REPORT ON THE FEASIBILITY OF PRODUCING MACADAMIA NUTS IN MR. HUSSEIN M. HUSSEIN'S FARM, KIBAHA DISTRICT, TANZANIA

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1.0. Background

Mr. Hussein M. Hussein, resident in Dar es Salaam has acquired a piece of land of about 100 acres in Pangani area, Kibaha District where he is intending to establish production of Macadamia Nuts (*Macadamia integrifolia / Macadamia tetraphylla*) for both local and export markets. In the month of July this year, Mr. Hussein visited Sokoine University of Agriculture to seek out advice and expertise on the development of the farm for production of the said crop, and was able to contact Prof. B.M. Msanya. After discussion and consultation, both Mr. Hussein (herein referred to as the client) and Prof. B.M. Msanya (herein referred to as the consultant) agreed on terms of reference for the execution of the work.

2.0. Scope and Purpose

The objectives set out by the client are as follows:

(a) Identification of the farm boundaries using the existing beacons to allow determination of the exact area of the farm

(b) Determination and provision of some ancillary information about the site including location characteristics and climate

(c) Reconnaissance survey to identify the major land units of the farm and their corresponding representative soil profiles, soil description and sampling

(d) Laboratory analysis for physical and chemical soil properties

(e) Interpretation of both field and laboratory data to determine the suitability of the farm for the production of Macadamia nuts

3.0. The Study

3.1. Study methods and materials

3.1.1. Soil survey methods

The work started by identifying the existing beacons following the boundary line around the farm. Global Positioning System (model GARMIN 12XL) was used to determine the geographical locations of the beacons. These positions were then used to calculate and confirm the actual area of the farm. Reconnaissance survey of the area was then carried out coupled with hand auger borings to observe soil characteristics, identify and delineate major landscape units, and select observation points for soil profile excavation based on the variability and homogeneity of soils in the study area. A total of 15 mini-pits and two soil profiles were excavated, studied and described according to the standard procedures as outlined in the FAO (1990) guidelines. Soil samples were collected from each soil profile for laboratory analysis as follows:

i) Disturbed soil samples for routine physical and chemical analysis

ii) Undisturbed soil samples for determination of bulk density

iii) Two composite soil samples (0 -20) cm depths were collected for general soil fertility evaluation.

3.1.2. Laboratory methods

Soil samples were air dried, ground and sieved through a 2 mm sieve to obtain the fine earth fractions. Particle size distribution was carried out by Hydrometer method (Gee and Bauder, 1986) after dispersing with sodium hexametaphosphate (calgon). Bulk density of the soils was determined by core method (Black and Hartge, 1986).

The pH of the soil samples was determined potentiometrically in water and in 1MKCl at the ratio of 1:2.5 soil-water and soil-KCl respectively (McLean, 1986). Organic carbon was determined by Walkley and Black wet-acid dichromate digestion method (Nelson and Sommers, 1982). Total nitrogen was determined by micro-Kjeldahl digestion followed by ammonium distillation titrimetric determination (Bremner and Mulvaney, 1982). Available phosphorus was determined by Bray-1 method (Bray and Kurtz, 1945).

The exchangeable bases were determined by atomic adsorption spectrophotometer (Thomas, 1982) and the adsorbed NH_4^+ displaced by K^+ using 1M KCl were determined by Kjeldahl distillation method for the estimation of CEC of soil. Total exchangeable bases, base saturation and ESP were determined by calculations.

3.1.3. Soil classification

Soil properties identified in the field and those determined from laboratory analysis were used to classify the soils based on FAO World Reference Base (WRB) System (FAO, 1998) up to third level soil unit names and United States Department of Agriculture (USDA) Soil Taxonomy (Soil Survey Staff, 1999) to the subgroup level.

3.2. Main findings

3.2.1. Location

The exact area of the farm was determined and confirmed as 109 acres (43.6 ha). The beacons demarcating the farm boundary are all located on the map together with distances between the beacons. The farm has irregular shape and can be identified by the following points: The centre has the coordinates 37M 0497346 UTM9256800; the north-most point is at 037M 0497382 UTM9257238 while the south-most point lies at 037M 0497390 UTM9256365; the west-most point is at 037M 0496955 UTM9256723 whereas the east-most point lies at 037M 0497669 UTM9256506. A sample of soil auger observation points, and representative soil profile locations are also plotted on the map.

The study area is very well located in terms of communication facilities. The farm is located just about 7 km north of the Morogoro-Dar es Salaam Highway. Accessibility to market opportunities in Dar es Salaam and Morogoro and other towns is quite easy. Kibaha is only about 50 km from Dar es Salaam International Airport; hence export possibilities are also available.

3.2.2. Climate

Climatic data used in this study were obtained from the nearest meteorological station namely, Kibaha Agricultural Research Institute (Table 1). The mean annual rainfall is about 950 mm. The rainfall distribution is bi-modal which is typical of the coastal areas of Tanzania, characterized by a pronounced main rainy season (*Masika*) from March to May and a weakly developed short rainy season (*Vuli*) in November-December. More than half of the annual rainfall occurs in the three months of the main rainy season. It is only in this period there is no moisture deficit in the area; in all other months potential evapotranspiration (PTE) exceeds rainfall.

Rainfall at the Kibaha Farm is not that reliable. The probability that the average annual rainfall of 950 mm is reached or exceeded is about 60%, nevertheless there is a large range in annual rainfall. Over a period of 30 years it can be as low as 550 mm and as high as 1300 mm. The monthly rainfall is much less reliable than the annual rainfall, and this is a big limitation to crop cultivation and planning at Kibaha. The most likely onset date of the growing period is the first half of March, but the onset dates are unreliable and vary from December to April (De Pauw, 1984)

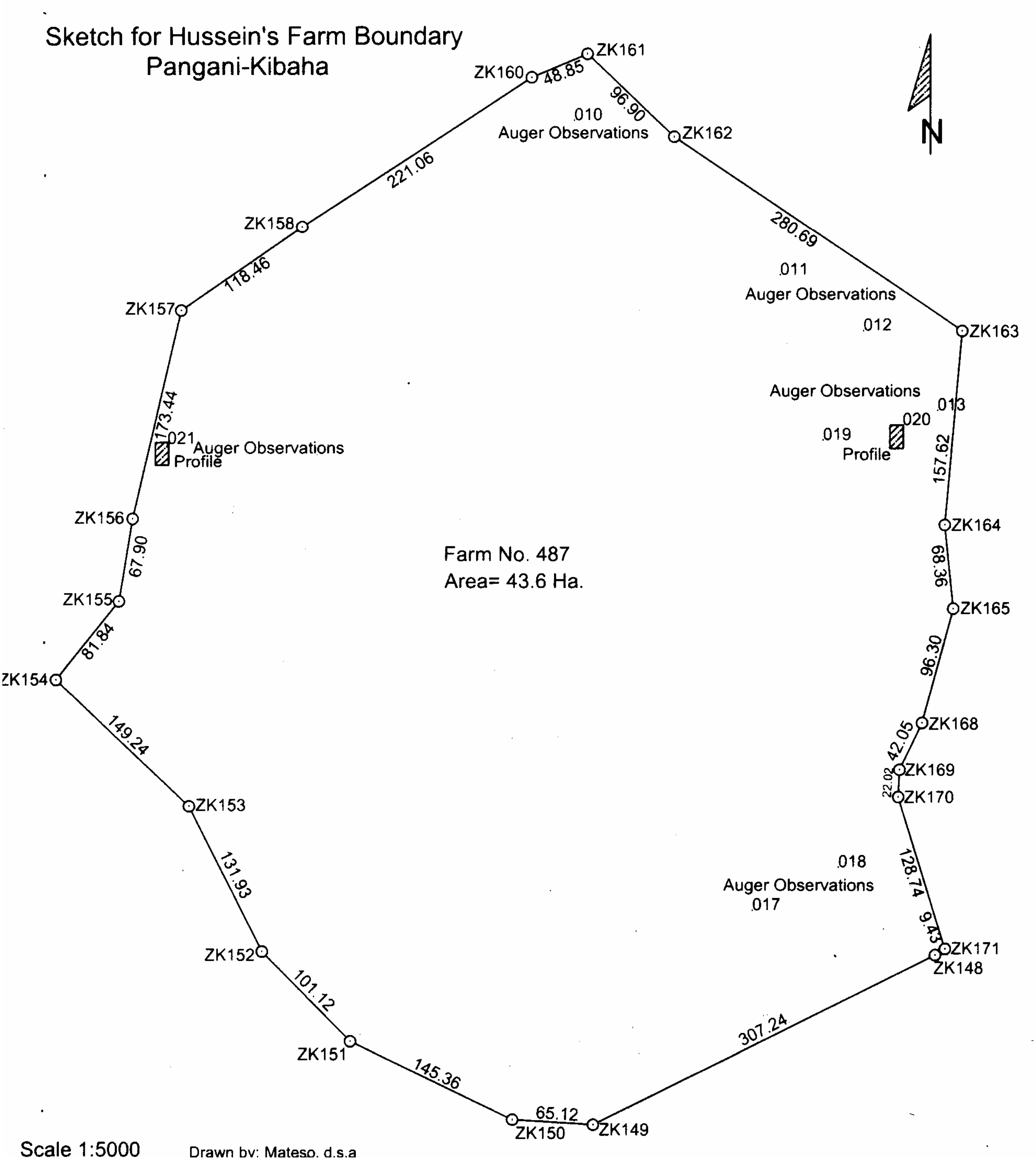

Figure 1. Sketch map of Hussein M. Hussein's Farm, Kibaha

Table 1. Climatic data for Hussein M. Hussein's Farm, Kibaha

	Year	January	February	March	April	May	June	July	August	September	October	November	December
Mean rainfall mm	947	70	78	139	257	123	26	28	11	32	28	64	91
Minimum rainfall mm	720	3	0	57	99	78	0	3	3	0	4	7	34
Maximum rainfall mm	1155	92	147	239	320	233	93	54	51	101	137	176	203
Mean temperature ºC	25.8	27.5	27.2	27.6	26.6	25.5	24.2	23.6	23.8	24.3	25.4	26.4	27.3
Minimum temperature ºC	21.0	23.5	23.3	22.9	22.5	21.1	19.2	18.5	18.2	18.6	19.9	21.0	23.0
Maximum temperature ºC	30.5	31.5	32.0	32.0	30.6	29.8	29.2	28.7	29.3	30.0	30.8	31.1	31.5
Potential evapo-transpiration	1714	159	143	156	141	137	130	131	134	133	146	145	159

Representative Meteorological Station: ***Kibaha Agricultural Research Station (Data collection period: - 1975 – 1983)***

The mean annual temperature is about 26 ^{o}C with little variation over the year. The mean monthly maxima range from 28^{o} to 32 ^{o}C while the mean monthly minima range from 18 ^{o} to 23 ^{o}C.

In terms of climate, the area is only marginally suitable for production of Macadamia nuts. The most favourable climatic conditions consist of mean annual rainfall from 1200 to 1600 mm and mean annual temperature between 18^{o} and 21^{o}C (Raemaekers, 2001). In Kibaha the mean annual rainfall is thus not sufficient. In terms of temperature, normally the minimum temperature should be greater than 13^{o}C while the maximum temperature should be less than 32 ^{o}C, which is the case for Kibaha.

3.2.3. Geology and physiography

Hussein's farm is located on an old, uplifted and dissected coastal plain, built up by thick layers of sandy deposits mostly of the Late Tertiary age. The altitude ranges between 135 m on the uplands and 129 m on the bottomlands (valley bottoms). The uplands, which form about three quarters of the farm, have straight slopes with an average gradient of 5% while the bottomlands forming the remaining quarter of the farm, are narrow and almost flat. The bottomlands are swampy in the main rainy season but practically dry during the rest of the year. People from the villages around the farm use these lands for paddy rice cultivation.

In terms of altitude, macadamia nuts can grow well from sea level to 800 and even more m above sea level. Thus the altitude at Kibaha is not a limitation.

3.2.4. Vegetation and land use

At the time of survey most of the area was composed of some kind of open woodland as natural vegetation with scattered trees and shrubs. Some Kassod trees (*Senna siamea*) (Mijohoro in Swahili) and some sisal were planted to mark the boundary lines of the farm. In some parts of the uplands some big cashewnut trees (*Anacardium occidentale*) were observed (see Plate 1). In the bottomlands residues of paddy rice and simsim after harvesting, were observed (see Plate 2).

Plate 1. Cashew nut trees are found in the farm, in some parts of the upland areas

Plate 2. In the bottomlands (lowlands) rice is normally grown in association with other crops including simsim

3.2.5. Characteristics of the soils of the area

Morphological and physical properties of the soils

The studied soil profiles are presented as Plates 3 and 4. Table 2 is a summary of some morphological and physical properties of the studied soils; detailed characteristics are presented in Appendix 1. Appendix 2 is a guide to general rating of both chemical and physical soil properties.

Bottomlands

The soils of this land unit are represented by profile KIB-P1. They are deep, moderately to poorly drained strong brown to pale brown sands overlain by black sandy clay loam topsoils, developed from coarse-textured marine parent materials. Topsoils have a sandy clay loam texture while the subsoils are loamy sands to sands. According to Raemaekers (2001), texture is not a limitation for the production of macadamia nuts as long as the

Table 2. Morphological and physical properties of the studied soils

Profile/ Horizon	Depth (cm)	Munsell soil colour		% Particle size distribution			Textural class	BD g/cc
		Dry colour	Moist colour	Sand	Silt	Clay		
KIB-P1								
Ap	0-15	7.5YR2.5/1 (bl)	7.5YR2.5/1 (bl))	74	5	21	SCL	1.4
Ah	15-35/49	7.5YR3/2 (db)	7.5YR2.5/1 (bl))	82	3	15	SL	-
C1	35/49-63	10YR7/3 (vpb)	10YR6/3 (pb)	92	1	7	S	1.5
C2	63-116+	-	7.5YR4/6 (sb)	88	3	9	LS	1.6
KIB-P2								
Ap	0-11/20	7.5YR3/3 (db)	7.5YR2.5/2 (vdb)	70	1	29	SCL	1.5
AB	11/20-31/40	7.5YR4/4 (b)	7.5YR3/2 (db)	70	1	29	SCL	-
Bw	31/40-60	7.5YR5/8 (sb)	7.5YR4/6 (sb)	66	1	33	SCL	1.7
BCg	60-88	7.5YR5/1 (g)	7.5YR6/1 (g)	64	1	35	gSCL	-
C1g	88-115	7.5YR4/6 (sb)	7.5YR6/6 (ry)	62	3	35	gSCL	1.7
C2	115-130+	5YR5/8 (yr)	5YR5/6 (yr)	68	3	29	gSCL	

Soil colour notation: bl = black; b = brown; sb = strong brown; db = dark brown; pb = pale brown; vpb = very pale brown; g = gray; ry = reddish yellow; yr = yellowish red
Soil texture notation: S = sand; SL = sandy loam; LS = loamy sand; SCL = sandy clay loam; gSCL = gravely sandy clay loam

Plate 3. Soil profile representing the lowlands (bottomlands)

Plate 4. Soil profile representing the uplands

soil is deep and well-drained with an adequate water holding capacity. The subsoil texture may pose some problem as it is too coarse (loamy sand and sand) to hold water and plant nutrients. The structure of the topsoil is weak medium and coarse sub-angular blocky while that of subsoil is structureless (single grained). The topsoils have soft consistence when dry, friable when moist, slightly sticky and slightly plastic when wet, while the subsoils are very friable when moist, non-sticky and non-plastic when wet. Thebulk density values of both topsoil and subsoil are not limiting to production of macadamia nuts. In this unit, drainage is one property that is a limitation to the production of macadamia nuts.

<u>Uplands</u>

The soils of this land unit are represented by profile KIB-P2. They are deep, well drained, gray, gravely sandy clay loams with very dark brown sandy clay loam topsoils developed from marine sands and loams. Soils of this area have sandy clay loam texture throughout the profile. The sandy clay loam texture is quite favourable for the production of macadamia nuts. With this kind of texture, the soils are likely to have a higher water and nutrient holding capacity than the soils of the bottomlands. The structure of the topsoil is weak, medium sub-angular blocky while the subsoil is structureless massive. The soils have slightly hard consistence when dry, friable when moist, slightly sticky and slightly plastic when wet in the topsoil while in the major part of the subsoil the soils have hard consistence when dry, slightly hard to hard when moist, sticky and plastic when wet. For the production of macadamia, the structure and consistence are not a limitations. The bulk density values are relatively higher than those of the bottomlands; however, they are not limiting to macadamia nut production.

Soil chemical properties

Chemical properties of the studied soils are summarised in Table 3. More details on chemical properties of the soils are presented in Appendix 1.

<u>Bottomlands</u>

The soils have a net negative charge as indicated by their pH (KCl) values being lower than pH (H_20). The soils are of medium to slightly acidic class (5.9 - 6.9). These pH values are said to be favourable for the production of macadamia nuts. The available phosphorus levels are low throughout the profile (<5 mg/kg). The levels of total N are low in the topsoil (0.10%) and decrease with soil depth. Organic carbon levels are rated as low in the topsoil (1.25%) with also a general tendency to decrease with soil depth.

Table 3. Selected soil chemical properties of the studied area

Profile/ Horizon	Depth (cm)	pH		% OC	% N	C:N ratio	P (mg/kg) Bray-1	P (mg/kg) Olsen	CEC Soil	Ca	Mg	K	Na	% BS	EC dS/m	ESP
		H_2O	KCl						(cmol(+)/kg)							
KIB-P1																
Ap	0 - 15	6.0	4.6	1.25	0.10	12.5	2.66	-	15.8	3.79	2.64	0.29	0.39	45.0	0.02	2.46
Ah	15 – 35/49	5.9	4.1	0.54	0.05	10.8	4.40	-	10.8	2.15	1.39	0.10	0.22	35.7	0.01	2.03
C1	35/49 - 63	6.3	4.7	0.18	0.02	9	1.06	-	6.2	0.26	0.05	0.003	0.13	7.1	0.01	2.10
C2	63 - 116+	6.9	5.6	0.26	0.02	13	1.06	-	5.2	0.38	0.32	0.01	0.16	16.7	0.01	3.10
Composite	0-40	5.3	4.0	0.60	0.06	10	0.46	-	11.6	1.87	1.21	0.09	0.21	29.1	0.01	1.81
KIB-P2																
Ap	0 – 11/20	5.8	4.3	0.77	0.07	11	0.44	-	19.4	2.35	4.19	0.06	0.37	35.9	0.01	1.91
AB	11/20 – 31/40	6.3	4.4	0.70	0.07	10	0.15	-	16.6	2.39	5.1	0.07	0.47	48.4	0.01	2.83
Bw	31/40 - 60	6.6	4.7	0.54	0.05	10.8	0.29	-	22.0	2.51	5.87	0.06	0.93	42.6	0.01	4.23
BCg	60 - 88	6.9	5.4	0.38	0.05	7.6	-	0.83	25.6	3.59	9.77	0.07	1.73	55.3	0.17	6.76
C1g	88 - 115	7.9	6.1	0.32	0.03	10.7	-	0.56	24.8	4.39	12.81	0.06	3.00	81.7	0.33	12.10
C2	115 – 130+	8.5	7.1	0.34	0.02	17	-	0.56	22.6	5.59	12.53	0.05	3.26	94.8	0.72	14.40
Composite	0 – 11/20	6.1	4.9	0.84	0.07	12	0.63	-	11.8	2.23	2.14	0.15	0.19	39.9	0.03	1.61

The soils of this area have medium levels of cation exchange capacity (CEC) in the topsoil (CEC of 15.8 cmol(+)/kg) and very low values in the subsoil (values <6 cmol(+)/kg). These low values of CEC are due to low clay and organic matter contents in the subsoil. Percentage base saturation (BS) levels are low, being <50% throughout the profile. The exchangeable calcium levels are medium in the topsoil ranging from 2.1 to 4.0 cmol(+)/kg), and are low in the subsoil (0.5 – 0.5 cmol(+)/kg). Magnesium levels are high in the topsoil (2.1 – 4.0 cmol(+)/kg) and low in the subsoil (0.2 – 2.5 cmol(+)/kg). Exchangeable K levels are medium in the topsoil (0.26 - 0.8 cmol(+)/kg) and very low in the subsoil (P <0.13 mg/kg). The levels of exchangeable sodium are medium in the topsoil (0.39 cmol(+)/kg) and low to very low in the subsoil. These values do not pose any threat to plant growth. The soils are non-saline and non-sodic as indicated by their low values of electrical conductivity (<1.7 dS/m) and exchangeable sodium percentage (<6%) respectively.

Uplands

The soils have a net negative charge as indicated by their pH (KCl) values being lower than pH (H_20). The pH in these soils increases with depth, and can be rated as slightly acid to neutral in the upper 88 cm of the soil. These values do not pose any problem to the production of macadamia nuts. In the C-horizon the pH values range from moderately alkaline to strongly alkaline suggesting conditions that may affect negatively plant growth. The available phosphorus levels are low throughout the profile (<7 and < 5 mg/kg respectively for P-Bray and P-Olsen). The levels of total nitrogen are very low throughout the profile (<0.10%) and decrease regularly with depth. OC content decreases with depth and can be rated as low in the topsoil (ranging between 0.60 and 1.25%) and very low in the subsoil (<0.60%).

The soils of this land unit have medium CEC values throughout the profile (ranging between 12.1 and 25.0 cmol(+)/kg). Base saturation levels are low in the topsoil (<50%) and are high in the subsoil (>50%). The exchangeable calcium levels are medium in the topsoil (ranging between 2.1 and 4.0 cmol(+)/kg) while those of the subsoil are rated as high (ranging between 4.1 and 6.0 cmol(+)/kg). Magnesium levels are very high throughout the profile (>4.1 cmol(+)/kg). The exchangeable potassium levels are low throughout the profile (<0.13 cmol(+)/kg). Exchangeable sodium levels are medium in the topsoil (ranging between 0.31 and 0.70 cmol(+)/kg) while the levels in the subsoil can be rated as high to very high. The Na levels in the subsoil are likely to pose some problems. However, looking at the electrical conductivity values (< 1.7 dS/m), and the exchangeable sodium percent (ESP) (ranging between 11 and 15 in the subsoil), the soils can be rated as non-saline and only moderately sodic in the subsoil). These values suggest that only the yield of sensitive crops may be slightly negatively affected by the subsoil sodicity.

Soil classification

Tables 4 and 5 give summaries of the morphological and diagnostic features and the classification of the studied soils according to both WRB and USDA Soil Taxonomy systems respectively. Using both FAO system of classification and USDA Soil Taxonomy (in brackets), the soils of the bottomlands classify as ***Haplic Umbrisols (Ustic Quartzipsamments)*** while those of the uplands classify as ***Epidystri-Chromic Cambisols ~Haplic*** (***Aquic Dystrustepts)***

Table 4. Summary of soil profile morphological and diagnostic features of the studied soils (FAO, 1998)

Profile	Diagnostic horizons	Other diagnostic features, properties/materials	Soil name
KIB-P1	Umbric horizon	Haplic	***Haplic Umbrisols***
KIB-P2	Ochric horizon Cambic horizon	Chromic, Epidystric, Haplic	***Epidystri-Chromic Cambisols (Haplic)***

Table 5. Summary of soil profile morphological and diagnostic features of the studied soils (Soil Survey Staff, 1999)

Profile	Diagnostic epipedons/horizons	Other diagnostic features, properties/materials	Soil name
KIB-P1	Umbric epipedon	Ustic SMR Isohyperthermic STR	***Ustic Quartzipsamments***
KIB-P2	Umbric epipedon, Cambic horizon	Aquic SMR, Isohyperthermic STR	***Aquic Dystrustepts***

General fertility status of the studied soils

The general soil fertility of the soils is best assessed from the analytical data of the composite topsoil (0 – 20 cm) samples collected to represent the two main land units of the study area. Composite samples are a collection of at least 10 subsamples collected from a single field, which are thoroughly mixed to form a representative sample. The analytical data for the composite samples are presented together with the soil profile data (Table 3).

The bottomlands have a pH of 5.3 (strongly acid) while the uplands have a pH of 6.1 (slightly acid). Macadamia nuts are relatively undemanding in terms of pH as long as the soil is well-drained.

Soils of both land units are characterized by low levels of organic matter (OM). The OC contents are respectively 0.60 and 0.84% for the bottomlands and uplands, corresponding to OM levels of 1.0 and 1.4%. Although the amounts of OM are low, the quality of the OM is good as reflected by the C:N ratio lying between 8 and 13. This is important since the release of nitrogen as plant nutrient depends on the quality of the OM. Successive wetting and drying increases mineralization and at the start of the rainy season decomposition of organic matter may bring about a small nitrogen flush. However, nitrogen levels at Hussein's Farm are so low that chemical nitrogen fertilizers will be required for sustained crop production.

Available P levels of both land units are very low, 0.46 and 0.63 mg/kg respectively for the bottomlands and the uplands. An available P level of 15 mg/kg is generally considered as the critical level below which P deficiencies are likely to occur in many crops.

The amounts of exchangeable K are very low (<0.13 cmol(+)/kg) for the bottomlands and low for the uplands (ranging between 0.13 and 0.25 cmol(+)/kg). It is more than likely that soils at Hussein's Farm in Kibaha will give a good response to K-fertilizer application in combination with N and P fertilizers. At least a maintenance application of K-fertilizer is required for most crops including macadamia nuts.

The amounts of exchangeable Ca are low in the bottomlands (value lying between 0.5 and 2.0 cmol(+)/kg for loamy soils) and high in the uplands (value lying between 2.1 and 4.0 cmol(+)/kg for loamy soils). Exchangeable Mg levels are medium in the bottomlands (value of 1.21 cmol(+)/kg for loamy soils) and high for the uplands (2.14 cmol(+)/kg for loamy soils).

The CEC (cation exchange capacity) is the capacity of the soil to retain and release cationic nutrients. The CEC values for both land units are rated as low (with values lying between 6.0 and 12.0 cmol(+)/kg). This implies that all fertilizers except for P fertilizers have to be applied in split portions so as to reduce nutrient losses through leaching.

The overall fertility of the soils of the two land units is low and the cationic nutrients are not well balanced. The main management recommendation would be to increase the present levels of organic matter in the topsoils. This could be achieved by adding good quality farmyard manure, by green manuring, mulching and turning under crop residues. For optimal production of most crops, addition of chemical fertilizers notably NPK formulations would be inevitable.

3.2.6. Agricultural production potential

General

The constraints to optimal crop production at Hussein's farm are the low and uncertain rainfall, and the coarse subsoil texture of the soils particularly those of the bottomlands (valley bottoms) which may be responsible for low water holding capacity of the soils. The low fertility status of the soils is another constraint but this can be amended to a large extent by applying fertilizers. On the overall, the soils of the farm are suited best to production of drought resistant crops like sorghum and millets. In the bottomlands, it is possible to cultivate paddy rice as well. Grazing of animals such as goats, sheep and cattle is another alternative, but has to be supported by water harvesting to get sufficient water for the welfare of the animals and for normal domestic use.

Under rainfed agriculture, the inadequate water supply could be improved by increasing the water holding capacity of the soils. This should be done by mulching, green manuring, and incorporating farm wastes in the soil, thus raising soil organic matter levels. Through these measures, soil fertility will be improved as well.

Agricultural potential for production of macadamia nuts

The client, Mr. Hussein M. Hussein has shown keen interest to produce macadamia nuts in his farm at Kibaha. This has necessitated carrying out a thorough assessment of the farmland to come up with land suitability classification with respect to the land utilization type (LUT) of interest to him, i.e. "***production of macadamia nuts***". Rating of land use requirements for macadamia nut production in the study area is summarized in Table 6. A comparison was made between the land use requirements and the actual land qualities of the two major land units to give the suitability rankings (Table 7). Each land quality was assessed separately to obtain the partial suitability classes for the two major land units in respect of the LUT *"macadamia nut production under rainfed conditions"*. The overall suitability assessment was obtained using the *"Law of*

Limiting Conditions" whereby the least favourable suitability class is taken as the overall suitability class for a particular land unit.

The overall suitability class for the bottomlands is $\mathbf{N_{w,na,o.}}$ This means that the land unit is not suitable for macadamia nut production, the main limitations being excess wetness during the rainy season, nutrient availability (low levels of OC, N and P) and oxygen availability (poor drainage). Moisture availability (inadequate rainfall), rooting conditions and nutrient retention capacity (low CEC and CEC) are also to macadamia nut production.

The overall suitability class for the uplands is $\mathbf{S3_{na,nr,m.}}$ The land unit is thus marginally suitable for macadamia nut production, the main limitations being nutrient availability (low levels of OC, N and P), nutrient retention capacity (low BS and CEC) and moisture availability (inadequate rainfall).

Table 6. Rating of land use requirements for macadamia nut production in Kibaha

Land use requirements (Land quality)	Land characteristics (Diagnostic factor)	Unit	Factor Rating			
			Highly suitable (s1)	Moderately suitable (s2)	Marginally suitable (s3)	Not suitable (n)
Moisture availability	Total rainfall in growing period	(mm)	1200 - 1600	800 - 1200	400 - 800	<400
Temperature regime	Mean temperature in growing period	^{o}C	18 - 21	15 - 18; 21 - 33	12 - 15; 33 - 36	<12; >36
Oxygen availability to roots	Soil drainage	class	Well	Moderately well	Imperfect	Poor, very poor
Rooting conditions	Effective soil depth	(cm)	>120	75-120	30-75	<30
	Soil texture	class	L, SCL, CL, SiCL.	SC, C, SL.	LS, SiC.	S
Nutrient availability	Soil reaction	pH	6.5 – 7.0	6.0 - 6.5; 7.0 - 7.5	5.5 - 6.0; 7.5 - 8.0	<5.5; >8.0
	Topsoil OC	%	>1.5	1.0-1.5	0.5-1.0	<0.5
	Topsoil N content	%	>0.1	0.05- 0.1	0.02 - 0.05	<0.05
	Topsoil avail. P.	mg/kg	>20	10 - 20	3 - 10	<3
Nutrient retention capacity	Base saturation	%	>60	40 - 60	20 - 40	<20
	Topsoil CEC_{soil}	cmol(+)/kg	>20	12 - 20	6 - 12	<6
Salinity	ECe	dS/m	0-4	4 - 6	6 - 8	>12
Wetness	Frequency of flooding		none	biannually	annually	daily, weekly, monthly
	Duration of flooding	days	0 - 1	1 - 5	5 - 15	>15
Erosion hazard	Slope angle	%	<6	6 - 8	8 - 16	>16

Table 7. Rating of land qualities and resulting final suitability for macadamia production in Kibaha

Land unit	Moisture availability	Temp. regime	O_2 availability	Rooting conditions		Nutrient availability				Nutrient ret. capacity		Salinity	Wetness		Erosion hazard	Final suitability
				Depth	Texture	pH	OC	N	P	BS	CEC		Freq. of flooding	Dur. of flooding		
Bottomlands																
	S2	S1	S3	S1	S2	S1	S2	S2	S3	S2	S2	S1	S2	N	S1	$N_{w,na,o}$
Uplands																
	S2	S1	S1	S1	S1	S1	S3	S3	S3	S3	S2	S1	S1	S1	S1	$S3_{na,nr,m}$

Classes and degree of suitability:
S1= Highly suitable
S2= Moderately suitable
S3= Marginally suitable
N= Not suitable

Limitations to suitability:
w= wetness, na= nutrient availability, o= oxygen availability, nr= nutrient retention capacity, moisture availability

Conclusions and recommendations

(i) Kibaha area is very well located in terms of communication facilities. It can be served by Morogoro-Dar es Salaam highway to link to different market destinations, both national and international.

(ii) Under rainfed conditions per se, the production of macadamia nuts is not feasible. The available data on climate clearly show that the rainfall at Kibaha is not adequate for optimum production of macadamia nuts. This means that there is no way this enterprise can be undertaken successfully without supplementary source of water. The source of supplementary water could be from a river or could be a source to be established on the farm through water harvesting techniques, or by drilling wells in appropriate sites. There is a big possibility that a dam could be made within the farm, and the land unit “bottomlands” could probably act as a reservoir for water. Further studies need to be made to ascertain the feasibility of the suggestions given above in respect of use of irrigation water for macadamia nut production

(iii) The soil fertility studies indicate that the soils of both the bottomlands and the uplands have low fertility status. This situation can be ameliorated by addition of organic and inorganic fertilizers. Levels of OC, N and P are particularly low. Mulching, green manuring, and incorporating farm wastes in the soil, will raise soil organic matter levels which will in turn increase also the water holding capacity of the soils. Addition of inorganic fertilizers in the form of NPK formulations is recommended for optimum production of macadamia nuts.

(iv) The land suitability classification has separated the two major land units in terms of their potential. Under improved sets of management practices, only the uplands should be used for the production of macadamia nuts, whereas the bottomlands should not be used for that purpose.

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Appendix 1. Soil profile descriptions and analytical data

Profile number: KIB-P1 Mapping unit: Agro-ecol. zone: Region: : COAST
District : Kibaha Map sheet no.: Yombo sheet 185/2
Co-ordinates: 37M 0497635E / UTM 9256931N
Location: Hussein's Farm, Pangani Area, Kibaha, 7 km north of the Morogoro-Dar es Salaam Highway through the road Kibaha-Pangani village
Elevation: 129 m asl. Parent material: marine sands and loams. Landform: Dissected and uplifted coastal plain, gently undulating with u-shaped valley bottoms. Slope: 1 to 2% at site; straight
Surface characteristics : Rock outcrops: none; Stones: none; Erosion:. Deposition: area of accumulation. Natural vegetation: Regrowth of miombo woodland (*Acacia spp*., *Brachystegia spp*.) and grass species including *Panicum maximun* and *Cynodon spp*. Land use: Fallow land but some places are planted with cashew nuts, simsim and rice (already harvested at the time of survey). Natural drainage class: moderately to poorly drained.

Described by B.M. Msanya and D. Mateso on 17/07/2007

Soil: Soils are deep, well drained strong brown loamy sands and sands with black sandy clay loam topsoils.

Ap 0 - 15 cm: black (7.5YR2.5/1) dry, black (7.5YR2.5/1) moist; sandy clay loam; soft dry, friable moist, slightly sticky and slightly plastic wet; weak medium and coarse subangular blocky; many fine and few medium pores; few coarse, many medium and few fine roots; clear smooth boundary to

Ah 15- 35/49 cm: dark brown (7.5YR3/2) dry, black (7.5YR2.5/1) moist; sandy loam; soft dry, friable moist, slightly sticky and slightly plastic wet; moderate medium subangular blocky; many fine and medium pores; few coarse, many medium and common fine roots; abrupt wavy boundary to

C1 35/49 – 63 cm: very pale brown (10YR7/3) dry, pale brown (10YR6/3) moist; sand; loose dry, very friable moist, non sticky and non plastic wet; structureless massive; very many fine and medium pores; few medium, many fine roots; abrupt smooth boundary to

C2 63 - 116+ cm: strong brown (7.5YR4/6) moist; loamy sand; very friable moist, non-sticky and non-plastic wet; single grain; very many fine and medium pores; few medium and fine roots.

SOIL CLASSIFICATION: WRB (FAO, 1998): ***Haplic Umbrisols***
USDA Soil Taxonomy (Soil Survey Staff, 1999): ***Ustic Quartzipsamments***

ANALYTICAL DATA FOR PROFILE KIB-P1

Horizon	Ap	Ah	C1	C2
Depth (cm)	0-15	15-35/49	35/49-63	63-116+
Clay (%)	21	15	7	9
Silt (%)	5	3	1	3
Sand (%)	74	82	92	88
Texture class	SCL	SL	S	LS
Bulk density (g/cc)	1.4	-	1.5	1.6
pH H_2O 1:2.5	6.0	5.9	6.3	6.9
pH KCl 1:2.5	4.6	4.1	4.7	5.6
Organic C (%)	1.25	0.54	0.18	0.26
Total N (%)	0.10	0.05	0.02	0.02
C/N	12.5	10.8	9.0	13.0
Avail. P Bray-1 (mg/kg)	2.66	3.4	2.2	1.5
Avail. Polsen (mg/kg)	-	-	-	-
CEC NH4OAc (cmol (+)/kg)	15.8	10.8	6.2	5.2
Exch. Ca (cmol (+)/kg)	3.79	2.15	0.26	0.38
Exch. Mg (cmol (+)/kg)	2.64	1.39	0.05	0.32
Exch. K (cmol (+)/kg)	0.29	0.10	0.003	0.01
Exch. Na (cmol (+)/kg)	0.39	0.22	0.13	0.16
Base saturation (%)	45.0	35.7	7.1	16.7
EC dS/m	0.02	0.01	0.01	0.01

Profile number : KIB-P2 Mapping unit: Agro-ecol. zone: Region COAST
District: Kibaha Map sheet no. : Yombo sheet 185/2
Co-ordinates : 37 M 0497044 / UTM 9256916 N
Location: : Hussein's Farm, Pangani Area, Kibaha, 7 km north of the Morogoro-Dar es Salaam Highway through the road Kibaha-Pangani village Elevation: 135 m asl.
Parent material: marine sands and loams. Landform: Dissected and uplifted coastal plain.
Slope: 5 %; straight.
Surface characteristics : Rock outcrops: none; Stones: none; Erosion: sheet; slight. Deposition: none . Natural vegetation: Regrowth of miombo woodland (*Acacia spp*., *Brachystegia spp*.) and grass species including *Panicum maximun* and *Cynodon spp*. Land use. Land use: Fallow land but some places are planted with cashew nuts trees. Natural drainage class: well drained.

Described by B.M. Msanya and D. Mateso on 17/07/2007

Soil: Soils are deep, well drained, gray, gravely sandy clay loams with very dark brown sandy clay loam topsoils.

Ap 0 - 11/20 cm: dark brown (7.5YR3/3) dry, very dark brown (7.5YR2.5/2) moist; sandy clay loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; weak medium subangular blocky; many fine, common medium pores; common fine and few medium roots; clear wavy boundary to

AB 11/20 – 31/40 cm: brown (7.5YR4/4) dry, dark brown (7.5YR3/2) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; weak medium subangular blocky; many fine, common medium pores; few fine and medium roots; clear wavy boundary to

Bw 31/40 – 60 cm: strong brown (7.5YR5/8) dry, strong brown (7.5YR5/8) moist; sandy clay loam; hard dry, slightly hard moist; sticky and plastic wet; weak medium subangular blocky; many fine and medium pores; few fine roots; clear smooth boundary to

BCg 60 – 88 cm: gray (7.5YR5/1) dry, gray (7.5YR6/1) moist; common sharp reddish and white mottles; gravely sandy clay loam; hard dry, slightly hard moist; sticky and plastic wet; structureless massive; few very fine pores; many fine and medium weathered subangular quartz fragments; few fine roots; clear smooth boundary to

C1g 88 - 115 cm: strong brown (7.5YR4/6) dry, reddish yellow (7.5YR6/6) moist; common sharp gray mottles; gravely sandy clay loam; hard dry, sticky and plastic wet; structureless massive; few very fine pores; many fine and medium weathered subangular quartz fragments; few medium roots; clear smooth boundary to

C2 115 – 130+ cm: yellowish red (5YR5/8) dry, yellowish red (5YR5/6) moist; many sharp red and white mottles; gravely sandy clay loam; very hard dry; sticky and plastic wet; structureless massive; few very fine pores; many fine and medium weathered subangular quartz fragments; few fine roots

SOIL CLASSIFICATION: WRB (FAO, 1998): ***Epidystri-Chromic Cambisols (Haplic)***
USDA Soil Taxonomy (Soil Survey Staff, 1999): ***Aquic Dystrustepts***

ANALYTICAL DATA FOR PROFILE KIB-P2

Horizon	Ap	AB	Bw	BCg	C1g	C2
Depth (cm)	0-11/20	11/20-31/40	31/40-60	60-88	88-115	115-130+
Clay (%)	29	29	33	35	35	29
Silt (%)	1	1	1	1	3	3
Sand (%)	70	70	66	64	62	68
Texture class	SCL	SCL	SCL	gSCL	gSCL	gSCL
Bulk density (g/cc)	1.5	-	1.7	-	1.7	-
pH H_2O 1:2.5	5.8	6.3	6.6	6.9	7.9	8.5
pH KCl 1:2.5	4.3	4.4	4.7	5.4	6.1	7.1
Organic C (%)	0.77	0.70	0.54	0.38	0.32	0.34
Total N (%)	0.07	0.07	0.05	0.05	0.03	0.02
C/N	11	10	10.8	7.6	10.7	17
Avail. P Bray-1 (mg/kg)	0.44	0.15	0.29	-	-	-
Avail. P Olsen (mg/kg)	-	-	-	0.83	0.56	0.56
CEC NH4OAc (cmol (+)/kg)	19.4	16.6	22.0	25.6	24.8	22.6
Exch. Ca (cmol (+)/kg)	2.35	2.39	2.51	3.59	4.39	5.59
Exch. Mg (cmol (+)/kg)	4.19	5.1	5.87	9.77	12.81	12.53
Exch. K (cmol (+)/kg)	0.06	0.07	0.06	0.07	0.06	0.05
Exch. Na (cmol (+)/kg)	0.37	0.47	0.93	1.73	3.00	3.26
Base saturation (%)	35.9	48.4	42.6	55.3	81.7	94.8

Appendix 2. Guide to general rating of some chemical and physical soil properties Compiled from EUROCONSULT (1989), Landon (1991), Sys (1993), Baize (1993), Msanya *et al*. (1996) and Kileo, (2000).

1. Organic matter and total nitrogen

	Very low	Low	Medium	High	Very high
Organic matter %	< 1.0	1.0-2.0	2.1-4.2	4.3-6.0	> 6.0
Organic carbon %	< 0.6	0.60-1.25	1.26-2.50	2.51-3.50	>3.5
Total nitrogen %	< 0.10	0.10-0.20	0.21-0.50	> 0.50	

C/N ratios give an indication of the quality of organic matter:

C/N 8-13: good quality

C/N 14-20: Moderate quality

C/N > 20: Poor quality.

2. Soil reaction

Extremely acid	pH <4.5	Neutral	pH 6.6 to 7.3
Very strongly acid	pH 4.5 to 5.0	mildly alkaline	pH 7.4 to 7.8
Strongly acid	pH 5.1 to 5.5	moderate alkaline	pH 7.9 to 8.4
Medium acid	pH 5.6 to 6.0	strongly alkaline	pH 8.5 to 9.0
Slightly acid	pH 6.1 to 6.5	very strongly alkaline	pH > 9.0

3. Available phosphorus

mg/kg	Low	Medium	High
Avail. P (Bray-Kurtz 1	< 7	7-20	> 20
Avail. P (Olsen)	< 5	5-10	> 10

NB. Available phosphorus is determined by the Bray-Kurtz 1 method if the pH H_2O of the soil is less than 7.0. In soils with a pH H_2O of more than 7.0 the Olsen method is used.

4. Cation exchange capacity (CEC)

cmol(+)/kg	Very low	Low	Medium	High	Very high
CEC	< 6.0	6.0-12.0	12.1- 25.0	25.0- 40.0	> 40.0

CEC is determined using 1 M ammonium acetate in soils with pH less than 7.5. In soils with pH greater than 7.5 CEC is determined using 1 M sodium acetate.

5. Electrical conductivity (ECe)

ECe	< 1.7 dS/m	no yield reduction
ECe	1.7 - 2.5 dS/m	up to 10% yield reduction
ECe	2.5 - 3.8 dS/m	up to 25% yield reduction
ECe	3.8 - 5.9 dS/m	up to 50% yield reduction
ECe	5.9 - 10 dS/m	up to 100% yield reduction

6. Exchangeable calcium

cmol(+)/kg	Very low	Low	Medium	High	Very high
Ca (clayey soils rich in 2:1 clays)	< 2.0	2.0-5.0	5.1-10.0	10.1-20.0	> 20.0
Ca (loamy soil)	< 0.5	0.5-2.0	2.1-4.0	4.1-6.0	> 6.0
Ca (kaolinitic and sandy soils)	< 0.2	0.2-0.5	0.6-2.5	2.6-5.0	> 5.0

7. Exchangeable magnesium (Mg)

cmol(+)/kg	Very low	Low	Medium	High	Very high
Mg (clayey soils)	< 0.3	0.3-1.0	1.1-3.0	3.1-6.0	> 6.0
Mg (loamy soils)	< 0.25	0.25-0.75	0.75-2.0	2.1-4.0	> 4.1
Mg (sandy soils)	< 0.2	0.2-0.5	0.5-1.0	1.1-2.0	> 2.0

The desired saturation level of exchangeable Mg is 10 to 15 percent; for sandy and kaolinitic soils 6 to 8 percent Mg saturation is still sufficient. Ca/Mg ratios of 2 to 4 are favourable.

8. Exchangeable potassium (K)

cmol(+)/kg	Very low	Low	Medium	High	Very high
K (clayey soils)	< 0.20	0.20-0.40	0.41-1.20	1.21-2.00	> 2.00
K (loamy soils)	< 0.13	0.13-0.25	0.26-0.80	0.81-1.35	> 1.35
K (sandy soils)	< 0.05	0.05-0.10	0.11-0.40	0.41-0.70	> 0.70

The desired saturation level of exchangeable K is 2 to 7 percent.
Favourable Mg/K ratios for most crops are in the range of 1 to 4.

9. Exchangeable sodium (Na)

cmol(+)/kg	Very low	Low	Medium	High	Very high
Na	< 0.10	0.10-0.30	0.31-0.70	0.71-2.00	> 2.00

More important than the absolute level of exchangeable Na is the exchangeable sodium percentage (ESP) calculated by dividing exchangeable Na by CEC (x 100). ESP values are a measure of the sodicity of the soil.

10. Soil sodicity

	Non-sodic	Slightly sodic	moderately sodic	Strongly sodic	Very strongly sodic	Extremely sodic
ESP %	< 6	6-10	11-15	16-25	26-35	> 35

ESP < 15% -up to 50 percent yield reduction of sensitive crops (maize, beans)
ESP 16-25% -up to 50 percent yield reduction of semi-tolerant crops (rice, wheat, sorghum, sugarcane)
ESP 35% - up to 50 percent yields reduction of tolerant crops (barley, cotton).

11. Basic infiltration rate (IR)

IR < 0.1 cm/h	extremely slow
IR 0.1-0.3 cm/h	very slow
IR 0.3-0.5 cm/h	slow
IR 0.5-2.0 cm/h	moderately slow
IR 2.0-6.5 cm/h	moderate
IR 6.5-12.5 cm/h	moderately rapid
IR 12.5-25.0 cm/h	rapid
IR > 25.0 cm/h	very rapid

Basic infiltration rate is the constant at which water enters the (pre-wetted) soil and which develops after 3 to 5 hours of infiltration.

12.0 Available water capacity (AWC)

AWC	< 25 mm/m	extremely low
AWC	25-50 mm/m	very low
AWC	50-100 mm/m	low
AWC	100-150 mm/m	medium
AWC	150-200 mm/m	high
AWC	> 200 mm/m	very high

Available water capacity is the capacity of the soil to store water that is readily available for uptake by plant roots; usually expressed in millimetres of water per metro depth of soils; technically the difference between the percentage of soil water at field capacity (normally taken as the water content at pF 2.0) and the percentage at wilting point (taken as the water content at pF 4.2). This is applicable for most tropical soils.

13. Aluminium saturation

	Very low	low	Medium	High	Very high
Al saturation %	< 10	10-30	31-50	51-80	> 80

Aluminium saturation as measure of toxicity is calculated by dividing exchangeable Al by the sum of exchangeable bases and exchangeable Al.