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Soil fertility capability classification (FCC) for rice production in Cameroon lowlands

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Fertility capability classification (FCC) system is a technical soil classification system focusing quantitatively on physical and chemical properties of soil important to soil fertility management. Lowland rice cultivation is a major activity in Cameroon, where demand for the commodity is increasing amidst increasing production constraints. This study was intended to classify lowland rice soils in major rice-growing areas into fertility capability classes, identify soil fertility limitations to increased lowland rice cultivation, and identify research areas needed to boost and sustain rice yields. Secondary data of selected soils characterized for morphological, physical and chemical properties was used. Soil fertility limitations characterizing lowland rice producing areas in Cameroon were: Fe- and Al-toxicities (a), low nutrient capital reserves (k), high leaching potential (e), and micronutrient deficiencies (Fe and Zn). The lowland soils were classified as: *Lagk, Cagk, Laegk, Cbgm, Caeg, Lbg, Lgk, Cgv, LCg and Cgv,* which reflect these limitations. A high potential exists to increase national rice production in Cameroon through research aimed at reducing the effects of Al and Fe toxicity, increasing nutrient capital reserves based on appropriate cultural and chemical techniques.

Key words: Fertility capability classification, lowland rice, floodplains, Inland valleys, Cameroon.

INTRODUCTION

Feeding the world's growing population in developing nations where drought and low soil fertility are primary constraints to food production is a serious challenge. Agricultural production in most sub-Saharan countries is under threat due to declining soil fertility (Sanchez, 2002). Because of inadequate use of fertility inputs, on-going soil degradation, and increasingly intense land use without organic and mineral inputs to improve on soil fertility by burgeoning populations, many cropping systems are experience declining soil fertility (St. Clair and Lynch, 2011). It is predicted that in the future, the characteristic low fertility constraint in the tropics may be exacerbated by climate change, which is characterized by rising temperature, drought and more intense precipitation events. St. Clair and Lynch (2011) reported that the negative impacts of climate change on soil fertility and mineral nutrition of crops will far exceed beneficial effects, intensifying food insecurity, particularly

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in developing countries.

Flood plains in river basins of many parts of the world have been used for agriculture because of their natural fertility (Verhoeven and Setter, 2010). In these plains and other wetlands, poorly managed cultivation resulted in their abandonment by cultivators because of soil fertility decline, erosion and desiccation (Babalola et al., 2011). Today, wetlands are facing several threats because of growing demand for food. A case in hand is rice cultivation. Rice is now consumed by most households in the tropics. It is in increasing demand, implying that more land has to be put into cultivation. Fifty percent of the world's wetlands have been lost to agriculture through expansion of agricultural land (Verhoeven and Setter, 2010).

As an alternative to expansion of land to increase production, crop yields can be increased through appropriate soil fertility management practices and by using improved varieties. Improving soil fertility provides several benefits for water productivity (e.g. including enhanced early vigor of seedlings, better competition against weeds, and root access to a larger area of soil water, and early maturation that avoids terminal drought). All of these contribute to higher yields and better management of risk in rainfed agriculture (Padgham, 2009). Long-term experiments have shown that integrating soil fertility and nutrient management is an advanced approach that can serve as remedy to improve crop yields and preserve soil fertility in the long-term (Farouque and Tekeya, 2008). However, a prerequisite for integrated soil fertility management is appropriate and rapid diagnosis of soil fertility limitations. Crop intensification under low or no nutrients input and poor land husbandry system as currently practiced by most small-scale farmers, could potentially aggravate soil degradation through nutrients loss (Westarp et al., 2004).

Soil fertility capability classification (FCC) system was developed for interpreting soil taxonomy and additional soil attributes in a way that is directly relevant to plant growth (Buol et al., 1975; Sanchez et al., 1982, 2003). The system is a good starting point to approach soil quality for the tropics, based on quantitative topsoil attributes and soil taxonomy (Sanchez et al., 2003). The FCC attributes can be positive or negative, depending on land use as well as temporal and spatial scales in question. The FCC considers topsoil parameters as well as specific subsoil properties appearing to be a suitable framework for agronomic soil taxonomy, acceptable to both pedologists and agronomists (Lin, 1989). It is a technical system of grouping soils with similar limitations, and management problems in terms of nutrient supply capacity of the soils. For any particular soil, the FCC is presented as a code (such as *Lek*, a soil which is loamy for topsoil and subsoil, having high leaching potential and low nutrient capital reserves). The fertility constraints are high leaching potential (e), and low nutrient capital reserves (k). The interpretation of the code provides information guiding users in choosing the right practices for the classified soil. Alternatively, the FCC interprets soil taxonomy and additional soil attributes such that it is directly relevant to plant growth (Sanchez et al., 2003). Through knowledge of FCC classes, researchers and agricultural extension staff can identify fertility, rooting and moisture limitations of land to specific crops and plan research activities aimed at circumventing the drawbacks as well as to facilitate agro-technological transfer. It has been widely used in the tropics (Sanchez et al., 2003).

Because of the importance of rice in household economy, prioritization of research on soil fertility is imperative. Inland valleys and flood plains are diverse in characteristics and potentials and require different management interventions to guide land use intensification. Abe et al. (2010) provides an evaluation of soil fertility potential of lowland rice soils in West Africa, relative to soils in Asia, which has been used to inform policy on rice production at the regional scale. The same kind of information is needed at national scales to inform decision-making on rice production.

Objectives

(1) To identify soil fertility limitations for rice production in inland valleys and floodplains at the national scale and establish fertility capability classes; and

(2) To identify axes for soil fertility research and compare them with the strategies to increase national rice production outlined by the Ministry of Agriculture and Rural Development (MINADER).

MATERIALS AND METHODS

Description of study sites

Two agro-ecological zones in Cameroon were considered in this study: Sudano-Sahelian savannah and the Western Highlands. The Sahel region of West Africa is defined roughly by average annual rainfall, extending from about 150 mm in the north (Latitude 18°N) to 1000 mm in the south (Latitude 10°N). Rainfall is highly seasonal, with a dry season extending from October to May. Average temperatures in January are around 25°C rising to 30°C in July. The vegetation is broadly described as tropical grassland savanna (De Longh et al., 2010). Within the Sahel savanna are the Waza-Logone and Logone-Chari flood plains. The Waza-Logone floodplain (6,000 km^2) is about 10% of the total surface of major inland wetlands in the West African Sahel (De Longh et al., 2010) within which are found the sites from which soil profiles were characterized: Waza, Moulvoudaye I and II, and Maga.

The western Highlands extend between Latitudes 5° and 7°N and longitudes 9°50' and 11°E, covering an area of about 31,200 km^2 of which 14,800 km^2 is cultivable (MINAGRI, 2000). It is a derived savanna agro-ecological zone modified by altitude and has a sub-humid climate with two distinct seasons: a long rainy season running from mid-April to mid-November and a short dry season from mid-November to mid-April. Mean annual rainfall is between, 1720 to 2200 mm, mean minimum annual temperature is 18°C and mean annual maximum temperature is 27°C. Within the western Highlands are Mbomi, Nzock (Nzong) (in the Mbo plain), Bafut-Menchum inland valleys and Bamunka (in the Ndop plain). The Bafut-Menchum area is an inland valley surrounded by steep

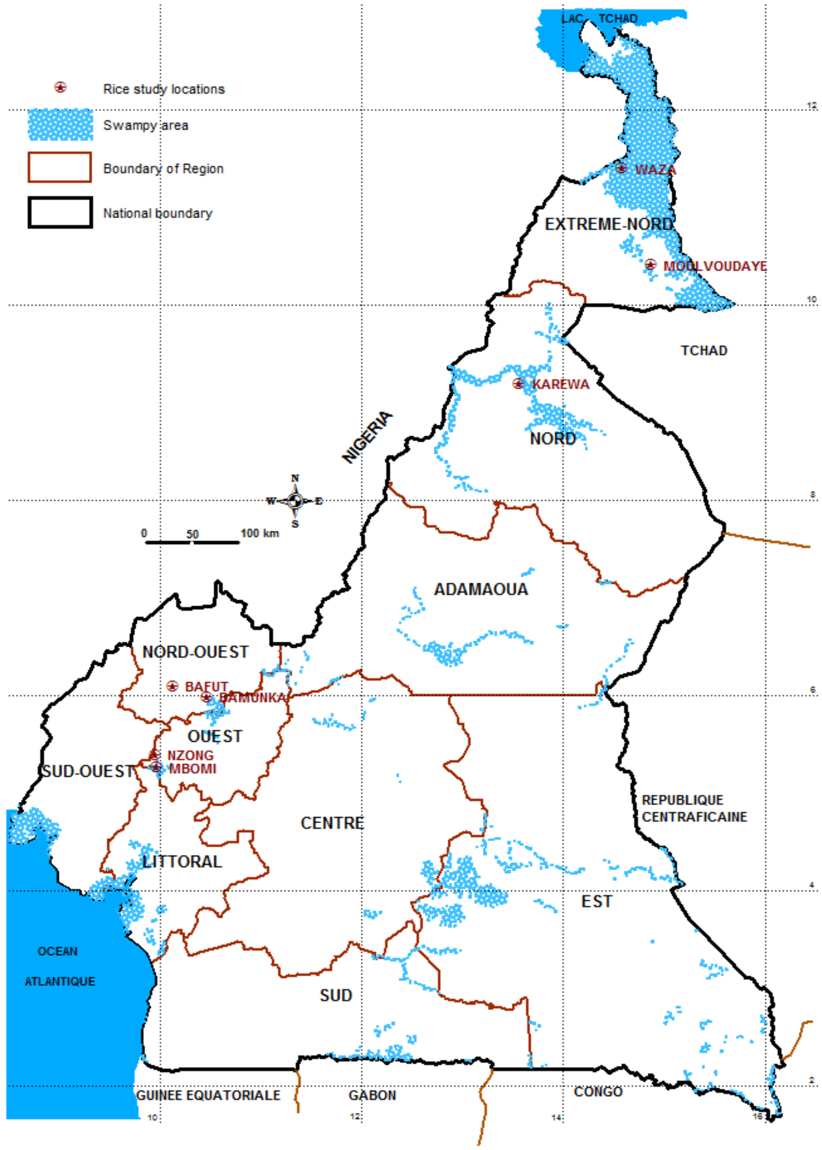

Figure 1. Map of Cameroon showing rice producing areas and study locations.

hills along the River Mezam emptying itself into the Menchum valley with settlement sites along the lowland and the hillsides.

Figure 1 and Table 1 show the sites considered and the sources of soil data respectively. Details on sampling procedures and laboratory analyses of soils are reported by the different authors. Soil profiles were characterized in Mbomi, Wum-Bafut (Obang), Waza, Moulvoudaye I and II, Maga and Kerawa. In Nzong, Bamunka and Logone and Chari flood plains, auger borings were obtained at 0 to 25 cm soil depth. The soils reported above represent major lowland rice producing areas in Cameroon.

Generally, routine soil analysis was run on fine soil. Particle size analysis was performed using pipette method (Pauwels et al., 1992), pH was measured both in water and KCl (1:2.5 soil/water mixture) using a glass electrode pH meter. Part of the fine soil was ball-milled for organic carbon (OC) and Kjeldahl-N analysis (Pauwels et al., 1992). Available P (Olsen P) was determined by method of Olsen and Sommers (Okalebo et al., 1993), exchangeable cations were determined by extracting with 1N ammonium acetate at pH 7, K and Na in the extract were determined using flame photometer and Mg and Ca determined by complex metric titration. Exchangeable acidity (EA) was extracted with 1M KCl followed by quantification of Al and H by titration (Pauwels et al., 1992). Effective cation exchange capacity (ECEC) was determined as sum of bases and EA. Apparent CEC (CEC7) was determined directly as outlined by Pauwels et al. (1992).

Fertility capability classification

Version 4 (Table 2) of the FCC (Sanchez et al., 2003) was used to identify soil fertility limitations and classify soils into FCC units. The FCC system consists of two categorical levels. The first (type/substrata type), describes topsoil and subsoil texture and is expressed in capital letters (e.g. S - sandy throughout; SC - sandy (S) topsoil underlain by clayey (C) subsoil). The second (condition modifier) consists of 17 modifiers defined to delimit specific soil

Table 1. Sources of pedological data and rice production sites.

Agro-ecological zone	Rice production sites	Elevation / m.a.s.l.	References
Sudano-Sahelian savannah	Waza	300	Van Ranst et al. (1989)
	Moulvoudaye II	340	Van Ranst et al. (1989)
	Moulvoudaye III	350	Van Ranst et al. (1989)
	Maga	-	Van Ranst et al. (1989)
	Logone/Chari plain	291	Omoko et al. (2000)
	Karewa	200	Ambassa-Kiki et al. (1999)
Western Highlands	Mbomi		Roy et al. (1988)
	Nzock 5 (Nzong)	-	Roy et al. (1988)
	Bafut-Menchum		Yerima and Van Ranst (2005); Tabi et al. unpublished
	Bamunka	-	Roy et al. (1988)

conditions affecting plant growth with quantitative limits. Each condition modifier is expressed as a lower case letter. Superscripts + or - indicate greater or lesser expression of the modifier. Whenever appropriate, estimates of mean values of soil properties were calculated at 50 cm soil depth. Based on the laboratory analysis of soil properties and thresholds or limits specified in the FCC guide, pedons were assigned FCC units.

RESULTS AND DISCUSSION

Morphological properties and chemical properties of some lowland soils in Cameroon lowlands are presented in Tables 3 to 5. The lowland soils considered in the study were poorly to imperfectly drained (g), and were of loamy to clayey textures. Soils in the western highlands were predominantly acid and those in the Sudano-Sahelian agro-ecological zone slightly acid to alkaline.

Based on the soil fertility classification guide, soil fertility limitations that characterize lowland rice producing areas in Cameroon (Table 6) were: Fe- and Al-toxicities (in the derived savanna agro-ecological zone), low nutrient capital reserve, high leaching potential, micronutrient deficiencies-Fe and Zn (in the Sahel Savanna). The lowland soils were classified as: *Lagk, Cagk, Laegk, Cbgm, Caeg, Lbg, Lgk, Cgv, LCg and Cgv*. Lowland soils in Moulvoudaye II and III, Logone and Chari plain and Waza had limited number of limitations relative to the soils in the western Highlands (Table 7). Soils in Maga, Moulvoudaye II and III and Logone and Chari floodplain had low water infiltration rates, high water holding capacity and were easy to puddle. The soils in Maga will shrink and crack (v = vertic property) when dry. An additional constraint with the Maga soil was that cracks may not close after drying, such that subsequent flooding will increase percolation and exacerbate N losses. Generally, Maga and Logone and Chari soils were very productive. Moulvoudaye II soils revealed potentials of high Fe and Zn deficiencies, and Moulvoudaye III, low nutrient capital reserve. Soils in Bafut-Menchum valley had good water holding capacity but were of low-to-medium infiltration rates, a condition favoring less water retention in years of low rainfall. They were highly acid, potentially Fe- and Al-toxic, and had low nutrient capital reserve. Soils in Mbomi and Bamunka had similar fertility limitations (high leaching potential, potentially toxic in Fe and Al) except for low nutrient capital reserves, which was characteristic of Mbomi soils. Nzong soils were also potentially toxic in Al and Fe and had low nutrient capital reserve.

Aluminium toxicity is caused by excessive amounts of Al^{3+} in soil solution. Its negative effects are poorly developed root systems, susceptibility to drought, lodging and nutrient deficiencies (Meriga et al., 2010). Iron toxicity is a nutrient disorder, associated with high Fe^{2+} concentrations in the soil solution (Cherif et al., 2009). It is a multiple nutritional stress which occurs when Fe^{2+} is abundantly taken up by the plant and becomes concentrated in the leaves. Iron toxicity causes limb discoloration, reduced tillering, stunted growth and reduced yields (Cherif et al., 2009; Olaleye et al., 2001; Audebert, 2006). Lowland rice cultivation in West African savannahs and forest lowlands is often hampered by iron toxicity. The high leaching potential of Mbomi and Bamunka soils indicate that long term rice production is not feasible without fertilizer application. Babalola et al. (2011) observed the same limitations reported earlier on similar soils in Nigeria.

Most of the soils studied in the Sahel savannah were comparable in Ca and K contents (10.4 cmol kg^{-1} and 0.4 cmol kg^{-1} respectively) with very productive Asian lowland rice soils as cited by Abe et al. (2010), but were lower in organic carbon. This might explain why the Far North Region of Cameroon (Sahel savannah) accounts for two-thirds of national rice production figures. Based on the results obtained from this study, the following researchaxes were identified for the two agro-ecological zones. In the western highlands, research should focus on reducing the effect of Fe- and Al-toxicities, leaching of nutrients and on increasing nutrient capital reserve. This would require the use of Fe-tolerant varieties and

Table 2. Fertility capability soil classification system: Version 4 (Sanchez et al., 2003).

FCC class and short description	Symbol	Definitions and some interpretations
Type: texture is the average of plough layer or 0 to 20 cm depth, whichever is shallower	S	Sandy topsoil: loamy sands and sands
	L	Loamy topsoil: < 35% clay
	C	Clayey topsoil: > 35% clay
	O	Organic soil: >12% organic C to a depth of 50 cm or more (Histosols and histic groups)
Substrata type: used if textural change is encountered within top 50 cm	S	Sandy subsoil: texture as in type
	L	Loamy subsoil: texture as in type
	C	Clayey subsoil: texture as in type
	R	Rock or other hard root-restricting layer within 50cm
	R-	As above, but layer can be ripped, plowed or blasted to increase rooting depth
Condition	**Modifier**	**Identifying criteria (if more than one, they are listed in decreasing desirability)**
Modifiers related to soil physical properties		
Waterlogging (gley): anaerobic condition, chemical reduction, denitrification; N_2O and CH_4 emissions	g	Aquic soil moisture regime; mottles < 2 chroma within 50 cm for surface and below all A horizons or soil saturated with water for > 60 days in most years
	g +	Prolonged waterlogging; soil saturated with water either naturally or by irrigation for > 200 days/year with no evidence of mottles indicative of Fe3+ compounds in the top 50 cm; includes paddy rice soils in which an aerobic rice crop cannot be grown without drainage; continuous chemical reduction can result in slower soil N- mineralization and Zn deficiencies in rice
Strong dry season (dry): Limits year-round cropping, interrupts pest cycles, Birch effect	d	Ustic or Xeric soil moisture regime: dry > 60 consecutive days/year but moist >180 cumulative days/year within 20 to 60 cm depth
	d +	Aridic or torric soil moisture regime: too dry to grow a crop without irrigation
Low soil temperatures	t	Cryic and frigid (< 8°C mean annual), non iso-soil temperature regimes, where management practices can help warm topsoils for short-term cereal production
	t +	Permafrost within 50 cm gelisols;no cropping possible
Gravel	r +	r + = 10-35%
	r + +	r + + > = 35% (by volume) of gravel size coarse fragments (2 to 25 cm in diameter) anywhere in the top 50 cm of the soil
	r + + +	More than 15% rock outcroppings
Slope		Where desirable place range in % slope (that is, 0 to 15%; 15 to 30%; > 305)
High erosion risk	SC, LC, CR, LR, SR, >30%	Soils with high erodibility due to sharp textural contrasts (SC, LC), shallow depth (R) or steep (> 30%) slope
Modifiers related to soil reaction		
Sulfidic (cat clays)	c	pH < 3.5 after drying; jarosite mottles with hues 2.5Y or yellower and chromas 6 or more within 60 cm sulfaquents, sulfaquepts, sulfudepts
Aluminium toxicity for most common crops	a	When > 60% Al saturation within 50 cm, or < 33% base saturaton of CEC (BS 7) determined by sum of cations at pH 7 within 50cm, or pH < 5.5 except in organic soils (O)
	a -	10 to 60% Al saturation within 50 cm for extremely acid-sensitive crops such as cotton and alfalfa
No major chemical limitations (includes former h modifier)	No symbol	When < 60% Al saturation of ECEC within 50 cm and pH between 5.5 and 7.2
Calcareous (basic reaction): common Fe and Zn deficiencies	b	Free $CaCO_3$ within 50 cm (fizzing with HCL), or pH > 7.3
Salinity	s	When > 0.4 sm-1 of saturated extract at 25°C within 1 m; salic groups; solonchaks
	s -	0.2-0.4 s m -1 of saturated extract at 25°C within 1m (incipient alkalinity)
Alkalinity	n	When > 15% Na saturation of ECEC within 50 cm; most solonetz
	N-	6 to 15% Na saturation of ECEC within 50 cm (incipient alkalinity)

Table 2. Contd.

Modifiers related to soil mineralogy		
Low nutrient capital reserves (K deficiencies)	k	When < 10% weatherable minerals in silt and sand fractions within 50 cm, or siliceous mineralogy, or exchangeable K < 0.20 c mole kg -1 soil, or exchangeable K < 2% of sum of bases, if sum of bases is < 10 cmolc kg – 1 soil
High P fixation by Fe and Al oxides (> 10 mg kg – 1 P added to achieve adequate soil test levels); Ci soils have excellent structure but low water holding capacity; Ci sub soils retain nitrates	i	Dithionate-extractable free R2 O3: clay ratio > 0.2, or > 4% citrate dithionate – extractable Fe in of topsoil, or oxisols and oxic groups with C type, or hues redder than 5YR and granular structure
	i-	As above, but soils have been recapitalized with P fertilizers to supply long- term P to crops; soil test > 10 mg Kg – 1 P by Olsen method
	i +	as above; potential Fe toxicity if soils waterlogged for long time (g +) or adjacent uplands have I modifier
Amorphous volcanic (X-ray amorphous); high P fixation by allophone (> 200 mg Kg -1 P added to achieve adequate soil test levels); low N mineralization rates	x	Within 50 cm pH > 10 (in 1 M NaF) or positive to field NaF test , or andisols and andic subgroups, other indirect evidences of allophone dominance in the clay size fraction, or > 90% P retention (Blakemore et al., 1981 method)
	x-	P retention between 30% and 90% ; medium P fixers
Cracking clays (vertic properties): very sticky plastic clay, severe topsoil shrinking and swelling v	v	> 35% clay and > 50% of 2:1 expanding clays, or coefficient of linear expansibility > 0.09 or vertisols and vertic groups
High leaching potential (low buffering capacity, low ECEC)	e	< 4 c mole kg – 1 soil as ECEC, or < 7 c mole kg – 1 soil by sum of cations at pH 7,or < 10 c mole kg – 1 soil by sum of cations + Al3+ +H+ AT pH 8.2
Modifier related to soil biological properties (new)		
Low organic carbon saturation (soil organic matter depletion, C sequestration potential)	m	80% total organic C saturation in the topsoil (Van Noorrdwijk et al., 1998) compared with a nearby undisturbed or productive site the same soil, which is equal to 100% OR < 80% 333 Mm KMnO4-extractable topsoil organic carbon saturation (Blair et al., 1997) compared with a nearby undisturbed or productive site of the same soil which is equal to 100%

Condition modifiers: in plowed layer or top 20 cm, whichever is shallower, unless otherwise specified; grouped into modifiers related to soil physical properties, soil reaction (pH), soil mineralogy and soil biological properties.

cropping systems expected to increase the nutrient capital reserve. In the Sahel savannah, appropriate technologies would be those that will increase soil organic matter content, reduce nitrogen losses and correct for micronutrient deficiencies. According to MINADER (2009), rice production continues to fall in Cameroon due to: the difficulty of access to input (fertilizers and pesticides), lack of or insufficient supply of improved seeds, weak organization into farming groups by producers, high postharvest losses due to inappropriate methods of storage, dilapidated or low output husking equipment, limited funding by government of agricultural activities in the form of research grants, loans and other forms of assistance to farmers and the isolation of major production areas, which hinders easy transport of rice from farmers' fields to markets as well as timely distribution of farm inputs. Considering the aforementioned, the national strategy for development of rice production seeks to improve productivity and competitiveness of local rice through: support for the acquisition of agricultural inputs; basic planning of irrigable areas and the rehabilitation of irrigation infrastructure (dams and canals) and agricultural equipment in the large rice irrigation schemes; support to structuring (producer associations) and professionalizing (providing requisite training) producers and for processing and marketing of rice. Although not mentioned as a major strategy to boost rice production, research on rice is implicated in the National Strategic Plan.

CONCLUSIONS AND RECOMMENDATIONS

Soil fertility limitations that characterize lowland rice producing areas in Cameroon were: Fe- and Al-toxicities (in the derived Savanna agro-ecological zone), low nutrient capital reserve, high leaching potential and micronutrient deficiencies-Fe and Zn (in the Sahel Savanna). The lowland soils were classified as: *Lagk, Cagk, Laegk, Cbgm, Caeg, Lbg, Lgk, Cgv, LCg and Cgv*. A high potential exists to increase national rice production, through research aimed at reducing the effects of Fe- and Al-toxicity and to enhance appropriateuse of fertilizers in the western highlands.

Table 3. Morphological properties of major soils in Cameroon lowlands.

Depth (cm)	Colour	Texture	Drainage
Waza			
0-7	10YR5/2	Clay	Well drained
7-45	10YR4.5/2	Clay	Wet
45-79	2.5Y5/2	Clay	Imperfectly drained
79-113+	10YR6/2	Loamy sand	
Bamunka-Ndop plain: Tropoquept			
0-25		Silty Clay	Poorly drained
		Moulvoudaye II	
0-12	1OYR4/2	sandy clay loam	Imperfectly drained
12-78	10YR5/2	Sandy loam	Imperfectly drained
78-180+	10YR6/2	Sandy loam	
Moulvoudaye III			
0-17	10YR4/1	Sandy loam	Imperfectly drained
17-42	10YR4.5/3	Sandy loam	Imperfectly drained
42-61+	2.5Y4/4	Sandy Clay Loam	imperfectly drained
Maga: Eutri-Chromic Vertisol			
0-20	2.5YR3/0	Clay	Imperfectly drained
20-57	10R3/1	Clay	Imperfectly drained
57-97	10YR4/2	Clay	Imperfectly drained
97-141+	10YR4/2	Clay	Imperfectly drained
Karewa: Eutric Vertisol			
0-18		Clay	Imperfectly to poorly drained
18-32		Clay	
Logone-Chari flood plain			
0-25		Clay	
Nzock 5 (Nzong), Paleaquult			
0-25		Clay	Imperfectly to poorly drained
Mbomi, Paleudult			
0-25		Sandy Loam	Imperfectly drained
Bafut-Menchum valley, Humi-Umbric Fluvisol			
0-10	10YR2/1	Sandy clay loam	Imperfectly drained
10-30	10YR3/2	Loam	
30-55	10YR3/1	Silty clay loam	Imperfectly drained
55+	10YR4/1	Clay loam	Imperfectly drained

Approaches to boost rice production should include cultural (selection of appropriate varieties, introduction of suitable cropping systems), chemical methods (right amounts and combination of nutrients) and a combination of these. Specifically, research on soil fertility is required to support the national strategy for the improvement of

Table 4. Chemical properties of major inland valley soils in Cameroon.

Depth (cm)	pH (H_2O)	Organic C (%)	Total N (%)	Available P	Exchangeable bases (cmol+/kg)				cmol+/kg			% BS	Exchangeable Mn
					K	Ca	Mg	Na	Exch. A	CEC7	ECEC		cmol+/kg
Wum_Bafut (Near Obang village): Humi-Umbric Fluvisol													
0-10	-	4.78	0.29	33	0.12	1.29	0.6	0.18	3.77		9.5		
10-30	4.8	2.5	0.14	12	0.01	4.09	0.5	9.08	0.72		5.6		
30-55	5	2.9	0.12	40	0.02	4.57	0.9	0.07	1.12		6.7		
55-65	4.8	2.42	0.13	38	0.02	3.44	0.2	0.07	2.44		6.8		
65-100	4.6	4.17	0.17	30	0.05	4.43	0.3	0.07	2.95		8.8		
100-120	4.6	1.42	0.07	11	0.06	2.07	0	0.08	3.34		6.3		
120-140	4.8	1.29	0.06	10	0.05	1.65	0	0.04	3.03		0.4		
Nzock-5 (Nzong) (Mbo Plain) Paleaquult													
0-25	4.7	0.5	0.17	3	0.05	0	0.21	0.04		10.31		3	
Mbomi-4 (Mbo Plain) Paleudult													
0-25	4.9	2.3	0.24	3.7	0.31	2.2	1.58	0.05	1.16		5.45		0.15

Table 5. Chemical properties of major floodplain soils in Cameroon.

Depth (cm)	pH (H_2O)	Organic C (%)	Total N (%)	Available P	Exchangeable bases (cmol+/kg)				Cmol + /kg			% BS	Exchangeable	
					K	Ca	Mg	Na	Exch. A	CEC7	ECEC		Fe	Mn
Waza														
0-7	7.7	0.33	0.025	3	2.35	25.56	4.04	1.22	-	30.2	-	-	-	-
7-45	7.8	0.18	0.032	4	2.49	25.6	5.2	1.39	-	32.7	-	-	-	-
45-79	7.9	0.23	-	-	2.71	25.95	4.85	1.72	-	31.6	-	-	-	-
79-113	8.1	0.19	-	-	2.9	27.2	4.8	1.73	-	32.8	-	-	-	-
113-119	8.4	0.09	-	-	0.57	4.8	0.8	0.24	-	5.5	-	-	-	-
119-122	8.4	0.16	-	-	0.53	7.34	1.71	0.54	-	9.7	-	-	-	-
122-140+	8.6	0.17	-	-	0.91	8.4	1.2	0.4	-	10.2	-	-	-	-
Bamunka-Ndop Plain: Tropoquept														
0-25	4.6	2.1	0.23	0.9	0.43	3	1.15	0.19	2.15	-	7.29	69	-	0.27

Table 5. Contd.

Moulvoudaye II														
0-12	8.3	0.57	0.042	7	0.47	12.8	2.48	0.23	-	13.9	-	-	-	-
12-78	8.7	0.23	0.021	4	0.6	27.16	3.64	0.32	-	15.4	-	-	-	-
78-180	9.6	0.17	-	-	2.86	32	2.8	1.15	-	15.6	-	-	-	-
180+	9.8	0.13	-	-	5.16	37.2	6.8	2.47	-	17.4	-	-	-	-
Moulvoudaye III														
0-17	5.9	0.54	0.039	3	0.18	4.12	1.88	0.07	-	7.5	-	83	-	-
17-42	6.1	0.27	0.025	6	0.22	4	1.6	0.09	-	7.6	-	78	-	-
42-61	5.9	0.21	0.025	-	0.24	8.4	1.6	0.11	-	10.6	-	98	-	-
61-90	6.1	0.09	-	-	0.26	7.6	1.8	0.1	-	10.6	-	92	-	-
90-140	6.6	0.05	-	-	0.23	8.02	1.88	0.1	-	10.6	-	97	-	-
140-180+	6.5		-	-	0.33	14.8	2.4	0-.17	-	10.9	-	100	-	-
Maga: Eutri-Chromic Vertisol														
0-20	5.7	0.67	-	-	0.6	9.6	7.2	0.4	-	-	-	55	-	-
20-57	6.1	0.52	-	-	0.4	12.1	7.3	0.7	-	-	-	73	-	-
57-97	6.6	0.47	-	-	0.5	13.4	7.5	1	-	-	-	78	-	-
97-141	7.5	0.35	-	-	0.5	16.2	8.8	1.4	-	-	-	86	-	-
141-187	7.7	0.22	-	-	0.5	20	7.6	1.3	-	-	-	100	-	-
187-216	7.4	0.1	-	-	0.4	12.6	6.5	1.1	-	-	-	80	-	-
216-260	7.1	0.08	-	-	0.4	12.7	6.3	1.1	-	-	-	78	-	-
260+	7	0.08	-	-	0.2	4.8	1.8	0.4	-	-	-	65	-	-
Karewa: Eutric Vertisol														
0-18	6.1	0.75	-	-		-	-	-	-	13.34	-	-	-	-
18-32	6.2	0.59	-	-		-	-	-	-	21.64	-	-	-	-
Logone-Chari flood plain														
0-25	6.52	0.57	-	12.44	0.25	5.12	2.96	0.15	-	26.8	8.5	-	-	-

Table 6. Soil fertility limitations and fertility capability classification units.

Location	Soil classification	Type	Sub strata type	Modifiers							
				a	b	e	g	k	m	v	FCC
Near Obang village	Humi_Umbric Fluvisol	L		+			+	+			Lagk
Nzock 5 (Nzong)	Paleaquult	C		+			+	+			Cagk
Mbomi	Paleudult	L		+		+	+	+	+	+	Laegk
Waza		C			+		+		+		Cbgm

Table 6. Contd.

Bamunka	Tropoquept	C		+		+	+			Caeg
Moulvoudaye II		L			+		+			Lbg
Moulvoudaye III		L					+	+		Lgk
Maga	Eutri-Chromic Vertisol	C					+		+	Cgv
Karewa	Eutric Vertisol	L	C				+			LCg
Logone and Chari plain		C					+		+	Cgv

L = Loam, C = clay, a = aluminium toxicity, b = basic reaction, e = high leaching potential, g = gley (waterlogging), k = low nutrient capital reserve, m = soil organic matter depletion, v = vertic properties.

Table 7. Soil fertility constraints of major lowland rice soils in Cameroon.

Soil fertility constraints	Rice growing areas
Aluminium toxicity	Nzong, Mbomi, Bamunka, Bafut-Menchum valley
Fe-toxicity	Mbomi, Nzong, Bamunka, Bafut-Menchum valley
Low nutrient capital reserve	Bafut-Menchum valley, Nzong, Mbomi, Moulvoudaye III
High leaching potential	Mbomi, Bamunka
Fe and Zn deficiencies	Waza, Moulvoudaye II

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