Characteristics of Major Lowland Rice-growing Soils in the Guinea Savanna Voltaian Basin of Ghana

J. K. Senayah, R. N. Issaka, C. D. Dedzoe
Email: jamessenayah@yahoo.co.uk
Soil Research Institute, Academy Post Office, Kwadaso-Kumasi, Ghana.
Received: September 2005 Accepted: February 2008

Resumé

Senayah, J. K., Issaka, R. N., Dedzoe, C. D. *Les caractéristiques des bas-fond principaux sols de culture du riz dans la Savanne guinéenne de la cuvette voltaïque du Ghana.* Le papier revue les sols principaux pour la cultivation du riz dans la Savanne guinéenne de la cuvette voltaïque du Ghana et évaluer leur potentialité pour la production du riz. Les sols principaux pour la cultivation du riz dans la Savanne guinéenne sont les séries Lima et Volta. Les autres incluent les séries Laplik, Siare, Pani, Kupela, Brenyase et Pale. Les propriétés physiques du sol étaient utilisées comme les paramètres principaux et l'estimation adaptée du Sys *et al.* (1993) étaient utilisées pour évaluer leur potentialité pour la cultivation du riz. La série volta (Gleysol dystrique ou entrique) était evaluée comme modérément convenable avec sa limitation principale étant le couche arable limoneux. Les séries Lima (Endogleyi-ferric planosol et Lapliki (Abrupti-stagnique Lixisol) étaient évaluées comme marginalement convénable grâce à un couche arable sableux-limoneux. Ces sols sont très vastes et sont les sols principaux pour la cultivation du riz dans cette zone. La gestion éfficace y compris l'irrigation et l'incorporation de la matière organique augmenteront significativement leurs évaluations puisque leur sous-sol est basiquement arigile. L'utilisation ĵudiciense de l'engrais et le chaulage modéré où le pH est moins que 5.0 augmenteront significativement leur productivité.

Mots clés: La savanne guinéenne, les propriétés physiques, les sols de la cultivation du riz et la cuvette voltaique.

Abstract

The paper reviews the maĵor soils for growing rice in the Guinea savanna Voltaian basin of Ghana and evaluates their potential for rice production. The maĵor soils for growing rice in the Guinea Savanna are Lima and Volta series. The others include Lapliki, Siare, Pani, Kupela, Brenyase and Pale series. Soil physical properties were used as the main parameters and ratings adapted from Sys *et al*. (1993) were used in evaluating their potential for growing rice. Volta series *(Dystric or Eutric Gleysol)* was assessed as moderately suitable, with its maĵor limitation being loamy or silty topsoil. Lima *(Endogleyi Ferric Planosol)* and Lapliki series *(Abrupti-Stagnic Lixisol)*, were assessed as marginally suitable on account of a sandy loam topsoil. These soils are very extensive and are the maĵor soils for rice production in this area. Proper management, including puddling and the incorporation of organic matter, will significantly improve their ratings since their subsoil is basically clay. Judicious use of fertilizer and moderate liming where the soil pH is below 5.0 will significantly improve their

Corresponding author

productivity.

Keywords: Guinea Savanna, physical properties, rice growing soils and Voltaian Basin.

Introduction

Rice is a maĵor staple, which is cultivated in all the agro-ecological zones of Ghana. As with other countries in West Africa, population growth and changing food preferences especially in urban centres in Ghana have tremendously increased rice consumption, which has resulted in high import and reduced self-sufficiency in rice (AICAF, 1995).

Ghana has the potential of being self-sufficient in rice production with her adequate soil and water resources. Rice is cultivated on uplands and inland valleys under rainfed and irrigated conditions. The most popular system is the flooded rice cultivation mainly practiced in the inland valleys (IVC, 1993). Various inland valley studies in Ghana (Dedzoe *et al.*, 2001a, b; Senayah *et al.*, 2001; Otoo and Asubonteng, 1995) have shown that these valleys are potential areas for sustainable development of rice-based production systems.

The Guinea savanna in Ghana covers an area of 8,630,242 hectares (86,302 km^2). Estimated regional distribution of inland valleys in Ghana, show that the Northern Region, which is within the zone, has the largest area of 32% (Senayah and Dedzoe, 1997). The Guinea savanna is one of the potential areas with favourable conditions for rice cultivation. Some of these conditions include a rice-growing culture, a generally flat and poorly drained lowlands, deep sandy loams to clay loams and abundant water resources from the maĵor rivers, comprising the Volta, Oti, Nasia, Daka, Kulda and their numerous tributaries, that could be tapped for irrigation. The soils are developed over shale or 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 sericite schist, Lapliki, Siare and Pani series found on floodplains of maĵor rivers and Lima and Volta series developed over shale and mudstone.

Under rainfed conditions, climate, relief and soil conditions are important physical parameters for rice production. Maĵor climatic requirements include long periods of sunshine with optimum air temperature ranging from 24 to 36^{o}C and precipitation >1600mm per annum (Sys *et al.*, 1993). Heavy textured and poorly drained soils are more preferred to the light textured soils largely due to their ability to retain moisture for longer periods (Sys *et al.*, 1993; Rehm and Espig, 1991).

The most commonly used soils for rainfed rice production in the Guinea savanna agro-ecological zone include the inland valley soils occurring within the shale or mudstone areas of the Voltaian Basin (Figure 1). Under irrigation, soils found on the old levees of the Volta and Nasia rivers, Lapliki series, are highly suitable. The soils selected for discussion, Lima, Volta and Lapliki series occupy almost flat, broad and very extensive terrain, which are favourable for mechanized cultivation. Lima and Volta soils in particular were widely used in the early 1970s when there was a general rush for rice farming in the Northern Region of Ghana. This could not be sustained probably due to lack of any feasibility studies. These soils occur along the maĵor tributaries of

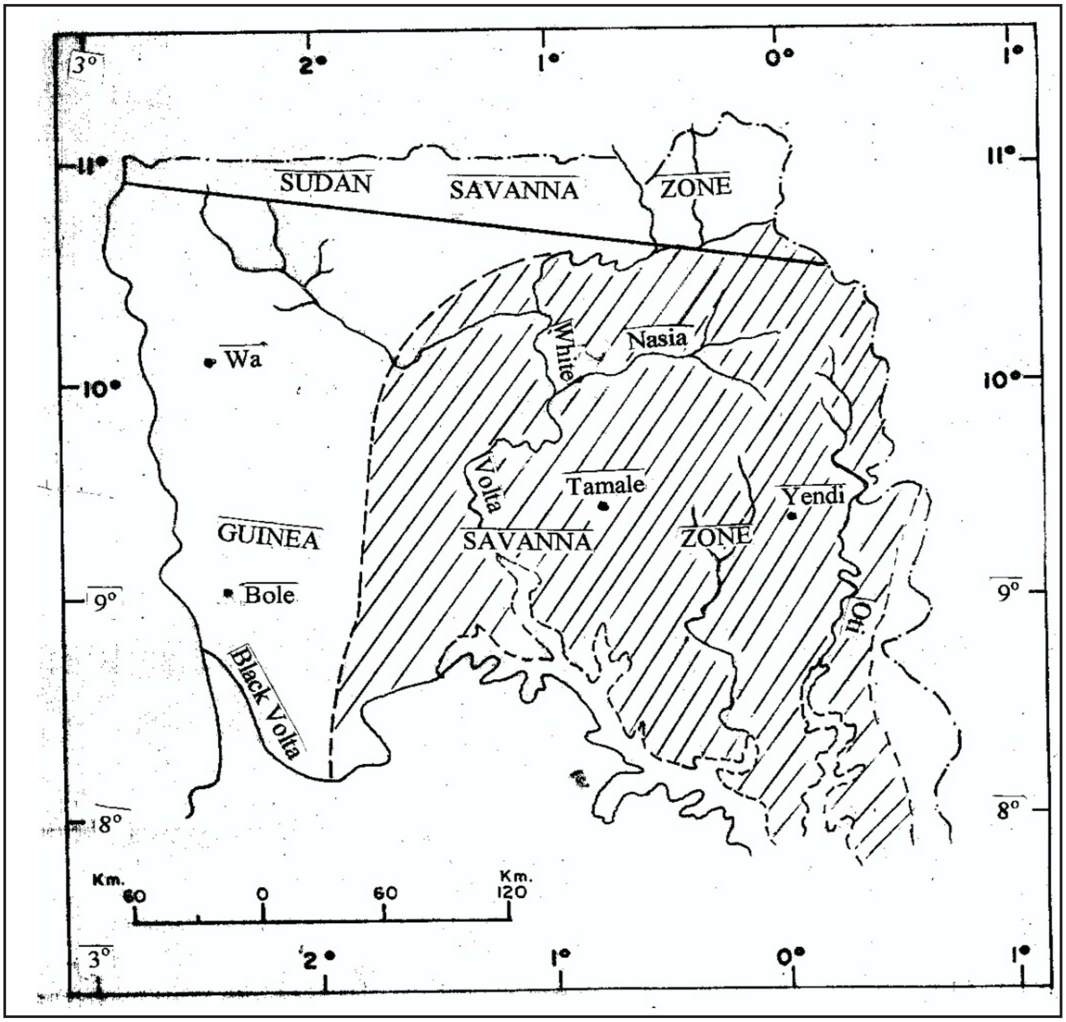

Figure 1. Location of the Voltaian Basin in Ghana.

the Volta River in the Voltaian Basin. They include the Oti, Daka, Nasia, Jolo, Mawli and their tributaries. Several studies have since been carried out on these soils, from which the suitability or potential for rice cultivation have been assessed (Dedzoe *et al*., 2001a,b; Senayah *et al*., 2001). This provides basic information for decision-making, planning and research for beneficiaries such as potential investors and researchers.

The objective of this paper was to examine and synthesize the properties and then determine the suitability of the rice-growing soils, Lima and Volta series occurring on shale and mudstone and Lapliki series found on old levees in the Guinea savanna zone of Ghana.

Methodology

Secondary data were obtained from various soil surveys carried out in the Guinea savanna zone. These include,

i) Soil surveys on the Lowland Rice Development Project in Sillum, Kulawuri and Kulda-Yaron Valleys (Dedzoe *et al.,* 2001a,b; Senayah *et al.*, 2001).
ii) Soil survey on valley bottom project at Tolon and Yepeligu (Senayah and Adjei, 1990).
iii) Reconnaissance soil survey of the Nasia Basin (Adu, 1995a).
iv) Reconnaissance soil survey of the Bole-Bamboi Region (Adu, 1995b).
v) Reconnaissance soil survey of the Navrongo-Bawku Region (Adu, 1969).
vi) Soil map of the reconnaissance soil survey of the Lawra-Wa Region (SRI, 1996).

Rated land or soil characteristics adapted from Sys *et al.* (1993) were used as the basis for soil suitability assessment. Soil physical properties such as drainage, texture, presence of concretions or gravels and depth were the parameters used in the evaluation. Fertility status of the soils was also discussed.

Results and Discussion

Soil and water requirements for rice production

Rice requires a soil saturated with water or flooded during most part of its life cycle (Rehm and Espig, 1991). This available water needs to be appropriately managed for good production. Physical conditions that ensure the good management of water include flat terrain, soil properties such as texture, structure, effective depth and the absence of coarse fragment (Fitzpatrick, 1994).

Description of the selected soils

The most widely used soils for rice production in the Guinea savanna, are Lima and Volta series originating from shale and mudstone. Reports from several surveys indicate that, 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 lowlands plains that are generally suitable for mechanization. In a catena, the fringes of the valley adĵoining the upland is occupied by Changnalili series (Stagnic Plinthosol), followed by Lima series (Endogleyi Ferric Planosol) and Volta series (Dystric or Eutric Gleysol) closest to the stream (Figure 2).

On the old levees of maĵor rivers, particularly the Volta and the Nasia, occurs the Lapliki series. It is very extensive and has the potential for rice production under irrigation.

Changnalili series (Stagnic Plinthosol)

This soil is concretionary and shallow with an underlying iron-pan usually at about 50 cm depth. The topsoil is sandy loam or loamy sand, which overlies silty clay loam subsoil containing abundant ironstone concretions. It is flooded during the rainy season as a result of the underlying impervious iron-pan. This soil occupies the fringes of the lowland (Figure 2).

Lima series (Endogleyi Ferric Planosol)

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 (Table 1).

Table 1. Profile description of Lima soil series (FAO/WRB: Endogleyi Ferric Planosol).

Horizon	*Depth (cm)*	*Description*
Ap	0- 23	Dark greyish 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.

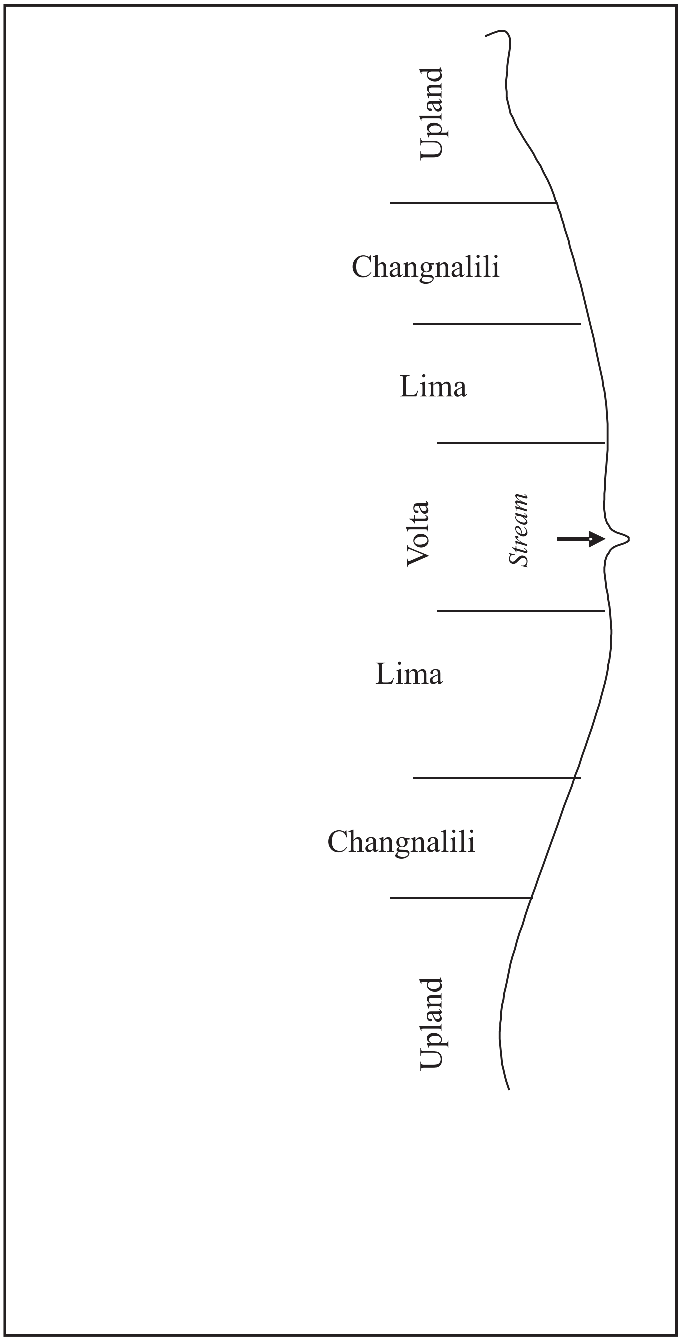

Figure 2. Topographic location of Volta, Lima and Changnalili soil series.

Volta series (Dystric or Eutric Gleysol)
Volta s oils are 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 silty loams and silty clay loams and in the underlying subsoil, silty clays and clays (Table 2). 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.

Lapliki series (Abrupti-Stagnic Lixisol)
Lapliki series is developed from mixed alluvial deposits, which are currently above the flood plain. 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 greyish brown to light grey sandy loam, which is usually less than 30 cm thick. This grades into brownish yellow compact sandy clay loam for about 30 cm and in turn overlies several metres of yellowish brown, mottled red sandy clay loam or sandy clay (Table 3).

Soil texture (particle size distribution)
Texture is a maĵor soil property that imparts certain qualities to the soil that may be difficult to modify. High clay content may result in relatively poor drainage and hence better conditions for rice growth. Tables 4a, 4b and 4c show clay content of Lima, Volta and Lapliki series respectively. Volta series has greater clay content than Lima and

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

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

Table 3. Profile description of Lapliki series (FAO/WRB: Abrupti Stagnic Lixisol).

Horizon	*Depth (cm)*	*Description*
A	0 - 17	Dark greyish soft iron concretions. brown (10YR 4/2); fine sandy loam; fine and medium granular structure; friable, non sticky, non plastic.
AE	17 - 24	Brown (10YR 4/3), loamy fine sand; weak fine and medium granular structure; friable.
E	24 - 34	Yellowish brown (10YR 5/4), sandy loam; weak fine granular structure; friable, non-sticky, non plastic.
Btcs	34 - 67	Pale brown (10YR 6/3); common fine faint yellowish brown and greyish brown mottles; sandy clay loam; weak fine and medium sub-angular blocky; slightly firm, sticky and plastic common fine soft and dark red iron concretions.
Btv	67 - 138	Light brownish grey (10YR 6/2), sandy clay loam; weak fine and medium sub-angular blocky; slightly firm, sticky and plastic; dark red and yellowish brown.

Lapliki series. Generally, clay content increases with depth for all the profiles. Mean clay content increased from >20% (20 cm depth) to >40% (40 cm depth) in the Volta series and 10% to 20% in the Lima series (Tables 4a, 4b). Clay content affects the water holding capacity of a soil (Fitzpatrick, 1994) and it is an important criterion in determining the suitability of a soil for rice production. Higher clay content in the Volta series may impart a better water retention capacity than the Lima series. This is significant since rice is a water-loving crop and performs poorly when water is limiting.

Table 4a. Particle size distribution of Lima series.

Depth (cm)	*sand %*	*silt %*	*clay %*	*Texture*
0 - 6	49.2	41.8	9.0	Loam
6 - 18	69.0	26.0	5.0	Sandy Loam
18 - 32	67.5	22.5	10.0	Sandy Loam
32 - 46	62.0	20.0	18.0	Sandy Loam
46 - 58	41.5	29.0	29.5	Clay Loam
58 - 74	40.5	30.0	29.5	Clay Loam
74 - 98	20.1	34.9	45.0	Clay
98 - 130	20.0	36.3	43.7	Clay

Table 4b. Particle size distribution of Volta series.

Depth (cm)	*sand %*	*silt %*	*clay %*	*Texture*
0 - 12	56.3	27.2	16.5	Loam
12 - 30	10.2	46.3	43.5	Silt Clay
30 - 45	14.1	26.5	59.4	Clay
45 - 69	9.0	24.5	66.5	Clay
69 - 90	9.0	25.5	65.5	Clay

Table 4c. Particle size distribution of Lapliki series.

Depth (cm)	*sand %*	*silt %*	*clay %*	*Texture*
0 - 7	86.8	8.1	5.1	Loamy sand
7 - 23	85.4	9.1	5.5	Loamy sand
23 - 56	79.4	9.5	11.1	Sandy Loam
56 - 88	65.9	8.1	26.0	Sandy Clay Loam
88 - 125	65.0	11.2	23.8	Sandy Clay Loam

The variation in clay content was relatively higher in Volta series than Lima series (Tables 4a, 4b). This is because the former has a greater alluvial influence in origin and the materials deposited, differed from one location to another

Soil fertility

Selected soil chemical properties of the various soils are in Tables 5a, 5b and 5c. Soil pH for both Volta and Lima series were strongly acid (mostly < 5.0). Topsoil pH ranged from strongly acid to neutral for Lapliki series. Available P was generally very low for all the soil types. Volta series showed relatively greater organic matter content (1.3-2.2%, topsoil) than Lima series (0.8-1.9%, topsoil). Exchangeable calcium was moderate and relatively greater for Volta series [2.2-5.8 cmol (+)kg^{-1} soil, topsoil values] than Lima series [1.76-2.24 cmol(+)kg^{-1} soil, topsoil values]. Issaka *et al.* (1997) reported similar acidic nature and generally poor soil chemical properties for some inland valleys in West Africa. Unlike soil physical properties, soil fertility status of these valleys can be improved through appropriate management for sustainable rice production.

Suitability of the soils

Soils are generally assessed as highly, moderately, marginally or non suitable, based on the kind and degree of their limitations with respect to the specified use or crop requirements (FAO, 1976, 1983). The severest limitation is used in deriving the final suitability assessment of the soil. On the basis of rated land or soil characteristics adapted from Sys *et al.* (1993) the soils were assessed for lowland rice production (Table 6). Volta series was assessed as moderately suitable and therefore the best among the selected soils (Table 7). Its limitation was the texture of the topsoil which ranged between loam and silt loam. Silty clay loam or clay loam topsoil would make it highly suitable and this occurs at some locations. Lima series was assessed as marginally suitable on account of the sandy loam topsoil. Several locations may have loam or silt loam topsoil, which may upgrade their

Table 5a. Selected soil fertility parameters of Lima series.

Depth (cm)	*pH (H_2O) 1:1*	*Organic Matter %*	*Total N %*	*Avail. P Bray No 1 ($mgkg^{-1}$)*	*Exchangeable Cations (cmol(+) kg^{-1})* Ca	*Mg*	*K*	*Total Acidity*
0 - 6	4.4	1.6	0.09	1.00	2.24	1.28	0.21	0.55
6 - 18	4.4	0.5	0.07	0.50	1.44	0.32	0.05	0.90
18-32	5.4	0.4	0.07	0.37	1.76	1.28	0.05	0.35
32-46	5.7	0.4	0.06	Trace	2.88	1.60	0.07	0.20
46-58	5.8	0.3	0.06	Trace	4.48	1.60	0.12	0.20
58-74	6.4	0.3	0.04	Trace	5.92	1.44	0.13	0.20
74-98	5.9	0.3	0.04	Trace	8.96	3.68	0.18	0.20

Table 5b. Selected soil fertility parameters of Volta series.

Depth (cm)	*pH (H_2O) 1:1*	*Organic matter %*	*Total N %*	*Avail. P bray No 1 ($mgkg^{-1}$)*	*Exchangeable Cations (cmol(+)/kg^{-1})* Ca	*Mg*	*K*	*Total acidity*
0-12	4.2	1.3	0.09	2.50	3.36	0.96	0 .18	0.70
12-30	4.1	1.1	0.06	1.50	3.20	1.92	0.25	2.80
30-45	4.1	0.8	0.06	0.63	3.20	3.04	0.36	5.00
45-69	4.0	0.8	0.06	0.37	3.84	4.48	0.62	5.30
69-90	4.1	0.8	0.06	0.37	3.84	4.48	0 .41	6.00

Table 5c. Selected soil fertility parameters of Lapliki series.

Depth (cm)	*pH (H_2O) 1:1*	*Organic Matter (%)*	*Total N %*	*Avail. P Bray No 1 ($mgkg^{-1}$)*	*Exchangeable Cations (cmol(+) kg^{-1})* Ca	*Mg*	*K*	*Total Acidity*
0-7	7.0	1.24	nd•	nd	3.14	0.94	0.13	nd
7-23	6.7	0.48	nd	nd	1.7	0.71	0.09	nd
23-56	6.8	0.28	nd	nd	1.49	0.72	0.09	nd
56-88	6.2	0.28	nd	nd	2.73	1.35	0.12	nd
88-125	5.8	0.24	nd	nd	2.58	1.2	0.12	nd

•nd = not determined.

Table 6. Landscape and soil requirements for rainfed wetland rice.

Land characteristics	*Suitability class, degree of limitation and rating scale* *S1*	*S2*	*S3*	*N*
Topography or				
Slope (%)	< 2	2 - 5	5 - 8	> 8
Drainage	Poor	Imperfect or very poor	Moderate	Excessive
Texture	C	SCL	LS	Gravels or sand
	CL	SiL	SL	
	SiCl	SiCL		
	SiC	Loam		
Coarse fragments				
(Vol. %)	<3	3 - 15	15 - 35	>35
Soil depth (cm)	90 - 75	75 - 50	50 - 20	< 20

Adapted from Sys C. *et al.*, 1993. *L = Loam, LS = Loamy sand, SL = Sandy loam, SCL = Sandy clay loam, C = Clay, SiL = Silt loam, SiCL = Silty clay loam.*
□ *S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = Not suitable.*

assessment to moderate. The sandy loam topsoil was assessed as marginal because of poor water retention. The situation becomes serious when there is an appreciable break in rainfall particularly at the onset of the rainy season. This condition may be improved by ensuring the maintenance of high organic matter levels. *Lapliki series (Abrupti-Stagnic Lixisol)* which has properties similar to Lima series was also assessed as marginally suitable.

Table 7. Assessment of selected characteristics of Lima, Volta, Changnalili and Lapliki soils.

Soil series	*Depth (cm)*	*Drainage*	*Texture*	*Concretions or gravel*	*Limitation*	*Assessment*
Lima	>140 (S1)□	Poor (S1)	Topsoil: Sandy loam (S3) Subsoil: Clay loam	Very few or nil: <3% (Sl)	Light-textured topsoil Some profiles are heavier	S3 Topsoil can be improved by Org. Mat.
Volta	>150 (S1)	Poor (S1)	Topsoil: Silt loam *(S2)* *Subsoil:* Clay	Nil (S1)	Topsoil but many locations are heavier	S2
Changnalili	50 (S3)	Poor to imperfect (S2)	*Topsoil*: Silt loam (S2) *Subsoil:* Silt Clay loam	Abundant : >40% *(S3)*	Shallow depth and concretions	S3
Lapliki	>150 (S1)	Imperfect (S2)	*Topsoil*: Sandy Loam (S3) *Subsoil:* Clay loam	Very few or nil: <3% (S1)	Drainage (inadequate moisture)	S3 Topsoil can be improved by Org Mat

□ *S1= highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = Not suitable.*

Conclusions

Soils found in the lowlands and valleys of the shale or mudstone in the Guinea savanna zone are quite extensive. Lima series is the most extensive in the landscape, occurring in association with Volta series in the inland valleys, while Lapliki serie s occurs at old levee sites of the maĵor rivers.

The maĵor soils, Lima series (*Endogleyi Ferric Planosol*), Volta series (*Dystric* or *Eutric Gleysol*) and Lapliki series (*Abrupti-Stagnic Lixisol*) series are generally suitable for wetland rice production.

Volta series is most suitable because of its heavy texture. It was assessed as moderately suitable due to its loamy or silty topsoil. Lima and Lapliki series have similar physical characteristics and are assessed as marginally suitable due to their sandy loam topsoil. Their suitability for wetland rice production can be improved by incorporation of organic matter and puddling to bring up the clayey subsoil. Adequate fertilization will be necessary to tap the full potentials of these soils.

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.

AICAF.1995. Final Report on Valley Bottom Rice Farming Study in West Africa as an alternative of food self-reliance in Africa. Association for International Cooperation of Agriculture and Forestry (AICAF), Tokyo, Japan.

Dedzoe, C. D., Senayah, J. K., Adĵei-Gyapong, T., Dwomo, O., Tetteh, F. M. & 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., Adĵei-Gyapong T., Dwomo O., Tetteh, F. M. & 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., Senayah, J. K., Asubonteng, K. O. & Otoo, E. 1997. Characterization of inland valleys in Ghana: A semi-detailed study of the Mankran system in Ashanti Region. In *Efficient Soil and Water Management: A Prerequisite for Sustainable Agriculture*. Proc. 14th and 15th Annual General Meeting of the

Soil Science Society of Ghana.
FAO. 1976. A Framework for Land Evaluation. *Soils Bulletin No. 32*. FAO Rome.
FAO. 1983. Guidelines: Land Evaluation for Rainfed Agriculture. *Soils Bulletin No. 52*. FAO, Rome.
Fitzpatrick, E. A. 1994. *An Introduction to Soil Science. Second Edition*. ELBS with Longman.
Inland Valley Consortium (IVC). 1993. Inland Valley Research in Sub-Saharan Africa. Priorities for a Regional Consortium. Proc. 1st Annual Workshop of the Inland Valley Consortium, WARDA, Bouake. Cote d'Ivoire, June 8-10, 1993.
Issaka, R. N., Ishida, M., Kubota, D. & Wakatsuki, T. 1997. Geographical Distribution of Soil Fertility Parameters of West Africa Inland Valleys. *Geoderma* 75: 99-116.
Otoo, E. & Asubonteng, K. O. 1995. Inland valleys in Southern Ghana: Reconnaissance characterisation. Report submitted to the Inland Valley Consortium,Bouake, Cote d' Ivoire.
Rehm, S. & Espig, G. 1991. The Cultivated Plants of the Tropics and Subtropics. Institute of Agronomy in the Tropics, University of Gottingen (IAT), CTA, verlag Josef margraf Scientific Books.
Senayah, J. K., Adĵei-Gyapong, T., Dedzoe, C. D., Dwomo, O., Tetteh, F. M. & 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. & Dedzoe, C. D. 1997. Potentials and constraints to productivity of inland valleys in Ghana: A reconnaissance study in the forest zone for rice-based systems. In *Efficient Soil and Water Management: A Prerequisite for Sustainable Agriculture*. Proceedings of the 14th and 15th Annual General Meeting of the Soil Science Society of Ghana.
Senayah, J. K. & Adĵei, S. 1990. Report on the detailed soil survey of valley bottom rice development proĵect area at Tolon and Yepeligu, Northern Region. *SRI Technical Report No. 158*, Soil Research Institute, Kumasi.
Soil Research Institute (SRI). 1996. *Soil Map*, Lawra Wa Region.
Sys, C., Van Ranst, E., Debaveye, J. & Beernaert, F. 1993. *Land evaluation Part III*, Crop Requirements. International Training Centre For Post Graduate Soil Scientists, University Ghent (ITC) Belgium. Agriculture Publications No. 7, General Administration for Development Co-operation, Brussels, Belgium.