid	0-20	5.3	4.2	1.62	0.162	7.25	21	7.82	279
			20-50	4.9	4.0	0.82	0.061	5.15	11	3.26	163
	Guinea Savannah Zone	Basic	0-20	6.4	5.7	1.55	0.123	16.62	65	n.d.	273
			20-50	6.4	5.5	0.79	0.072	15.59	54	n.d.	273
		Acid	0-20	5.9	5.3	0.65	0.087	4.50	67	22.60	402
			20-50	5.2	4.5	0.30	0.054	3.39	56	14.14	344
		Sedim	0-20	5.3	3.9	0.54	0.033	3.57	58	3.35	152
			20-50	5.4	4.0	0.37	0.027	5.03	52	2.07	216
	Sudan Savannah Zone	Basic	0-20	5.7	4.7	0.85	0.061	9.97	51	4.11	330
			20-50	6.2	5.1	0.34	0.035	5.06	56	1.67	280
		Acid	0-20	6.7	5.3	0.14	0.016	4.80	89	n.d	91
			20-50	68	5.0	0.14	0.051	5.82	91	n.d	65
		Sedim	0-20	6.2	5.0	0.64	0.049	8.39	73	n.d	136
			20-50	5.9	4.5	0.27	0.039	5.78	48	n.d	77
Valley Bottoms	Equatorial Forest Zone	Basic	0-20	6.5	3.8	1.93	0.042	4.04	59	n.d	148
			20-50	6.4	3.6	0.20	0.010	1.39	21	n.d	30
		Acid	0-20	5.1	4.3	2.54	0.209	9.62	27	8.19	198
			20-50	45	4.1	0.88	0.071	5.11	29	4.28	128
	Guinea Savannah Zone	Basic	0-20	6.4	5.5	2.04	0.156	18.28	70	n.d.	641
			20-50	6.4	5.5	0.81	0.069	16.27	68	n.d.	311
		Acid	0-20	5.6	4.6	1.13	0.209	8.09	61	7.20	263
			20-50	57	4.6	0.39	0.081	6.45	59	2.28	157
		Sedim	0-20	5.1	4.1	1.04	0.088	9.73	51	3.04	272
			20-50	5.1	4.1	0.63	0.051	7.15	31	4.30	137
	Sudan Savannah Zone	Basic	0-20	6.0	4.7	0.85	0.065	12.10	66	1.98	430
			20-50	6.0	4.6	0.33	0.051	8.89	72	0.92	230
		Acid	0-20	6.4	5.0	0.52	0.021	6.43	89	n.d.	105
			20-50	6.5	4.9	0.06	0.020	4.26	97	n.d.	42
		Sedim	0-20	5.7	4.6	0.94	0.072	9.04	61	n.d.	133
			20-50	5.5	41	0.52	0.041	6.92	50	n.d.	64

n.d. = not determined

Annex 3a. Soil constraints (Low Cation Exchange Capacity, Aluminium Toxicity)

CORAF/WECARD Zone/Country	Total area ('000km^2)	Low CEC ('000km^2)	Low CEC (%)	Al toxicity ('000km^2)	Al toxicity (%)
Sahelian					
Burkina Faso	276	20	7	3	1
Chad	1284	193	15	0	0
Gambia	12	0	0	0	0
Mali	1250	159	13	7	1
Mauritania	1054	92	9	0	0
Niger	1189	351	28	0	0
Senegal	197	53	28	0	0
Central Africa					
Cameroon	465	12	3	262	56
Cent. Afr. Rep	622	108	17	320	51
Gabon	268	31	12	122	47
Congo Rep.	344	99	29	148	43
Congo Dem.Rep.	2343	592	26	1363	60
West Africa Coastal					
Côte d'Ivoire	324	11	3	185	58
Benin	118	1	1	0	0
Ghana	240	9	4	59	26
Guinea	246	6	2	97	40
Guinea Bissau	34	1	4	2	9
Liberia	98	9	9	61	63
Nigeria	914	119	13	76	8
Sierra Leone	72	3	4	43	59
Togo	57	1	1	0	0

Source: FAO TERRASTAT Database accessed on 30/6/2011

Notes: 1. These are estimates by FAO made from study of small scale maps and inventories.

2.Data apply to the total areas of countries ,not their arable, or agricultural land only.

3. The level of constraints are based on the Fertility Capability Classification of Sanchez et al.(1982)

Annex 3b. Soil constraints (Vertic properties, High P fixation, Salinity)

CORAF/WECARD Zone/Country	High P fix (‘000km^2)	High P fix (%)	Vert. props (000km^2)	Vert. props (%)	Salinity (000km^2)	Salinity (%)
Sahelian						
Burkina Faso	0	0	27	10	13	5
Chad	0	0	83	7	35	3
Gambia	0	0	0	0	1	9
Mali	0	0	15	1	20	2
Mauritania	0	0	3	0	9	1
Niger	0	0	9	1	11	1
Senegal	0	0	4	2	7	3
Central Africa						
Cameroon	21	4	13	3	2	0
Cent. Afr. Rep.	24	4	2	0	1	0
Gabon	21	8	0	0	2	1
Congo,Rep.	17	5	0	0	0	0
Congo, Dem. Rep.	494	22	7	0	2	0
West Africa Coastal						
Côte d’Ivoire	9	3	1	0	0	0
Benin	0	0	3	2	0	0
Ghana	2	1	4	2	0	0
Guinea	7	3	1	0	3	1
Guinea Bissau	0	0	0	0	2	9
Liberia	12	12	0	0	3	3
Nigeria	0	0	17	2	20	2
Sierra Leone	1	2	0	0	3	4
Togo	0	0	2	3	1	1

Source: FAO TERRASTAT Database accessed on 30/6/2011

Notes: 1. These are estimates by FAO made a from study of small scale maps and inventories.

2. Data apply to the total areas of countries, ,not their arable, or agricultural land only.

3. The level of constraints are based on the Fertility Capability Classification of Sanchez et al.(1982).

Annex 3c. Soil constraints (sodicity, shallowness, erosion risk)

CORAF/WECARD Zone/Country	Sodicity (000 km^2)	Sodicity (%)	Shallow (000 km^2)	Shallow (%)	Erosion risk (000 km^2)	Erosion risk (%)
Sahelian						
Burkina Faso	13	5	66	24	55	20
Chad	75	6	200	16	105	8
Gambia	0	0	0	4	1	7
Mali	0	0	203	17	137	11
Mauritania	0	0	226	22	92	9
Niger	10	1	150	12	84	7
Senegal	1	1	36	19	19	10
Central Africa						
Cameroon	6	1	26	6	100	22
Cent. Afr. Rep.	0	0	46	7	122	20
Gabon	0	0	25	10	27	10
Congo, Rep.	0	0	2	1	23	7
Congo, Dem.Rep.	0	0	9	0	109	5
West Africa Coastal						
Côte d'Ivoire	0	0	19	6	85	27
Benin	1	1	9	8	24	22
Ghana	6	3	23	10	48	21
Guinea	0	0	80	32	71	29
Guinea Bissau	0	0	6	21	6	21
Liberia	0	0	8	8	17	18
Nigeria	36	4	129	14	241	26
Sierra Leone	0	0	13	18	9	12
Togo	1	1	9	16	13	24

Source: FAO TERRASTAT Database accessed on 30/6/2011

Notes: 1. These are estimates by FAO made from a study of small scale maps and inventories.

2. Data apply to the total areas of countries, not their arable, or agricultural land only.

3. The level of constraints are based on the Fertility Capability Classification of Sanchez et al.(1982).

Annex 4a. Soil management recommendations based on landscape positions for the Sahelian zone

Landscape Position	Technology
Crest, Slope and Foot slope Soils	**Integrated soil fertility management** (mineral fertilization, use of reactive phosphate rocks where available, composting, animal manures); **Conservation of water, soils and plant cover** (anti-erosive ditches, anti erosive bunds, stone lines, vegetative strips, zai, half moons, crop residue cover, crop rotations, minimum tillage); **Agroforestry** (shelter belts, farmer managed natural regeneration, parklands); **Integrated crop livestock management** (night corralling, rotational fertilization)
Valley fringes and Bottomland soils	Drainage/water control, mineral fertilization, use of reactive phosphate rocks where available

Annex 4b. Soil management recommendations for specific problem soils in the Sahelian zone

Soil Group	Technology
Vertisols	Evacuation of excess surface water, gully control, storage of excess water within the watershed, water harvesting in areas with vertisols, improvement of rooting conditions
Solonchalks	Irrigation with water above irrigation requirement so as to flush out salts and drainage to keep groundwater table below critical level
Solonetzs	Improvement of the porosity of the subsurface soil, lowering the exchangeable sodium percent through the incorporation of gypsum

Annex 4c. Soil management recommendations based on landscape position for the Savannah zone

Landscape Position	Technology
Crest, Slope and Foot slope Soils	**Integrated soil fertility management** (mineral fertilization, use of reactive phosphate rocks where available, composting, animal manures); **Conservation of water, soils and plant cover** (anti-erosive ditches, anti erosive bunds, stone lines, vegetative strips, zai, half moons, crop residue cover, crop rotations, minimum tillage, scarification, subsoiling); **Agroforestry** (shelter belts, farmer managed natural regeneration, parklands, farming with trees on contours, perimeter fencing); **Integrated crop livestock management** (night corralling, rotational fertilization, small stock manure production).
Valley fringes and Bottomland Soils	Drainage/water control, mineral fertilization, use of reactive phosphate rocks where available

Annex 4d. Soil management recommendations for specific problem soils in the Savannah zone

Soil Group	**Technology**
Lixisols	Avoidance of tillage of wet soils and use of heavy machinery
Leptosols	Should be allowed to remain under vegetation
Plinthosols	Amelioration of soil acidity and P fixation with organic materials, cultivation of shallow rooting crops
Thionic Fluvisols	Limit pyrite oxidation by maintaining high groundwater table, that is, keeping tidal swamps under salt water and timing planting to when the rains would have washed out salts from the rooting zone.

Annex 4e. Soil management recommendations based on landscape position for the forest zone

Landscape	**Technology**
Crest,Slope, Foot slope Soils	**Integrated soil fertility management** (mineral fertilization, use of reactive phosphate rocks where available, composting, animal manures); **Conservation of water, soils and plant cover** (anti-erosive ditches, anti erosive bunds, stone lines, vegetative strips, crop residue cover, crop rotations, minimum tillage,); **Agroforestry** (farming with trees on contours, perimeter fencing, multistorey cropping, home gardens, improved fallows);
Valley fringes and Bottomland Soils	Drainage/water control, mineral fertilization, use of reactive phosphate rocks where available

Annex 4f. Soil management recommendations for specific problem soils in the Forest zone

Soil Group	**Technology**
Thionic Fluvisols	Limit pyrite oxidation by maintaining high groundwater table, that is, keeping tidal swamps under salt water and timing planting to when the rains would have washed salts out of the rooting zone.
Gleysols	Control of iron toxicity in certain inland valley swamps by diversion of iron-rich water from uplands, appropriate drainage, fertilization and incorporation of rice husk/bran.