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SOILS AND LAND EVALUATION OF PART OF THE SOKOINE UNIVERSITY OF AGRICULTURE FARM (TANZANIA) FOR SOME CROPS UNDER RAINFED CONDITIONS

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ABSTRACT A detailed soil survey of about 420 ha of the central part of the Sokoine University of Agriculture farm was carried out for soil characterization, laboratory physico-chemical characterization, soil classification and land suitability evaluation of the area with respect to maize (*Zea mays*), sorghum (*Sorghum bicolor*), paddy rice (*Oryza sativa*) and field beans (*Phaseolus vulgaris*); all under rainfed conditions. The soils were mapped at 1/10,000 scale besed on slope, soil drainage, topsoil texture and effective soil depth and five mapping units were identified. Land suitability evaluation indicated that none of the identified mapping units was highly suitable for the above listed crops.

Key Words: Land evaluation; Rainfed agriculture; Soil classification; Soil survey.

INTRODUCTION

An assessment of the properties of soils and their response to management is required in planning for agriculture and other land uses. Soil survey involves determining the pattern of the soil cover and dividing this pattern into homogeneous units, and then mapping their distribution and characterizing them. It enables better predictions about specific uses of the land. Soil survey allows useful statements to be made with respect to land use potential and behaviour towards different management practices.

The Sokoine University of Agriculture (SUA) farm covers about 2,300 ha of land. The functions of this farm include commercial agriculture production, basic and applied research in agriculture, teaching and providing extension services to farmers in the country. At the time of this study the soils of SUA farm were still largely unknown. So far, 1,097 ha have been properly surveyed (Mpepo, 1986). Earlier studies on the soils were mostly soil chemistry/fertility assessments scattered in different parts of the farm (Msanya, 1980). It was, therefore, necessary to carry out detailed soil survey to expand the knowledge about the soils of the farm.

Various food crops, including maize, sorghum, paddy rice, field beans and several other leguminous crops, are grown on the SUA farm under rainfed conditions. However, no land evaluation has been done to indicate the suitability of the soils for these crops. Since different crops have different soil and ecological requirements for optimum growth, they require different qualities of land for optimum

performance. Similarly, each soil type has specific properties or qualities, which affect crop performance directly; and hence, the need to assess the suitability of the soils occuring in the farm for the various crops commonly grown.

The information gathered from this study will enable the land users and developers of the farm to make proper decisions on what crops to be grown and the kind of management to be adopted for each of the land units identified. The study covered 420 ha of land and the specific objectives were:

(1) to carry out a detailed soil survey and prepare a detailed soil map of the central part of the farm,
(2) to characterize and classify the soils according to the two classification systems commonly used in Tanzania, i.e. the US Soil Taxonomy and the FAO-UNESCO system, and
(3) to evaluate the suitability of the soils of the area for rainfed production of maize, sorghum, paddy rice and field beans using the FAO Framework and Guidelines for land evaluation.

MATERIALS AND METHODS

I. General Characteristics of the Study Area

The SUA farm is situated near Morogoro town, Tanzania (Fig. 1). The centre of the farm is approximately at longitude 37°39′ E and latitude 6°50′ S. It is bordered on the east by the town, to the south-east by Uluguru Mountains and to the north-west by Lugala Hills. Its area is approximately 2,300 ha, including the 420 under

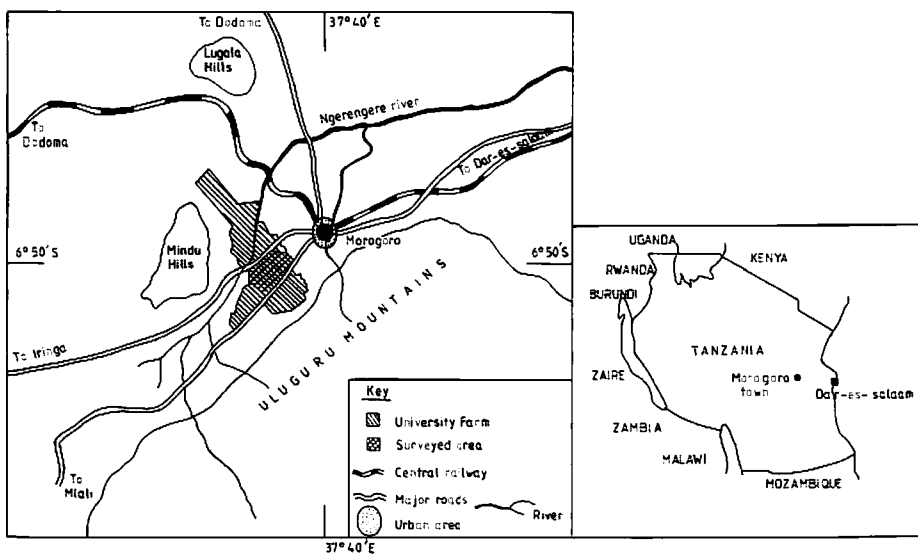


Fig. 1. Sketch map showing location of the SUA Farm in relation to Morogoro Township.

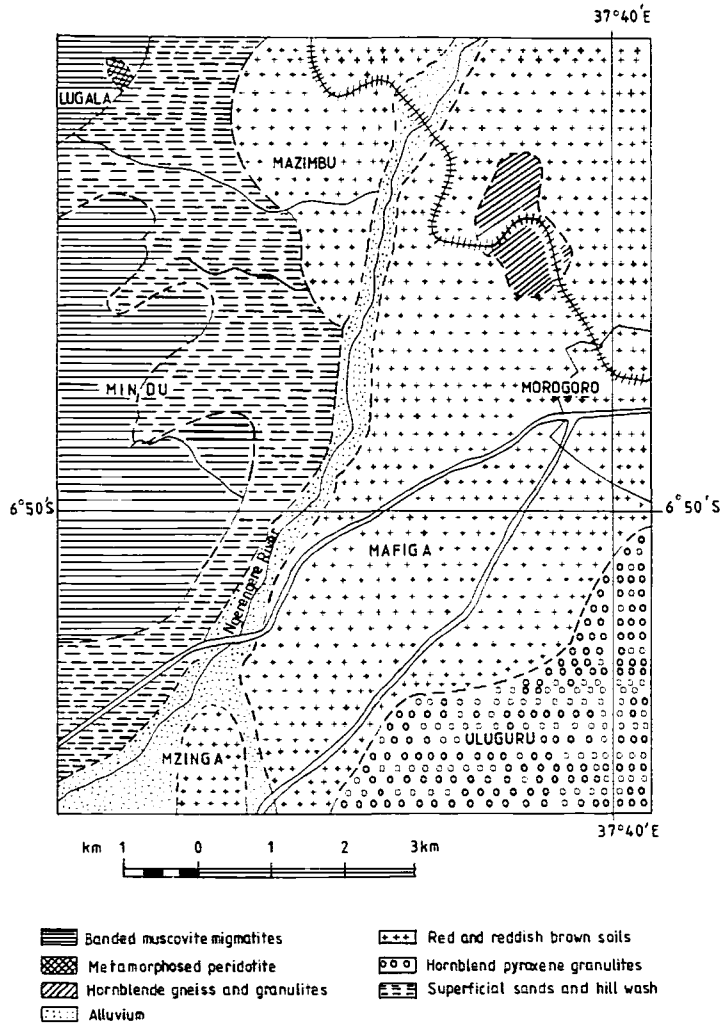


Fig. 2. Geological cover of the surveyed area.

this study.

Most of the studied soils are derived from colluvial materials from the Uluguru Mountains (Kesseba et al., 1972) and have undergone substantial pedogenesis as expressed by the morphological features of their profiles. The younger soils along the Ngerengere River, which crosses the farm, are derived from parent materials brought from the Uluguru Mountains by fluvial erosion followed by deposition on the Ngerengere flood-plain (Msanya, 1980; Moberg et al., 1982; Msanya & Msaky, 1983). Table 1 gives a summary of the site characteristics of the studied soils. Locations of the sites are shown in Figure 4.

The geological survey of Morogoro (Sampson et al., 1961) indicates that the

study area is covered mostly by red and reddish brown soils. The Uluguru Mountains belong to the Precambrian Usagaran Geological System of the Mozambiquan belt. The rocks are metasediments made up of mainly pyroxene granulites containing plagioclase and quartz-rich veins. Figure 2 shows the general geological cover of the study area and its neighbourhood.

Most of the geomorphological features of the SUA farm have been described by Mpepo (1986). The farm has a saucer-like shape as it is surrounded by the Uluguru Mountains rising up to a height of over 2,000 m a.s.l., and the Mindu Mountains and Lugala Hills, of 1,200 m and 820 m a.s.l., respectively. The study area, to a large extent, lies on undulating slopes to almost flat land at an altitude of 480 to 600 m a.s.l. (Table 1).

An extensive account on the climate of the study area has been documented by Msanya (1980), Moberg et al. (1982) and Kaaya (1989). The climate at SUA farm

Table 1. Site features of the studied soils.

*Pedon	Elevation m a.s.l.	Slope %	Mode of formation	Internal profile drainage	Local map coordinates (Topo-sheet183/3)
1	524	3–4	Colluvial and in situ	Well drained (class 4)	37 M CC 500428
2	507	<1	In situ	Well drained (class 4)	37 M CC 498433
3	498	4	Colluvial and in situ	Well drained (class 4)	37 M CC 489439
4	508	<1	Fluvial	Imperfect (class 2)	37 M CC 497433
5	525	1–2	Fluvial	Well drained (class 4)	37 M CC 502429
6	511	<1	Colluvial and in situ	Well drained (class 4)	37 M CC 498435
7	518	2–3	Colluvial and in situ	Well drained (class 4)	37 M CC 505438
8	513	1–2	In situ	Well drained (class 4)	37 M CC 498445
9	513	3	Colluvial	Well drained (class 4)	37 M CC 501448
10	518	3–4	Colluvial and in situ	Well drained (class 4)	37 M CC 505448
11	526	<1	In situ	Well drained (class 4)	37 M CC 509443
12	523	3–4	Colluvial	Well drained (class 4)	37 M CC 511443

*The term "pedon" (Soil Survey Staff, 1975) instead of soil profile has been used to emphasize that soil is a three dimensional entity.

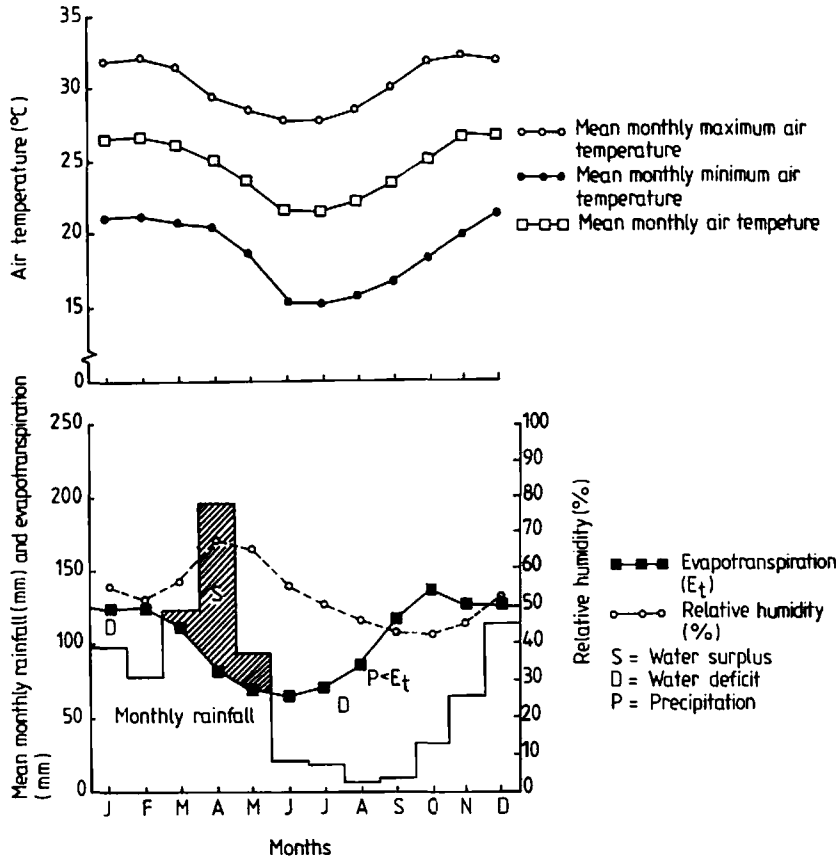


Fig. 3. Climatic data for SUA farm (1971–1986).

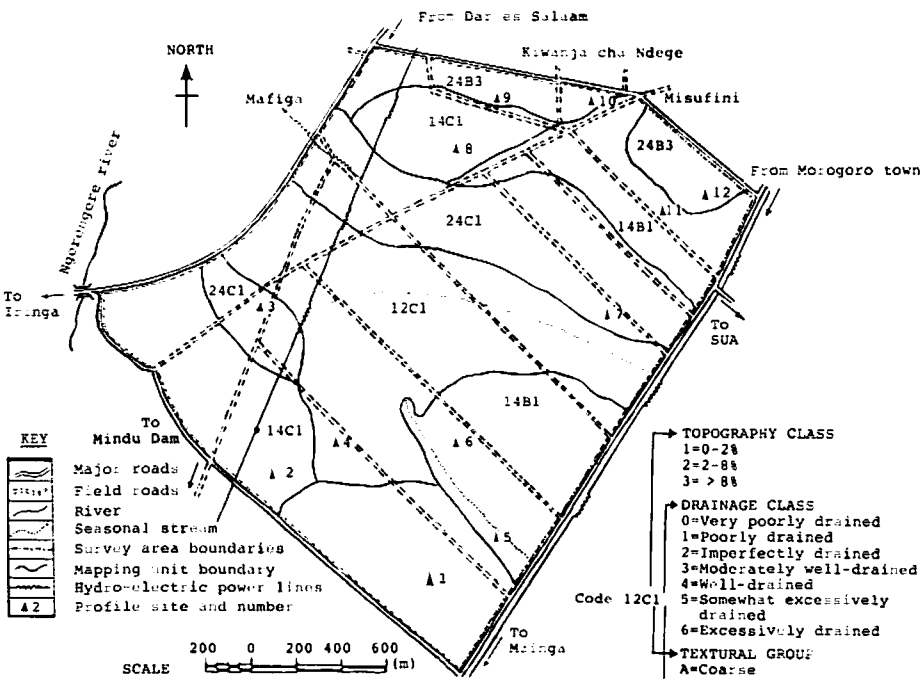
is of a sub-humid tropical type. The area experiences two rainfall peaks in a year (Fig. 3). The short and lighter rains last from November to January with the peak in December. They are followed by a short, dry period in mid-January or February. The long and heavier rains last from March to May with the peak period in April. The onset and distribution of the rainfall are irregular and unreliable.

Information on air temperature is also given in Figure 3. The mean monthly temperature varies from 21.4°C and 21.3°C in June and July, respectively, to 26.4°C in November to February. The mean monthly maximum temperature ranges from 27.5°C, during the coldest months, to 32.0°C, during the hottest months. The mean monthly minimum temperature ranges from 15.1°C, during the coldest months to 21.5°C, during the hottest months. The mean annual air temperature for the period considered in compiling Figure 3 (1971–1986) is 24.4°C. The average soil temperature has been estimated as 25.4°C, by adding 1°C to the mean annual air temperature (after Soil Survey Staff, 1975) and, thus, the soil temperature regime is isohyperthermic.

Nearly all the vegetation in the farm has been disturbed by man through cultivation. The local vegetation is mainly grassland dominated by *Andropogon* spp., Hyparrhenia spp. and *Themeda* spp. Cultivation of maize and sorghum is the main land use in the study area. Beans and rice are also cultivated. All these crops are grown under rainfed conditions.

II. Soil Survey, Laboratory Analysis and Soil Classification

A grid survey was employed in the field supported by some information gathered from aerial photographs. A total of 182 auger holes were examined resulting in an overall survey intensity of 1 observation per 2 ha. Supplementary auger hole observations were later made to locate the position of soil boundaries. At least one representative soil profile was excavated for each mapping unit identified. A total of 12 pedons (see Fig. 4) were studied. Soils were described according to the FAO (1977) and Soil Survey Staff (1951) guidelines. Soil color was determined using



SOIL MAP LEGEND

Map unit	Slope (%)	Effective soil depth (cm)	Soil drainage	Topsoil texture	Extent (ha)
12C1	0-2	> 100	Imperfect	Sandy clay	110
14C1	0-2	> 100	Well	Sandy clay	74
14B1	0-2	> 100	Well	Sandy clay loam	84
24B3	2-8	50-75	Well	Sandy clay loam	29
24C1	2-8	> 100	Well	Sandy clay	123

Fig. 4. Soil map of the central part of SUA farm.

Munsell Color Charts (Munsell Color Company, 1954). Both disturbed and undisturbed soil samples were collected from each horizon for physico-chemical characterization in the laboratory.

Standard laboratory methods were employed. Texture was determined by Bouyoucos hydrometer method (Day, 1965) after dispersion with Na-hexametaphosphate. Bulk density was determined using the core sample method (Blake, 1965). The water contents at 33 kPa and 1,500 kPa were determined using a pressure plate and a pressure membrane apparatus (US Soil Conservation Service, 1967). The PH was measured potentiometrically in 1:2.5 soil/water suspension and in 1:2.5 soil/0.01M $CaCl_2$ (Dewis & Freitas, 1970). Organic carbon was determined by the wet oxidation method of Walkley and Black (Nelson & Sommers, 1982). The Kjeldahl method (Bremner & Mulvaney, 1982) was employed to determine total nitrogen. Phosphorus was extracted by the Bray and Kurtz-1 method (Bray & Kurtz, 1945) and determined spectrophotometrically (Murphy & Riley, 1962; Watanabe & Olsen, 1965). The CEC and exchangeable bases were extracted by saturating soils with neutral 1m NH_4OAc (Thomas, 1982) and the adsorbed NH_4^+ displaced by K^+ using 1M KCl and then determined by the Kjeldahl distillation method for estimation of CEC. The bases Ca^{++}, Mg^{++}, K^+ and Na^+ displaced by NH_4^+ were measured by atomic absorption spectrophotometry.

Using both field and laboratory data, the soils were classified up to the subgroup level of the US Soil Taxonomy (Soil Survey Staff, 1990), and to sub-unit level of the FAO-UNESCO Soil Classification System (FAO, 1988).

III. Land Evaluation

The land suitability evaluation was done using the principles of the FAO Framework (FAO, 1976) for land evaluation and the FAO Guidelines on land evaluation for rainfed agriculture (FAO, 1984). Using the climatic data, the information obtained from field and laboratory, together with the ecological requirements of the selected crops, the relevant land qualities were used in rating the land by matching crop requirements with the land qualities of each mapping unit. The overall land suitability class for each mapping unit was obtained by subjective combination of the individual ratings (FAO, 1984).

The land qualities used in this evaluation include moisture availability, temperature regime, oxygen availability to roots, rooting conditions, nutrient availability, nutrient retention capacity, potential for mechanization, erosion hazard and conditions for land preparation.

RESULTS AND DISCUSSION

I. Soil Map, Soil Classification and Soil Properties

The soil map is presented as Figure 4. Five mapping units were identified on the basis of topography, drainage, texture and depth. The soil physico-chemical properties are presented in Tables 2 and 3, whereas soil classification results and related

Table 2. Soil physical properties.

Soil sample and depth cm	Munsell soil colour notation		%Particle size distribution			Bulk density g/cc	Water between 33 & 1500kPA
	Moist	Dry	Sand	Silt	Clay		
Pedon 1:							
Ap 0–11	7.5YR 4/4	7.5YR 5/4	53	3.5	43.5	1.4	10.5
B21t 11–36	5YR 4/8	5YR 5/8	33.3	3.5	63.2	1.6	10.7
B22t 36–82	5YR 5/8	5YR 6/8	30.3	3.5	66.2	1.6	14.6
B23t 82–152+	5YR 5/8	5YR 6/8	27.2	4.8	68.0	1.6	14.4
Pedon 2:							
Ap 0–15	5YR 3/4	5YR 4/4	39.3	4.8	55.9	1.1	15.1
B21t 15–49	5YR 4/8	5YR 5/8	30.8	4.7	64.5	1.1	17.2
B22t 49–95	5YR 4/8	5YR 5/8	26.2	6.1	67.7	1.2	16.6
B23t 95–130	5YR 5/8	5YR 6/8	26.3	4.8	68.9	1.3	17.8
B24t 130–150+	5YR 4/8	5YR 5/8	27.2	4.8	68.0	1.3	18.1
Pedon 3:							
Ap 0–17	10R 3/6	10R 4/6	45.8	7.5	46.7	1.2	14.6
B21t 17–43	10R 4/8	10R 5/8	34.3	5.0	60.7	1.3	11.1
B22t 43–83	10R 4/8	10R 5/8	30.8	4.9	64.3	1.3	10.9
B23t 83–115	10YR 3/6	10R 4/8	24.1	5.8	70.1	1.4	13.4
B24t 115–153+	10YR 3/6	10R 4/8	24.1	6.3	69.6	1.4	14.4
Pedon 4:							
Ap 0–10	5YR 2/1	5YR 2/2	48.4	5.7	45.9	1.2	15.4
B1 10–32	5YR 2/1	5YR 2/2	33.6	10.7	55.7	1.4	12.7
B21g 32–65	5YR 3/2	5YR 4/2	50.7	5.6	43.7	1.6	7.3
B22g 65–115	5YR 3/2	5YR 4/2	43.8	5.7	50.5	1.4	6.2
B23g 115–152+	5YR 3/2	5YR 4/2	44.2	5.6	50.2	1.5	6.0
Pedon 5:							
Ap 0–14	5YR 3/3	5YR 3/4	68.6	8.2	23.2	1.5	10.2
B21 14–46	2.5YR 2/4	2.5YR 3/4	66.1	3.2	30.7	1.6	9.2
B22 46–58	2.5YR 3/4	2.5YR 3/6	71.8	4.5	23.7	1.6	7.7
B23 58–72	2.5YR 2/4	2.5YR 3/4	59.6	8.2	32.2	1.6	8.1
B24 72–96	2.5YR 3/4	2.5YR 4/4	82.3	2.4	15.3	1.6	5.4
B25 96–110	2.5YR 2/4	2.5YR 3/4	57.3	7.5	35.2	1.6	7.4
B26g 110–152+	2.5YR 3/2	2.5YR 3/4	45.8	7.4	46.8	1.6	11.8
Pedon 6:							
Ap 0–19	5YR 3/3	5YR 4/4	77.7	5.0	17.3	1.4	8.3
B21t 19–33	5YR 3/3	5YR 4/4	62.7	7.5	29.8	1.5	10.0
B22t 33–70	2.5YR 3/4	2.5YR 4/4	56.6	5.0	38.4	1.5	10.8
B23t 70–150	5YR 4/6	5YR 5/6	56.2	5.0	38.8	1.6	6.6
B24t 150–160+	5YR 4/6	5YR 5/6	32.2	10.0	52.8	1.6	17.0
Pedon 7:							
Ap 0–16	10R 3/3	10R 3/4	53.9	5.2	40.9	1.2	7.1
B21t 16–40	10R 3/6	10R 4/6	39.8	7.4	52.8	1.3	5.2
B22t 40–88	10R 4/6	10r 5/8	37.0	6.2	56.8	1.3	6.1
B23t 88–158+	10R 3/6	10R 4/8	36.6	3.7	59.7	1.3	6.7
Pedon 8:							
Ap 0–13	2.5YR 3/4	2.5YR 4/4	60.0	3.7	36.3	1.4	12.6
B1t 13–44	10R 3/6	10R 4/8	48.5	2.5	49.0	1.3	10.4
B21t 44–76	10R 3/6	10R 4/8	36.1	4.9	56.0	1.4	14.8
B22t 76–122+	10R 4/6	10R 5/8	36.8	3.7	59.5	1.4	16.4

Table 2 cont.

Pedon 9:							
Ap 0–8	2.5YR 2/4	2.5YR 3/4	52.0	4.9	30.1	1.5	11.4
B2 8–20	10R 3/6	10R 4/6	59.5	3.7	36.8	1.5	10.0
B3 20–80	10R 3/6	10R 4/6	54.1	5.4	40.5	1.5	5.8
C 80–122+	10R 3/6	10R 4/6	59.0	6.2	34.8	1.6	n.d.
Pedon 10:							
Ap 0–17	5YR 3/2	5YR 4/2	74.0	6.2	19.8	1.5	10.6
B2t 17–46	2.5YR 3/4	2.5YR 4/4	53.2	8.7	38.1	1.5	11.6
B3t 46–102	2.5YR 3/4	2.5YR 4/4	58.0	4.9	37.2	1.6	6.2
c 102–124+	n.d.	n.d.	n.d	n.d.	n.d.	n.d	n.d.
Pedon 11:							
Ap 0–17	5YR 3/3	5YR 4/3	63.6	6.2	30.2	1.4	12.0
B21t 17–42	2.5YR 3/6	2.5YR 4/6	50.2	3.7	46.1	1.4	13.6
B22t 42–100	2.5YR 4/6	2.5YR 4.576	45.5	4.9	49.6	1.4	13.4
B23t 100–124	2.5YR 4/6	22.5YR 4.576	49.3	6.2	44.5	1.4	14.5
B24t 124–146	2.5YR 3/6	2.5YR 4/6	43.4	7.5	49.1	1.5	16.6
c 146–153+	n.d.	n.d.	n.d	n.d.	n.d.	n.d	n.d.
Pedon 12:							
Ap 0–12	5YR 3/4	5R 4/4	58.2	7.4	34.4	1.4	10.6
B2 12–51	5YR 3/3	5YR 4/4	51.1	8.7	40.2	1.4	9.9
B3 51–60	5YR 4/4	5YR 5/4	47.2	7.4	45.4	1.6	6.8
c 60–125+	n.d.	n.d.	n.d	n.d.	n.d.	n.d	n.d.

Table 3. Soil chemical properties.

Soil sample and depth (cm)		pH H_2O	pH $CaCl_2$	P (mg kg^{-1})	C %	N %	Ca	Mg	K	Na	NH_4OAc CEC	BS
							me/100g soil				me/100g soil	%
Pedon 1:												
Ap	0–11	5.8	4.5	1.3	1.1	0.21	1.70	0.86	0.90	0.08	13.72	25.8
B21t	11–36	5.3	4.3	1.3	0.7	0.11	1.12	0.58	0.35	0.15	16.66	13.2
B22t	36–82	5.3	4.3	1.4	0.5	0.08	0.47	0.66	0.10	0.08	17.64	7.4
B23t	82–152+	5.3	4.2	1.1	0.3	0.05	0.70	1.36	0.09	0.27	15.68	15.4
Pedon 2:												
Ap	0–15	5.6	4.6	4.4	1.6	0.22	3.85	1.56	0.67	0.08	18.62	33.1
B21t	15–49	5.6	4.4	3.5	0.5	0.14	1.88	1.23	0.18	0.16	15.68	22.0
B22t	49–95	5.8	4.5	3.5	0.4	0.09	0.94	0.82	0.10	0.29	20.58	10.4
B23t	95–130	5.7	4.5	3.5	0.4	0.08	1.52	1.56	0.08	0.30	19.60	17.7
B24t	130–155+	6.2	5.0	3.5	0.2	0.08	4.56	2.10	0.08	0.47	20.09	35.9
Pedon 3:												
Ap	0–17	6.6	5.6	5.3	1.4	0.15	5.03	2.18	1.04	0.18	20.09	42.0
B21t	17–43	6.1	5.0	3.5	0.8	0.12	2.23	1.93	0.35	0.21	16.17	29.2
B22t	43–83	6.0	5.0	3.5	0.6	0.11	1.29	2.22	0.21	0.24	16.17	24.5
B23t	83–115+	7.0	5.3	3.5	0.4	0.08	1.33	2.59	0.18	0.53	19.11	24.2
B24t	115–152+	6.3	5.5	2.4	0.4	0.08	2.04	2.10	0.10	0.73	16.66	29.8
Pedon 4:												
Ap	0–10	7.1	6.4	10.5	1.6	0.20	13.00	3.70	0.44	2.35	31.36	62.1
B1	10–32	7.3	6.3	8.8	0.8	0.14	22.93	5.14	0.48	0.72	30.87	94.8
B21g	32–65	7.2	6.2	5.3	0.7	0.10	13.70	3.40	0.25	0.55	25.48	70.3
B22g	65–115	7.5	6.7	5.3	0.5	0.08	20.11	5.25	0.21	1.46	33.32	81.1
B23g	115–152+	7.8	7.0	5.3	0.3	0.08	19.16	7.61	0.21	2.20	32.34	90.2

Table 3 cont.

Pedon 5:												
Ap	0–14	7.7	6.6	18.4	1.0	0.13	6.67	1.89	0.58	0.15	15.68	59.2
B21	14–46	7.6	6.4	3.5	0.5	0.11	6.20	2.18	0.18	0.18	14.21	61.5
B22	46–58	7.6	6.4	2.6	0.4	0.09	3.62	1.65	0.18	0.22	10.29	55.1
B23	58–72	7.6	6.3	2.8	0.4	0.08	6.20	2.78	0.18	0.24	14.70	63.9
B24	72–96	7.7	6.8	2.2	0.2	0.07	2.45	0.99	0.07	0.21	7.84	47.4
B25	83–110	7.7	6.2	2.6	0.2	0.07	7.14	3.09	0.18	0.36	16.17	66.6
B3g	110–152+	7.7	6.3	3.5	0.2	0.07	10.42	0.12	0.21	0.67	21.07	73.2
Pedon 6:												
Ap	0–19	7.2	6.3	12.3	0.8	0.14	5.96	1.03	0.58	0.15	11.27	68.5
B21t	19–33	7.2	6.4	8.8	0.7	0.10	8.55	1.69	0.51	0.21	15.19	72.2
B22t	33–70	7.0	6.3	3.5	0.4	0.09	9.25	2.26	0.21	0.18	15.68	75.9
B23t	70–150	7.4	6.4	2.6	0.4	0.08	4.56	1.07	0.11	0.39	6.86	89.4
B24t	150–160+	8.0	6.6	1.8	0.3	0.10	9.78	4.22	0.28	1.63	26.46	60.1
Pedon 7:												
Ap	0–16	7.0	6.2	3.5	1.1	0.17	5.03	1.56	1.00	0.18	8.33	93.3
B21t	16–40	6.1	4.9	2.6	0.4	0.12	2.21	1.48	0.38	0.13	7.27	57.8
B22t	40–88	6.3	4.8	1.8	0.3	0.10	1.51	1.56	0.25	0.16	7.27	47.9
B23t	88–158+	6.6	5.2	1.8	0.3	0.08	1.51	1.65	0.25	0.27	7.27	50.6
Pedon 8:												
Ap	0–13	6.4	5.5	1.8	1.3	0.16	5.03	1.73	0.71	0.10	10.29	73.6
B1t	13–44	5.6	4.2	1.8	0.8	0.12	3.15	1.52	0.18	0.13	16.66	29.9
B21t	44–76	6.0	5.0	0.9	0.5	0.12	2.68	2.35	0.09	0.16	11.76	44.9
B22t	76–152+	6.4	5.3	0.9	0.4	0.08	2.91	2.43	0.08	0.22	10.29	54.8
Pedon 9:												
Ap	0–8	6.8	5.8	3.5	1.2	0.18	8.78	2.06	0.35	8.78	12.74	89.0
B2	8–20	6.5	5.5	2.8	0.8	0.12	6.90	1.56	0.21	6.90	15.68	57.2
B3	20–80	6.9	5.7	0.9	0.5	0.11	7.37	2.10	0.06	7.37	13.72	71.0
C	80–122+	7.0	6.1	0.6	0.3	0.07	9.72	2.14	0.08	9.72	13.23	92.4
Pedon 10:												
Ap	0–17	6.8	5.6	7.9	1.0	0.12	4.79	0.82	0.77	0.13	6.86	94.9
B2t	17–46	5.5	4.6	2.6	0.6	0.11	2.91	0.82	0.25	0.15	9.80	42.1
B3	46–102	6.2	4.9	1.8	0.4	0.09	3.39	1.15	0.18	0.24	10.78	46.0
C	102–124+	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Pedon 11:												
Ap	0–17	6.4	5.6	1.8	1.1	0.14	4.32	1.48	0.81	0.13	12.74	52.9
B21t	17–42	6.1	5.1	1.8	0.6	0.11	2.68	1.98	0.18	0.18	13.72	36.6
B22t	42–100	6.6	5.4	0.9	0.4	0.10	1.98	2.72	0.09	0.16	14.21	34.8
B23t	100–121+	6.8	5.5	0.9	0.4	0.08	2.21	2.67	0.13	0.24	25.00	21.0
B24t	121–146	6.9	5.6	0.9	0.3	0.08	3.39	2.98	0.12	0.45	28.42	24.4
C	146–153+	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Pedon 12:												
Ap	0–12	7.8	6.8	3.5	1.0	0.18	34.18	0.99	0.48	0.10	44.59	80.2
B2	12–51	7.8	6.9	1.8	0.4	0.10	36.69	1.32	0.21	0.16	39.20	97.9
B3	51–60	7.9	7.0	1.8	0.3	0.09	39.56	2.06	0.21	0.18	42.14	99.7
C	60–125+	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d

n.d=not determined.

details are summarized in Table 4. There were four soil orders of the US Soil Taxonomy, namely Entisols, Alfisols, Ultisols and Oxisols were identified corresponding to six soil units of the FAO-UNESCO Soil Classification System, namely, Eutric Fluvisols, Eutric Nitisols, Dystric Nitisols, Chromic Luvisols, Eutric Cam-

Table 4. Mapping units and soils of the studied area.

Mapping unit	Total area (ha)	Representative soils		Pedon No.
		US Soil Taxonomy	FAO-Unesco Classification	
12Cl	110	Vertic Ustifluvents	Eutric Fluvisols	4
14Cl	74	Oxic Paleustalfs,	Eutric Nitisols,	8
		Typic Paleustalfs	Dystric Nitisols	2
14B1	84	Typic Rhodustults,	Dystric Nitisols	11
		Mollic Ustifluvents,	Eutric Fluvisols	5
		Typic Haplustalfs	Chromic Luvisols	6
24B3	29	Typic Ustorthents,	Eutric Cambisols	9 and 12
		Rhodic Paleustalfs	Dystric Nitisols	10
24C1	123	Paleustults	Dystric Nitisols	1
		Typic Haplustults	Dystric Nitisols	3
		Kandiustalfic Eutrustox	Rhodic Ferralsols	7

bisols and Rhodic Ferralsols. Of the 420 ha surveyed, 281 ha and 139 ha were, respectively, moderately suitable (S_2) and marginally suitable (S_3) for maize. For sorghum, 310 ha and 110 ha were, respectively, moderately suitable (S_2) and marginally suitable (S_3), while for rice, not suitable (N_1) and moderately suitable (S_2), respectively. 281 ha were moderately suitable (S_2) and 139 ha were marginally suitable (S_3) for field beans. Limitations common in the mapping units in the study were low soil fertility and low moisture availability due to insufficient and sporadic rainfall during the growing period. Proper soil management practices including application of fertilizers and maintenance of soil organic matter will improve soil fertility and water-holding capacity of the soils of SUA farm and, hence, improve their productivity. Irrigation is deemed necessary to supplement moisture supply both at the beginning and towards the end of the growing period. Soil Fertility evaluation for the different mapping units is discussed hereafter, based on the rating established by Euroconsult (1989) and Landon (1984).

Mapping unit 12Cl

Soils of this mapping unit were classified as Vertic Ustifluvents (US Soil Taxonomy) and correspond to Eutric Fluvisols (FAO-UNESCO Classification). These soils, which are represented by pedon 4, are deep with imperfectly drained black sandy clay topsoil over dark reddish brown clay subsoil and have poorly developed horizons. Based on both the physical and chemical properties, they are of medium fertility status. The major soil fertility limitations include low available phosphorus, water-logging conditions and mechanical resistance to root penetration.

Mapping unit 14Cl

Pedons 8 and 2 represent the soils of this mapping unit. These soils were classified as Oxic Paleustalfs and Typic Paleustalfs, respectively (US Soil Taxonomy), and correspond to Eutric and Dystric Nitisols, respectively, in the FAO-UNESCO Classification. They are deep and well-drained, with well-developed horizons. Based on the levels of organic matter, CEC, the amount of individual exchangeable cations, soil reaction and the available water content, mapping unit 14Cl is of low fer-

tility status.

Mapping unit 14B1

The soils of this mapping unit are represented by pedons 11, 5 and 6. They have been classified as Typic Rhodustults, Mollic Ustifluvents and Typic Haplustalfs, respectively, in the US Soil Taxonomy and correspond to Dystric Nitisols, Eutric Fluvisols and Chromic Luvisols in the FAO-UNESCO Classification. The soils are generally deep, well-drained, medium to coarse-textured, and have low available water content. They can be considered of low to medium fertility status.

Mapping unit 24B3

Pedons, 9, 12 and 10 represent the soils of this mapping unit. The first two pedons were classified as Typic Ustorthents (US Soil Taxonomy) and as Eutric Cambisols (FAO-UNESCO Classification), while the third was classified as Rhodic Paleustalfs (US Soil Taxonomy) and as Dystric Nitisols (FAO-UNESCO Classification). The soils are moderately deep and well-drained, and their topsoil texture ranges from sandy loam to sandy clay loam. Based on the physical and chemical properties, the soils of this mapping unit are of low fertility status. They have low available phosphorus and low CEC.

Mapping unit 24C1

The soils in this mapping unit are represented by pedons 1, 3 and 7. Pedon 1 was classified as Paleustults and pedon 3 as Typic Haplustults (US Soil Taxonomy) and they were both classified as Dystric Nitisols (FAO-UNESCO Classification), while pedon 7 was classified as Kandiustalfic Eutrustox (US Soil Taxonomy) and as Rhodic Ferralsols (FAO-UNESCO Classification). They are deep and well-drained, and their textures vary gradually with depth from sandy clay in the surface horizons to clay in the subsurface horizons. These can be considered of low fertility as they have low available water content, low organic matter and nitrogen content, very low amounts of phosphorus and low CEC.

II. Land Suitability Classification

The ratings of land use requirements for the various land utilization types have been compiled and summarized in Tables 5a, 5b, 5c and 5d for maize, sorghum, rice and field beans, respectively (FAO, 1976, 1984). The land qualities of the different mapping units were matched with the said requirements. The results on the land suitability ratings are given in Tables 6a, 6b, 6c and 6d, respectively, for maize, sorghum, rice and beans. Table 7 presents a summary of the overall land suitability classification of the different mapping units for the four crops under consideration, specifying the various suitability classes, their area and percentage in the surveyed area. The subjective combination method described by FAO (1984) was used to obtain the overall land suitability classes, whereby the most important land qualities are given more weight in assigning the final suitability class.

The common limitations in the surveyed area are low fertility status (f) as indicated by low CEC, low base saturation and low organic matter content, total nitro-

Table 5a. Rating of land use requirements for rainfed maize production.

Land quality	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	>600	400–600	200–400	<200
Temperature regime	Mean temperature in growing period	°C	24–30	20–24, 30–32	15–20, 32–35	<15, >35
Oxygen availability to roots	Soil drainage	Drainage class	well	Moderately well	Imperfect	Poor, very poor
Rooting conditions	Effective soil depth	cm	>120	75–120	30–75	<30
Nutrient availability:	Soil reaction	pH	6.0–6.5	5.5–6.0, 6.5–7.0	5.0–5.5, 7.0–8.2	<5.0, >8.2
	Topsoil organic C	%	>2.0	1.0–2.0	0.5–1.0	<0.5
	Topsoil N content	%	>0.2	0.1–0.2	0.02–0.1	<0.02
	Topsoil available P	mg/kg	>40	10–40	3–10	<3
Nutrient retention Capacity:	Base saturation	%	>80	40–80	20–40	<20
	Topsoil CEC	me/100g	>25	13–25	6–12	<6
Potential for mechanization	Slope angle	%	<8	8–20	20–40	>40
Erosion hazard	Slope angle	%	<4	4–8	8–16	>16

gen and available phosphorus. None of the five mapping units falls under highly suitable (S1) class, because of the low soil fertility status. Moisture availability (m) is another limitation which affects crop production in the farm. The rainfall is not very reliable and sometimes not evenly distributed during the growing season. Oxygen availability to plant roots (w) is a limitation only in mapping unit 12Cl, where soils are imperfectly drained. Rooting conditions (r) could be a limitation in mapping unit 24B3, where some soils are shallow. Shallow soils reduce the ability of plant roots to exploit their environment, working as a physical barrier to root development. The coarse texture (t) of topsoil of mapping unit 24B3 is a severe limitation for rice production as rice requires soils with medium to fine texture. The slopes of mapping units 24B3 and 24C1 makes land preparation (v) a severe limitation to rice production. There is almost no limitation to mechanization (q) in the study area as the slope of the land is generally less than 6%. Soil workability (p) is a slight limitation for crop production only in mapping unit 12C1, because its moist soil consistency is generally firm.

More details regarding the suitability ratings of the mapping units are presented hereafter.

Table 5b. Rating of land use requirements for rainfed sorghum production.

Land quality	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	>600	300–600	150–300	<150
Temperature regime	Mean temperature in growing period	°C	24–32	20–24, 32–35	15–20, 35–40	<15, >40
Oxygen availability to roots	Soil drainage	Drainage class	Well, moderately well	Imperfect	Imperfect	Poor, very poor
Rooting conditions	Effective soil depth	cm	>100	50–100	30–50	<30
Nutrient availability:	Soil reaction	pH	6.0–7.5	5.6–6.0, 7.5–8.0	5.0–5.5, 8.0–8.5	<5.0, >8.5
	Topsoil organic C	%	>2.0	1.0–2.0	0.5–1.0	<0.5
	Topsoil N content	%	>0.2	0.1–0.2	0.02–0.1	<0.02
	Topsoil available P	mg/kg	>40	10–40	3–10	<3
Nutrient retention capacity:	Base saturation	%	>80	40–80	30–40	<30
	Topsoil CEC	me/100g	>25	13–25	6–12	<6
Potential for mechanization	Slope angle	%	<8	8–20	20–40	>40
Erosion hazard	Slope angle	%	<4	4–8	8–16	>16

Mapping unit 12C1

This mapping unit is classified as marginally suitable with suitability subclass S_3 wf for maize, sorghum, and field beans. The major and severe limitation for these crops is low oxygen availability to plant roots due to the imperfect drainage of the soils. Due to the low levels of nitrogen and phosphorus, soil fertility is a slight limitation to crop production in this mapping unit. As for rice, the mapping unit 12C1 is classified as moderately suitable in subclass S_2fm. Paddy rice prefers waterlogged conditions. The fine texure of the soil is preferable for this crop as it increases the soil water retention capacity, while the flat topography of the land provides suitable conditions for rice field preparation. However, the low levels of nitrogen and phosphorus, and low moisture availability at some periods in the growing season are a moderate limitation for the crop. Except for the month of April, the area receives less than 160 mm of average monthly rainfall during the growing period (see Fig. 3), which is less than the monthly rainfall requirement for rainfed rice. With irrigation and fertilizer addition, the soils of this mapping unit can be highly productive.

Table 5c. Rating of land use requirements for rainfed rice production.

Land quality	Diagnostic factor	Unit	Factor rating			
			Highly suitable (sl)	Moderately suitable (s2)	Marginally suitable (s3)	Not suitable (n)
Moisture availability	Total rainfall in growing period	mm	>200	150–200	100–150	<100
Moisture rentention	Texture of topsoil	Textural class	C, SiC, CL	SC, SiCL SiL	SL, L and SCL	S, LS
Temperature regime	Mean temperature in growing period	°C	24–28	22–24, 28–30	18–22, 30–35	<18, >35
Rooting conditions	Effective soil depth	cm	>75	50–75	25–50	<25
Nutrient availability:	Soil reaction	pH	5.5–6.0	5.0–5.5, 6.0–7.0	4.0–5.0, 7.0–8.0	<4.0, >8.0
	Topsoil organic caborn	%	2.0–4.0	1.0–2.0	0.5–1.0	<0.5 >5.0
	Topsoil N content	%	>0.2	0.1–0.2	0.05–0.1	<0.05
	Topsoil available P	mg/kg	>40	20–40	10–20	<10
Nutrient retention capacity	Base saturation	%	>75	50–75	30–50	<30
	Topsoil CEC	me/100g	>25	13–25	6–13	<6
Conditions for land preparation	Slope angle	%	<1	1–2	2–4	>4

C: clay; CL: clay loam; L: loam; LS: loamy sand; S: sand; SC: sandy clay; SCL: sandy clay loam; SL: sandy loam; SiC: silty clay; SiCL: silty clay loam; SiL: silty loam.

Mapping unit 14C1

This mapping unit is moderately suitable (subclass S_2fm) for rainfed maize, sorghum, and field beans. The limitations are insufficient moisture availability, due to shorter rainfall period relative to growing period, and low soil fertility status. As far as rice is concerned, this mapping unit is rated as not suitable (N_1 tm), the major limitations being the coarse texture of the topsoil, which reduces the soil water retention capacity, low fertility and insuficient soil moisture supply during the growing period.

Mapping unit 14B1

This mapping unit is moderately suitable (subclass S_2fm) for rainfed maize, sorghum and field beans and is not suitable (subclass N_1vtm) for rice. The major limitations for crop production under rainfed conditions are suboptimal moisture availability and low soil fertility status. The average monthly rainfall during the growing period is below the rainfed rice requirement of 160–300 mm.

Mapping unit 24B3

This mapping unit is classified as moderately suitable (subclass S_2fm) for sorghum, marginally suitable for rainfed maize and field beans (subclass S_3rfme

Table 5d. Rating of land use requirements for rainfed field beans production.

Land quality	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	>600	400–600	300–400	<300
Temperature regime	Mean temperature in growing period	°C	16–20	14–16, 20–24	10–13, 25–27	<10, >27
Oxygen availability to roots	Soil drainage	Drainage class	Well	Moderately well	Imperfect	Excessive, poor, very poor
Rooting conditions	Effective soil depth	cm	>75	50–75	25–50	<25
Nutrient availability:	Soil reaction	pH	6.0–6.8	5.6–6.0, 6.8–7.0	5.2–5.5, 7.0–7.2	<5.2, <7.2
	Topsoil organic C	%	>2.0	1.0–2.0	0.5–1.0	<0.5
	Topsoil N content	%	>0.2	0.1–0.2	0.02–0.1	<0.02
	Topsoil available P	mg/kg	>40	20–40	5–20	<5
Nutrient retention capacity	Base saturation	%	>80	50–80	30–50	<30
	Topsoil CEC	me/100g	>25	13–25	6–12	<6
Potential for mechanization	Slope angle	%	<8	8–20	20–40	>40
Erosion hazard	Slope angle	%	<4	4–8	8–16	>16

and S_3rfm), and not suitable (subclass N_1vtmr) for rainfed rice. The major and severe limitation for arable crop production in this mapping unit is insufficient soil depth. Maize and field beans require deep soils for optimal growth. Low soil fertility status and low moisture supply are the other limitations for growth for many arable crops in this area. The mapping unit is not suitable for rainfed rice, mainly due to the undulating topography (slope 3–5%) which makes land preparation difficult. Moreover, the relatively coarse texture of the topsoil is unsuitable for rainfed rice.

Mapping unit 24C1

This mapping unit is moderately suitable for rainfed maize (subclass S_2fme) and moderately suitable for sorghum and field beans (subclass S_2fm). The common limitations are low soil fertility status and suboptimal moisture supply due to low and unreliable rainfall during the growing period. There is a moderate risk of soil erosion, particularly for maize at an early stage of growth, due to the substantially barren land surface at this stage and the slope of the land which is in the range of 3–5%. This mapping unit is not suitable (subclass N_1vtm) for rainfed rice because of limitations imposed on land preparation due to the relatively high slope. Also

Table 6a. Land suitability rating for rainfed maize.

Land quality/Land use requirement	Mapping units and their suitability ratings									
	12C1	14C1		14B1			24B3		24C1	
	Pedon 4	Pedon 8	Pedon 2	Pedon 11	Pedon 5	Pedon 6	Pedon 9, 12	Pedon 10	Pedon 1, 3	Pedon 7
Moisture availability	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
Temperature regime	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
Oxygen availability	s3	s1	s1	s1	s1	s1	s1	s1	s1	s1
Rooting conditions	s1	s1	s1	s1	s1	s1	s3	s3	s1	s1
Nutrient availability:										
Soil reaction	s3	s1	s2	s1	s3	s3	s2	s2	s2	s2
Topsoil organic C	s2	s2	s2	s2	s2	s3	s2	s2	s2	s2
Topsoil N	s1	s2	s1	s2	s2	s2	s2	s2	s2	s2
Topsoil available P	s2	n	n	n	s2	s2	s3	s3	s3	s3
Nutrient retention capacity:										
Base saturation	s2	s2	s3	s2	s2	s2	s1	s1	s1	s1
Topsoil CEC	s1	s3	s2	s2	s2	s3	s3	s2	s3	s3
Potential for mechanization	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
Erosion hazard	s1	s1	s1	s1	s1	s1	s3	s2	s3	s2
Overall land suitability*	S_3wf	S_2fm	S_2fm	S_2fm	S_2fm	S_2fm	S_3rfme	S_3rfme	S_2fme	S_2fme

*The symbols for overall land suitability classification in Tables 6a, 6b, 6c and 6d are described under Table 7.

the relatively coarse texture of the topsoil and other physical properties are conducive for high water percolation, which is not good for the growth of rice. Moisture availability is also low for the growth of rainfed rice.

Table 6b. Land suitability ratings for rainfed sorghum.

Land quality/Land use requirement	Mapping units and their suitability ratings									
	12C1	14C1		14B1			24B3		24C1	
	Pedon 4	Pedon 8	Pedon 2	Pedon 11	Pedon 5	Pedon 6	Pedon 9, 12	Pedon 10	Pedon 1, 3	Pedon 7
Moisture availability	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
Temperature regime	s1	s1	s1	s2	s2	s2	s2	s2	s2	s2
Oxygen availability	s3	s1	s1	s1	s1	s1	s1	s1	s1	s1
Rooting conditions	s1	s1	s1	s1	s1	s1	s2	s2	s1	s1
Nutrient availability:										
Soil reaction	s1	s1	s2	s1	s2	s1	s1	s1	s1	s2
Topsoil organic C	s2	s2	s2	s2	s2	s3	s2	s2	s2	s2
Topsoil N	s1	s2	s1	s2	s2	s2	s2	s2	s2	s2
Topsoil available P	s3	n	n	n	s2	s2	n	s3	s3	n
Nutrient retention capacity:										
Base saturation	s2	s2	s3	s2	s2	s2	s1	s1	s3	s1
Topsoil CEC	s1	s3	s2	s2	s2	s3	s2	s3	s2	s3
Potential for mechanization	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
Erosion hazard	s1	s1	s1	s1	s1	s1	s2	s2	s1	s2
Overall land suitability	S_3wf	S_2fm	S_2fm	S_2fm	S_2fm	S_2fm	S_2fm	S_2fm	S_2fm	S_2fm

Table 6c. Land suitability rating for rainfed rice.

Land quality/Land use requirement	Mapping units and their suitability ratings									
	12C1	14C1		14B1			24B3		24C1	
	Pedon 4	Pedon 8	Pedon 2	Pedon 11	Pedon 5	Pedon 6	Pedon 9, 12	Pedon 10	Pedon 1, 3	Pedon 7
Moisture availability	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
Temperature regime	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
Moisture retention capacity	s1	s2	s1	s3	s3	s3	s3	s3	s2	s2
Rooting conditions	s1	s1	s1	s1	s1	s1	s3	s3	s1	s1
Nutrient availability:										
Soil reaction	s2	s2	s1	s2	s3	s3	s3	s2	s2	s2
Topsoil organic C	s2	s2	s2	s2	s2	s3	s3	s2	s2	s2
Topsoil N	s1	s2	s1	s2	s2	s2	s2	s2	s2	s2
Topsoil available P	s3	n	n	n	s3	s3	n	n	n	n
Nutrient retention capacity:										
Base saturation	s1	s2	s3	s2	s2	s2	s1	s1	s3	s1
Topsoil CEC	s1	s3	s2	s2	s2	s3	s2	s1	s2	s3
Conditions for land preparation	s1	s1	s1	s1	s3	s3	n	n	n	n
Overall land suitability	S_2fm	N_1ftm	N_1fm	N_1vtm	N_1vtm	N_1vtm	N_1vtmr	N_1tmr	N_1vtm	N_1vtm

Table 6d. Land suitability ratings for rained field beans.

Land quality/Land use requirement	Mapping units and their suitability ratings									
	12C1	14C1		14B1			24B3		24C1	
	Pedon 4	Pedon 8	Pedon 2	Pedon 11	Pedon 5	Pedon 6	Pedon 9, 12	Pedon 10	Pedon 1, 3	Pedon 7
Moisture availability	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
Temperature regime	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
Oxygen availability	s3	s1	s1	s1	s1	s1	s1	s1	s1	s1
Rooting conditions	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
Nutrient availability:										
Soil reaction	n	s1	s2	s1	n	s3	n	s1	s2	s2
Topsoil organic C	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
Topsoil N	s1	s2	s1	s2	s2	s2	s2	s2	s2	s2
Topsoil available P	s3	n	n	n	s2	s3	n	s3	n	n
Nutrient retention capacity:										
Base saturation	s2	s2	s3	s2	s2	s2	s1	s1	s3	s1
Topsoil CEC	s1	s3	s2	s3	s3	s3	s2	s3	s2	s3
Potential for mechanization	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
Erosion hazard	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
Overall land suitability	S_3wf	S_2fm	S_2fm	S_2fm	S_2fm	S_2fm	S_3rfm	S_3rfm	S_2fm	S_2fm

Table 7. Summary of the land suitability classification for rainfed crops in the surveyed area.

Mapping unit	Area (ha)	Proportion of the surveyed area (%)	Land utilization types and suitability* subclasses			
			Maize	Sorghum	Rice	Field beans
12C1	110	26.2	S_3wf	S_3wf	S_2fm	S_3wf
14C1	74	17.6	S_2fm	S_2fm	N_1ftm	S_2fm
14B1	84	20.0	S_2fm	S_2fm	N_1vtm	S_2fm
24B3	29	6.9	S_3rfme	S_2fm	N_1vtmr	S_3rfm
24C1	123	29.3	S_3fme	S_2fm	N_1vtm	S_2fm

*Land suitability class symbols: S_1: Highly suitable; S_2: Moderately suitable; S_3: Marginally suitable; N_1: Currently not suitable.
Land suitability subclass symbols: w: oxygen availaibility limitation; f: soil fertility limitation; t: soil texture limitation; r: rooting condition limitation; e: erosion hazard limitation; m: moisture availability limitation; v: land preparation limitation.