LOWLAND SOILS FOR RICE CULTIVATION IN GHANA

Buri M. M.[1], Issaka R. N.[1] H. Fujii[2] and Wakatsuki[3]

[1]*CSIR - Soil Research Institute, Academy Post Office, Kwadaso- Kumasi, Ghana*
[2]*Japan International Research Center for Agricultural Sciences (JIRCAS), Japan*
[3]*Faculty of Agriculture, Kinki University, Nara, Japan*

INTRODUCTION

In Ghana lowlands mostly comprising floodplains and inland valleys occur throughout the whole country. These lowlands have been characterized to be heterogeneous in morphology, soil type, vegetation and hydrology. Lowland soils therefore occur across all the agro-ecological zones of the country. These agro-ecological zones include the drier Savannahs (Sudan, Guinea, and Coastal) which cover the northern and coastal parts and the Forest which covers the western, central and eastern corridors of the country. According to estimates, the country has over one million hectors of lowlands (Wakatsuki et al, 2004a, b) which can be developed for effective and sustainable rice cultivation, beside the pockets of areas used to dry season vegetable production. This chapter is therefore describing the natures of lowland soils in Ghana, their suitability for rice production and possible effective measures that need to be put in place for their sustainable use.

In the Savannah agro-ecological zones rice cultivation is common due to the presence of abundant poorly drained lowlands. These soils are deep sandy loams to clay loams and abundant water resources from the major rivers, comprising the Volta, Oti, Nasia, Daka, Kulda and their numerous tributaries that could be tapped for irrigation. The soils are developed over shale / mudstone, sandstone, granites and phyllites (Adu, 1995a, 1995b, 1969; Dedzoe et al, 2001a & b). They include *Kupela* (Vertisol) and *Brenyase* (Fluvisol) series occurring over granite, *Pale* series (Gleysol) occurring over Birimian schist, *Lapliki, Siare* and *Pani* series found on floodplains of major rivers and *Lima* and *Volta* series developed over shale and mudstone. The most commonly used soils for rain-fed rice production in the Savannah agro-ecological zone include the inland valley soils occurring within the shale / mudstone areas of the Voltaian Basin. Under irrigation, soils found on the old levees of the Volta and Nasia rivers, *Lapliki* series, are highly suitable.

The Savannah agro-ecological zones experience the lowest rainfall (< 1000mm) amounts for the year. There is only one growing season, commonly referred too as the rainy season. The rainy season starts when the rains commence from May/June and ends in September/October. A long dry period is experienced from November to April. Temperatures are normally high and quite uniform throughout the year. Average monthly temperatures range from 25^{o} to 35^{o}.

The Forest agro-ecological zones on the other hand, experience relatively higher rainfall amounts (> 15000mm per annum) with a bimodal pattern. The major season rains occur between March and mid-July with a peak in May/June. There is a short dry spell from mid-July to mid-August. The minor rainy season starts from mid-August to about the end of October with a peak in September. A long dry period is experienced from November to February with possibilities of occasional rains. The rains appear to be nearly well distributed throughout the year, with amounts considered adequate for crop production occurring in the two peaks. Temperatures are normally high throughout the year with very little variations. The mean monthly temperatures range from 25^{o}C in July/August to 29^{o}C in March/April

Agriculture is the dominant land use for these lowlands. Across the country, the lowlands are commonly cultivated to rice and vegetables. Within the forest ecology, maize, cocoa, oil palm, plantain and citrus are also cultivated, while maize, sorghum and millet are also cultivated within these lowlands in the Savannah agro-ecological zones.

SOIL TYPES

Soils of Savannah agro-ecological zones:

The most extensive lowland soils in the Savanna agro-ecological zones are *Lima* and *Volta* series, which originate from shale and mudstone. *Lima* series is the most extensive, followed by *Volta* and *Changnalili* series respectively (Dedzoe et al, 2001a & b; Senayah et al, 2001). These soils occupy a generally flat (0-3% slope), broad and very extensive lowland plains that are generally suitable for mechanization. In a catena, the fringes of the valley adjoining the upland is occupied by *Changnalili* series (Stagnic Plinthosol), followed by *Lima series* (*Endogleyi–Ferric Planosol*) and with the *Volta* series (*Dystric or Eutric Gleysol*) occurring closest to the stream bed. A general description (Senayah et al,) of some of these soil series are as given below.

(i) Lima series (Endogleyi – Ferric Planosol)

The profile description of *Lima series* is presented in Table 1. *Lima* soils are deep (>140 cm) and imperfectly to poorly drained. At the peak of the wet season, they are flooded intermittently, depending on the duration of breaks in the rainfall. Topsoil textures are loam, silt loam or sandy loam and the underlying subsoil textures range from sandy clay loams to clays.

(ii) Volta series (Dystric or Eutric Gleysol)

Table 2 shows a typical profile description of the *Volta series*. *Volta soils* are also very deep (>150 cm) and poorly drained. They occur close to streams or in depressions as compared to Lima. Textures are heavier and they are flooded for much longer periods than Lima soils. Topsoil textures are mainly silt loams and silt clay loams and in the underlying subsoil, silt clays and clays. The limitation of this soil is the difficulty of working when it is wet or dry. When wet, it is very sticky and easily gets stuck to implements and very hard when dry.

(iii) Lapliki series (Abrupti-Stagnic Lixisol)

Lapliki series is developed from mixed alluvial deposits and occur above flood plains. Unlike the *Volta* and *Lima* series, it is seldom flooded. It could be used under irrigation. The soil is moderately well to imperfectly drained and occurs on middle to lower slopes. *Lapliki* series has a topsoil of grayish brown to light grey sandy loam, which is usually less than 30 cm thick. This grades into brownish yellow compact sandy clay loam below 30 cm and in turn overlies several meters of yellowish brown, mottled red sandy clay loam or sandy clay.

Table 1: Profile description of a typical *Lima* soil series (FAO/WRB: *Endogleyi-Ferric Planosol*)

Horizon	Depth (cm)	Description
Ap	0- 23	Dark grayish brown (10YR 4.5/2) to light brown (7.5YR 6/3); few brownish yellow mottles; sandy loam; weak fine and medium granular; loose
Eg	23 - 36	blocky; friable. yellowish brown (10YR 5/4); many (15%) distinct brownish yellow mottles; sandy clay loam; weak fine and medium sub-angular
Btg c	36 – 68	Light yellowish brown (10YR 6/4); many (20%) distinct brownish yellow and yellowish red mottles; clay loam to clay; weak to moderate fine, medium and coarse sub-angular blocky; slightly firm to firm; many (20%) iron and manganese dioxide concretions.
Btg	68 – 140	Light brownish grey (10YR 6/2); common (10%) distinct dark red mottles; clay; strong medium prismatic; very firm; common (10%) iron nodules

Table 2. Profile description of a typical *Volta* soil series (FAO/WRB: *Eutric Gleysol*)

Horizon	D*epth (cm)*	*Description*
Apg	0 – 35	Dark grayish brown (10YR 4/2); few distinct brownish yellow mottles; silt clay loam; moderate fine and medium sub-angular blocky; friable to slightly firm; very few (<3%) iron concretions
Bwg 1	35 – 60	Grayish brown (10YR 5/2); common distinct brown mottles; silt clay; moderate fine and medium sub-angular blocky; slightly firm; few (3%) hard iron and manganese dioxide concretions
Bwg2	60 – 116	Grayish brown (10YR 5/2; common (10%) distinct dark red and yellowish brown mottles; clay; moderate fine and medium sub-angular blocky firm; common (10%) iron and manganese dioxide concretions

Soil of Forest agro-ecological zones:

Soils within the forest agro-ecology, on the other hand, are developed from the Lower Birimian rocks. The soils fall under the Akumadan – Bekwai / Oda Complex and Bekwai – Zongo / Oda Complex associations (Adu, 1992). The lower slope is occupied by imperfectly drained gravel–free yellow brown silty clay loams, *Kokofu series*, which are developed from colluvium from upslope, *Temang series* which are gray, poorly drained alluvial loamy sands and *Oda series* which are clays occupy the valley bottoms. Most of the major streams are flanked by low, almost flat (0 – 2%) alluvial terrace consisting of deep, yellowish brown, moderately well to imperfectly drained silty clay loams, *Kakum series*. The Bekwai – Zongo / Oda complex association also consists of Bekwai, Nzima, Kokofu, Temang, Oda and Kakum series but in addition has a large tract of seepage iron pan soils called *Zongo series*. *Zongo* soils consist of sandy loam topsoil overlying yellow brown, imperfectly drained, clay loams containing ironstone concretions and iron pan boulders in the subsoil. On the other hand, *Nzima* soils are characterized by a high content of stones and gravel in some places resulting from the break up during weathering of veins and stringers of quartz injected into the phyllite. This results in the formation of the *Mim series.* A brief but general description of these soils includes:

(i) Mim Series (Ferric Acrisol)

Mim series is a moderately well to well drained soil found on middle slopes of 5-8%. The topsoil is dark reddish brown sandy loam. This overlies many to abundant (40-80%) quartz and stones in a reddish brown clay loam soil. This soil differs from the *Nzima series* by the higher gravel and stone content in the subsoil. Its effective depth is determined by the amount of quartz gravel and stones, where it becomes so abundant that there is only little soil material which varies between 30 and 60cm depth.

(ii) *Zongo series (Plinthosol).*

Zongo series is a moderately well to imperfectly drained soil, found on middle to lower slopes. The topsoil is dark grey sandy loam. The underlying subsoil is pale brown sandy clay loam containing ironstone gravel from 40cm, which increases with depth from many (15-40%) to abundant (40-80%).

(iii) Kakum series (Gleyic Lixisol)

Kakum soils are very deep (> 150cm), imperfectly to moderately well drained, occurring on the slightly raised old alluvial flats along the banks of major rivers/streams. The profile consists of dark brown, weak granular friable sandy loam at the topsoil. The subsoil is yellowish brown and faintly mottled, strong brown friable clay loam and a structure that is weak to moderate fine and medium sub-angular blocky granular. Below 100cm, the mottles become prominently reddish yellow.

(iv) *Kokofu series (Gleyic Lixisol)*

Kokofu series is found below *Nzima series* and occupies lower slope sites with slope gradients of 1-3%. It is developed from colluvial material from upslope. The soil is deep, non gravelly and moderately well or imperfectly drained. The topsoil consists of dark brown friable silt loam. The underlying subsoil consists of yellowish brown silt clay loam, faintly mottled yellow

(v) *Temang series (Haplic Gleysol)*

This soil is developed from alluvial material and occupies the valley bottoms of 0-1% slope and depressions that are subjected to water-logging during the rainy season. The soil is deep and poorly drained. The topsoil consists of brown, faintly mottled dark yellowish brown friable loam. The underlying subsoil is pale brown to light brownish grey friable sandy loam with dark yellowish brown mottles.

Table 3. Profile description of typical *Oda* soil series (FAO/WRB: *Eutric-Gleysol*)

Horizon	*Depth (cm)*	*Description*
Apg	0-6	Dark grayish brown (10 YR 4/2) with clear smooth rusty mottles, moderate sub-angular blocky with a sandy loam texture
Bacg	6-17	Dark grayish (10 YR 3/2) with clear waxy yellow mottles, moderate granular and sandy loam in texture
Bcg	17-34	Grayish (10 YR 6/2) with clear smooth yellow mottles, moderate crumbly and sandy loam in texture
Bcg2	34-75	Grayish (10 YR6/1) with clear smooth rusty mottles, fine granular with a sandy clay loam texture
Cg1	75-89	Grayish (10 YR 6/2) with clear smooth rusty mottles, moderate crumbly and sandy clay loam
Cg2	89-140	Grayish (10 YR7/1) clear smooth rusty mottles, fine granular and a sandy clay loam texture

Asubonteng et al, (2001).

General soil fertility status of lowlands in Ghana:

Across the sub-region, various studies (Issaka et al, 1999a, b, 1997, Buri et al, 1996, 1998, 2000, 2006) have shown that lowlands are generally low in soil fertility with wide variations in fertility levels across the different and varied agro-ecological zones. Soil fertility levels as compared to other regions of the world showed the sub region to be quite deficient in available phosphorus and relatively lower in the basic cations particularly calcium and potassium, thus reflecting lower levels of eCEC. Thus soils of West African lowlands in general are characteristically low in basic plant nutrients.

Soil Reaction

In Ghana, soil pH within the drier Savannah agro-ecological zones, particularly both the *Volta* and Lima series are strongly acid (mostly < 5.0). Topsoil pH ranges from strongly acid to neutral for *Lapliki* series. However, pH of lowlands within the Forest agro-ecological zones is relatively uniform. Soil pH is relatively neutral being generally greater than 5.5. Even though some of the soils within this zone show are relatively acid, this is on a limited scale. Exchangeable acidity is also relatively higher within the savannah agro-ecology (mean = 1.0 cmol (+) kg^{-1}) which can adversely affect basic cation balances particularly Ca and Mg leading to adverse effect on rice growth. However, generally and under reduced conditions, pH levels may not pose any serious problem for rice production, since hydromorphic/reduced conditions under rice cultivation tend to favour and enhance pH increases.

Total Carbon and Nitrogen

Within the forest agro-ecological zones, lowland soils have low to moderate levels of organic carbon. Organic Carbon levels could be as low as 4 g kg^{-1} at some sites and rising to 37g kg^{-1} at some locations. Mean levels are around 12.0 g kg^{-1}. However, within the savannah agro-ecology, organic carbon levels are comparatively lower with general mean levels around 6.0 g kg^{-1} with a 50% coefficient of variability across locations. *Volta* series shows relatively higher organic matter content (13-22 g kg^{-1}) than *Lima* series (8-19g kg^{-1}) within the topsoil. In the same vein total Nitrogen levels show a similar trend to that of Carbon, being slightly higher for the forest than the savanna agro-ecological zones. Total Nitrogen has a mean value of 1.1g kg^{-1} within the forest agro-ecology with very little variability. The savannah zones show much lower levels of total Nitrogen with much lower variability when compared to the forest ecology. Mean levels across locations is lower than 0.7g kg^{-1}.

Available Phosphorus (P)

Available P is generally very low for all the soil types and across all agro-ecological zones (Buri et al, 2008a, b). Available P is the single most limiting nutrient. It varies very greatly across locations within the forest agro-ecological zones. Mean levels within the Forest is about 5 mg kg^{-1} but varied very greatly (CV > 90%). Within the Savanna zones, mean available P levels for lowlands is even lower and also varies significantly (CV > 60%). Mean level is about 1.5 mg kg^{-1}. Under hydromorphic conditions, P utilization and availability is enhanced. This makes current available P levels very inadequate and therefore very limiting to the utilization of these lowlands for rice cultivation.

Exchangeable Bases:

Exchangeable cations (K, Ca, Mg) levels within the forest ecology are generally moderate to medium across most locations, even though they also vary significantly (CV > 60%). Exchangeable Potassium (K) has a mean value of 0.4cmol (+) kg^{-1}. Exchangeable Ca and Mg have mean values of about 7.5 cmol (+) kg^{-1} and 4 cmol (+) kg^{-1} respectively. Exchangeable Na levels are, lower {mean = 0.32 cmol (+) kg^{-1}} but show much higher variability (CV > 80%). Effective Cation Exchange Capacity (eCEC) values with the forest agro-ecology are relatively moderate, a reflection of the moderate levels of exchangeable cations. Most lowlands within the forest are therefore relatively adequate in Ca, Mg and Na, but with some areas showing potential K deficiencies.

Exchangeable cation levels within the Savannah agro-ecological zones are, however, generally low when compared to those of the forest agro-ecological zone. Topsoil exchangeable calcium is moderate and relatively higher for *Volta* series {2.2-5.8 cmol (+) kg^{-1}} than the Lima series {1.76-2.24 cmol (+) kg^{-1}}. Mean levels of exchangeable K {0.22 cmol (+) kg^{-1}}, Mg {0.9 cmol (+) kg^{-1}} and Na {0.11 cmol (+) kg^{-1}} are also quite low with coefficient of variability levels of over 74%, 90%, and 77% respectively. Effective cation exchange capacity levels are therefore relatively low across locations, indicative of the need to consider improving upon the levels of these nutrients under any effective and sustainable cropping program (Table 4).

Table 4. Typical chemical and physical characteristics lowlands soils in comparison with lowland soils of West Africa and Tropical Asia

Parameter		Ghana	West Africa	South East Asia
Samples (no.)		212	247	410
pH (water)		5.1	5.3	6.0
Total Carbon	(g kg^{-1})	9.0	12.3	14.1
Total Nitrogen	(g kg^{-1})	0.87	1.08	1.30
Av. Phosphorus	(mg kg^{-1})	3.2	8.4	17.6
Ex. Potassium	{cmol (+) kg^{-1}}	0.3	0.3	0.4
Ex. Calcium	{cmol (+) kg^{-1}}	4.8	2.8	10.4
Ex. Magnesium	{cmol (+) kg^{-1}}	2.5	1.3	5.5
Ex. Sodium	{cmol (+) kg^{-1}}	0.2	0.3	1.5
Effective CEC	{cmol (+) kg^{-1}}	8.6	5.8	17.8
Clay	(g kg^{-1})	96	230	280

Soil Texture:

Within the drier Savannah agro-ecological zones, lowland soils are relatively low in clay content. Most locations show less than 10% clay content but again with higher variability (CV > 60%). The soils, however, show appreciable levels of silt (mean > 60%) and are therefore mostly Silt loam in texture, with isolated areas being sandy loam. They occur abundantly and cover a greater part of the lowlands. The soils are generally deep but water retention capacity may be low due to low clay contents. Typical examples are as described earlier. Within the forest ecology, the soils are also relatively low in clay (mean = 13%). They also contain relatively higher levels of silt (mean > 50%). Some are deep while others are very shallow. Textures vary from sandy loam through silt loam to loam. The water retention capacity of these soils is better when compared to those of the savannah zones.

RECOMMENDED MANAGEMENT OPTIONS:

Lowland soils in Ghana are deficient in most basic nutrient elements which vary considerably across location. These are soils with heterogeneous characteristics and therefore require different/varied management options. The major constraints to the use of these sites for rice cultivation include luck of proper land preparation methods, ineffective water management and low soil fertility. Generally, greater emphasis is laid on the development of improved planting material (varieties) to the neglect of the micro-environment in which the improved planting material will grow. Consequently, the high yielding varieties perform poorly because soil fertility cannot be maintained. This has led to farmers not realizing the full potential of improved rice varieties. There is the need for the integration of genetic and natural resource management. Therefore for the effective utilization of these lowlands, the development of technologies that will result in a balance between bio-technology (varietal improvement) and eco-technology (environmental improvement) are very essential.

The provision of water management structures will greatly improve the utilization and nutrient management options of these lowlands. The development of technologies that will be easy-to-adopt and using affordable materials for water harvesting will make more farmers adopt water harvesting for use on their rice fields. This therefore calls for the development of technologies that will enhance water harvesting from small streams and springs that occur abundantly in these lowlands. Due to farmers inability to use the recommended amounts of mineral fertilizers, integrated nutrient management options are very necessary. The combined use of farm organic matter, mineral fertilizers and effective cropping systems will help improve soil fertility. The recycling of farm organic matter will be very useful. Farmer organic matter may be used directly on rice fields or may be treated (compost, ashed, charred). The constant burning off of farmer organic matter should be discouraged. Instead, farmers should be educated on how to do partial burning under special conditions.

The adoption of improved rice production technologies such as the “Sawah” systems will significantly lead to improved water and nutrient management. The concept and term

“Sawah” refers to man-made improved rice fields with demarcated, bunded, leveled, and puddle rice fields with water inlets and outlets which can be connected to various irrigation facilities such as canals, ponds, weirs, springs, dug-outs or pumps. Field demarcation based on soil, water and topography need to be considered seriously for the sustainable use of these lowlands. Site specific nutrient management options are therefore recommended. However, while nutrient deficiency limitations can be corrected through improved organic matter management, additions of mineral fertilizers and/or integrated nutrient management options, water management under current traditional systems is very poor. This tends to negatively affect both soil nutrient retention and availability for plant use. As a step towards improving water management, simple and cost effective management structures are necessary for harvesting surface water for temporal storage and use. Land preparation methods for rice cultivation should be improved to include the construction of bunds and leveling in addition to ploughing. The uses of heavy land preparation machinery such as tractors are not suitable for most lowlands due to their sizes, topography, wetness and nature of soils. The use of lighter and affordable land preparation machinery such as the power tiller (two wheel tractor) should be preferred.

On the basis of generally observed nutrient levels, lowland soils in Ghana are deficient in most basic nutrient elements which vary considerably from location to location. Site specific nutrient management options are therefore recommended. However, generally, nutrient deficiency limitations can be corrected through improved organic matter management, additions of mineral fertilizers and adoption of sustainable and improved rice production technologies (e.g. “Sawah” system). The “Sawah” system which is intrinsic and conservative can help improve and/or maintain nutrient levels within these environments.

REFERENCES

Adu S. V. 1995a. Soils of the Nasia Basin, Northern Region, Ghana. Memoir No. 11 CSIR-Soil Research Institute, Kwadaso – Kumasi. Advent Press.

Adu S. V. 1995b. Soils of the Bole-Bamboi Area, Northern Region, Ghana. Memoir No. 14 CSIR-Soil Research Institute, Kwadaso – Kumasi. Advent Press.

Adu S. V. 1969. Soils of the Navrongo-Bawku Area, Upper Region, Ghana. Memoir No. 5. Soil Research Institute (CSIR), Kumasi

Asubonteng K. O, Andah W. E. I., Kubota D., Hayashi K., Masunaga T., and Wakatsuki T. (2001). Characterization and Evaluation of Inland Valleys of the Sub-humid Tropics for Sustainable Agricultural Production: Case study of Ghana. In Proceedings of the International workshop on Integrated Watershed Management of the Inland Valley – Ecotechnology Approach, Novotel, Accra, Ghana, February 6-8th, 2001

Buri M. M., Oppong J., Tetteh F. M. and Aidoo E. (2008). Soil Fertility Survey of Selected Lowlands within the Mankran Watershed in the Ashanti region of Ghana. CSIR – Soil Research Institute Technical Report No. 274

Buri M. M., Aidoo E. and Fujii H. (2008). Soil Fertility Survey of Selected Lowlands within the Jolo Kwaha Watershed near Tamale in the Northern region of Ghana. CSIR – Soil Research Institute Technical Report No. 279

Buri M. M., Issaka R. N. and Wakatsuki T. (2007). Determining Optimum Rates of Mineral Fertilizers for Economic Rice grain Yields under the "Sawah" system in Ghana. West African Journal of Applied ecology, Vol. 12. 19-31

Buri M. M., Issaka R. N. and Wakatsuki T. (2006). Selected lowland soils in Ghana: Nutrient levels and distribution as influenced by agro-ecology. Proceedings of the International Conference and the 17th and 18th Annual General Meetings of the Soil Science Society of Ghana. Pp 149-162

Buri M. M., Issaka R. N., Wakatsuki T. and E. Otto (2004). Soil Organic Amendments and Mineral fertilizers: Options for Sustainable Lowland Rice Production in the Forest Agro-ecology of Ghana. Agriculture and Food Science Journal of Ghana. Vol. 3, 237-248

Buri M. M., Masunaga T. and Wakatsuki T. (2000). Sulfur and Zinc levels as limiting factors to rice production in West Africa lowlands. Geoderma 94 (2000), 23-42.

Buri M. M., Fusako I., Daisuki K., Masunaga T. and Wakatsuki T. (1998). Soils of Flood plains of West Africa. General Fertility Status. *Soil Sci. and Plt Nutr.* 45(1). 37-50

Buri M. M. and Wakatsuki T. (1996). Soils of flood plains of West Africa: Geographical and regional distribution of some fertility parameters. Proceedings of the International Symposium on "Maximizing Sustainable Rice Yields through Improved Soil and Environmental Management." held in Khon Kaen, Thailand, November 11-17. Pp 445-455

Dedzoe C. D., Senayah J. K. Adjei-Gyapong T., Dwomo O., Tetteh F. M. and Asiamah R. D. 2001a. Soil characterization and suitability assessment for lowland rice production in the Northern Region. Phase 1- SILLUM VALLEY. SRI Technical Report No. 203. Kwadaso, Kumasi

Dedzoe C. D., Senayah J. K., Adjei-Gyapong T., Dwomo O., Tetteh F. M. and Asiamah R. D. 2001b. Soil characterization and suitability assessment for lowland rice production in the Northern Region. Phase III – KULDA-YARONG VALLEY. SRI Technical Report No. 213.

Dedzoe C. D, Seneyah J. K and Adjei-Gyapong T. (2002). Soil characterization and Suitability Assessment for lowland rice production in the Northern region of Ghana. SRI Technical Report No. 213.

FAO, ISRIC and ISSS (1998). World Reference Base for Soil Resources. World Soil Resources Report No. 84

Issaka, R. N., Ishida, M., Kubota, D. and Wakatsuki, T. (1997): Geographical Distribution of Soil Fertility Parameters of West Africa Inland Valleys. Geoderma 75: 99-116.

Issaka R. N., Masunaga T., Kosaki T., and Wakatsuki T. (1996). Soils of Inland Valleys of West Africa. General Fertility Parameters. *Soil Sci. and Plt Nutr*.. 42. 71-80.

Issaka, R. N., Masunaga, T. and Wakatsuki, T. (1996): Soils of Inland Valleys of West Africa: Geographical Distribution of selected soil fertility parameters. Soil Sci. Plant Nutr., 42. 197-201

Senayah J. K. Adjei-Gyapong T., Dedzoe C. D., Dwomo O., Tetteh F. M. and Asiamah R. D. 2001. Soil characterization and suitability assessment for lowland rice production in the Northern Region. Phase 2 – KULAWURI VALLEY. SRI Technical Report No. 207. Kwadaso, Kumasi

Senayah J. K, R. N. Issaka and C. D. Dedzoe (In Press). Characteristics of Major Lowland Rice- growing Soils in the Guinea Savanna Voltaian Basin of Ghana. In Press: Agricultural and Food Science Journal of Ghana.

Wakatsuki T, Buri M. M. and Fashola O.O (2004a). Rice Green Revolution and Restoration of Degraded Inland Valley Watersheds in West Africa through Participatory Strategy for Soil and Water Conservation. ERECON Institute of Environmental Rehabilitation and Conservation. 241-246

Wakatsuki T, Buri M. M. and Fashola O.O (2004b). Ecological Engineering for Sustainable Rice Production of Degraded Watersheds in West Africa. World Resource Research 2004, IRRI

.