Physical Land Suitability Evaluation for Rainfed Production of Cotton, Maize, Upland Rice and Sorghum in Abobo Area, western Ethiopia

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Abstract

Appropriate land use decisions are vital to achieve optimum productivity of the land and ensure environmental sustainability. Physical land suitability was carried out in Abobo area, western Ethiopia, following the FAO methodology for the determination of length of growing period and maximum limitation method for suitability classification. The result of the study revealed that the climate of the study area is moderately suitable (S2) for the considered varieties of cotton, maize and sorghum, whereas it is marginally suitable (S3) for upland rice. Considering soil and landscape suitability, the most limiting factors were soil depth, wetness, and soil fertility, mostly nitrogen. Based on the FAO model, the potential yields of cotton, maize, upland rice and sorghum were 2,645, 6,409, 4,774 and 4,194 kg ha^{-1}, respectively. However, yield reductions of 7.32 to 12.09% and 6.01 to 11.16% were observed in simulated rainfed yield for maize and upland rice, respectively, as compared with their corresponding potential yields. The differences might mainly be induced due to water limitation, soils and landscape attributes, which suggests use of supplementary irrigation and soil management for optimum and sustainable production. All the limitations, except soil depth, can be improved so as to attain the potential suitability through improving and sustaining soil OM and practicing integrated soil fertility management.

Key words: Suitability evaluation, potential yield, rainfed yield, limiting factor

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1. Introduction

Appropriate land use decisions are vital to achieve optimum productivity of the land and to ensure environmental sustainability. Land should be used based on its capacity to meet human needs and ensure the sustainability of ecosystems (Amiri and Shariff, 2011). Sustainable agriculture would be achieved if lands be categorized and utilized based upon their capacity (FAO, 1983). Thus, land evaluation is a vital link in the chain leading to sustainable management of land resources (FAO, 2007). Land evaluation is the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable (FAO, 1985) and it is also the process of making predictions of land performance over time based on specific types of uses (Al-Mashreki *et al*., 2011). These predictions are then used as a guide in strategic land use decision making.

Physical land suitability evaluation plays an important role in maintaining and developing land use on a spatial basis. It identifies the levels and geographical patterns of biophysical constraints and evaluates potential capacity of land and its sustainable use. A clear assessment of land potentials and of existing resource-related production constraints, as well as the identification ways to attain the potentials and/or alleviate limitations is essential to develop an adequate and sustainable use of land resources (Teshome, 1994). Physical land suitability evaluation can contribute towards better land management; mitigation of land degradation; and designing land use pattern that prevents environmental problems through segregation of competing land uses (Ziadat and Al-Bakri, 2006).

Agriculture in Ethiopia has long been a priority and focus of national policy, such as Agricultural Development-Led Industrialization (ADLI), and various large-scale programs, such as the Plan for Accelerated and Sustained Development to End Poverty (PASDEP). Future overall country development is also expected to be driven by the progress in the agricultural sector. The basis for its development is therefore its natural resources. However, the knowledge about the suitability, productivity and management of those resources are limited. The task of assessing the natural resources of the country and evaluating their suitability for agricultural use and management is extremely urgent.

In the western lowland region of the country, where this research was carried out, some small scale studies were conducted to assess the natural resources of the region mainly for the purpose of regional land use planning (Selkhozpromexport, 1990; Yeshibir, 2003). However, local variability of natural resources cannot be addressed by small scale studies, particularly for Ethiopia which is characterized by great landscape diversity (Fritzsche *et al*., 2007). The land suitability evaluations made by the previous studies were too general, specific land utilization types were not considered. Thus, to contribute in filling this gap, the study was initiated to evaluate the physical land suitability of Abobo area for rainfed cotton, maize, upland rice and sorghum production.

2. Materials and Methods

2.1. Description of the Study Area

The study area, Abobo District, is located at 42 km south of Gambella town and about 808 km from Addis Ababa in the western direction (Figure 1). It lies between 07^0 50’ 47.3” to 08^0 01’ 59.3” N and 34^0 28’ 59.5” to 34^0 34’ 37.1” E. The altitude of the study area ranges from 446 to 490 meters above sea level (masl) with slope ranging from level (0.2-0.5%) to gently sloping (2-5%).

The climate of the region is influenced by the tropical monsoon which is characterized by high rainfall in the wet period from May to October and has little rainfall during the dry period from November to April (Yeshibir, 2003). The mean minimum monthly temperature of the area varies from 16.2 to 21.2 ^{0}C and the mean maximum monthly temperature ranges from 32.1 to 38.2 ^{0}C, whereas the average annual rainfall is 955.5 mm (Figure 2). The region is drained by a number of perennial rivers including, Baro, Alwero, Gillo and Akobo and their tributaries.

The geology of Abobo is characterized by undifferentiated Pleistocene Holocene deposits. According to Davidson (1983), granite, gneiss, schist, sandstone and basalt are the rock types that exist in the region. The major soils of Abobo District include Dystric and Eutric Plinthosols, Dystric and Chromic Cambisols, Eutric Vertisols and Planosols, where Cambisols occur at the upper slope north of Abobo while Plinthosols and Vertisols cover the middle and lower slopes, respectively (Yeshibir, 2003).

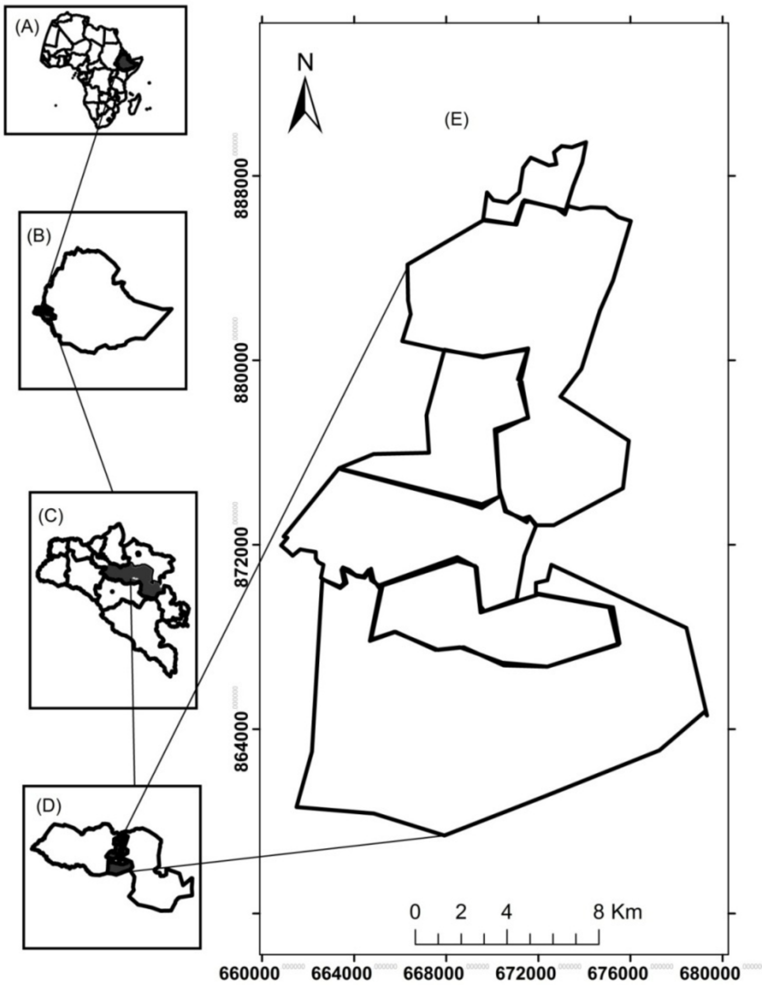

Figure 1. Location of the study area: Ethiopia in Africa (A), Gambella Regional State in Ethiopia (B), Abobo District in Gambella Region (C), specific study area in Abobo District (D) and map of the study area (E).

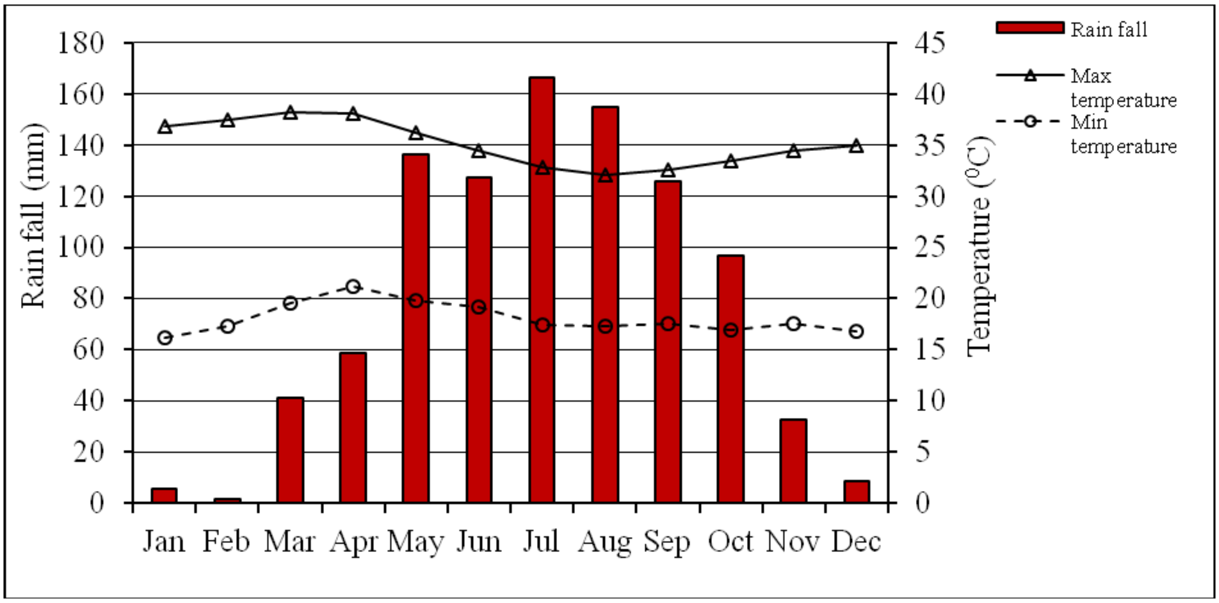

Figure 2. Mean monthly rainfall, monthly minimum (Min) and maximum (Max) temperatures of Abobo area for the years 1975 to 2011.

The Abobo district encompasses forest land, wood land, shrub land, grass land and cultivated lands occupying, 143,086, 75,227, 5,793, 62,997 and 19,854 hectares (ha), respectively (WBISPP, 2001). The forest cover is continuously declining due to settlement and agricultural expansion. The major crops grown by farmers include maize (*Zea mays* L.), sorghum (*Sorghum bicolor*), groundnut (*Arachis hypogae*) and sesame (*Sesamum astivum*), whereas cotton (*Gossypium sp*.) and rice (*Oryza sativa* L.) are cultivated by state farms and investors operating in and around the study area.

2.2. Land Utilization Types and Their Requirements

The land use types considered for the study were under rainfed condition cultivation of three maize, one sorghum, two cotton and three rice varieties. The maize varieties considered were: Abobako with growing period of 112 days; Gusawo with growing period of 116 days; and local cultivar with growing period of 90 days. The sorghum variety was Gambella 1107 with growing period of 90 days. Cotton varieties: Deltapay with growing period of 120 days and Gedera with growing period of 120. Rice variety: Nerica-3, Nerica-4 and Superica-1 with growing period of 120 days.

Maize, sorghum and rice are among the cereals which have high potential in attaining food self sufficiency in the region in particular and in the country at large. Cotton is also very important cash crop adaptable in the study area, which has a growing demand for domestic and international market.

The agro-climatic requirements for the considered land utilization types were temperature (^{0}C), length of growing period (days) and total growing period rainfall (mm). For soil and landscape attributes drainage class, texture, slope (%), soil depth (cm), pH, base saturation (%), sum of basic cations (cmol (+) kg^{-1} soi1), organic matter (%), top soil nitrogen (0-200 mm), top soil available phosphorus (0-200 mm), salinity (ECe, dSm^{-1}) and alkalinity (ESP, %), were considered.

The crop requirements were established following the approach of FAO (1983), FAO/UNDP (1984), and Sys *et al*. (1993). The physical land suitability was done using maximum limitation method.

2.3. Agro-climatic Analysis

The length of growing period was determined by comparing dekedal rainfall with reference evapotranspiration (ETo) (Sys *et al.* 1993). The start and end of the growing period and start and end of the humid period were determined using linear interpolation technique as described in Sys *et al.* (1993). The climatic resources data was obtained from Gambella Meteorological Agency, Abobo Meteorological Station. The rainfall and temperature data were obtained from 1975-2011 and for relative humidity, wind speed and sunshine hours from 2006-2011. The data for relative humidity, wind speed and sunshine hours were available in Gambella Meteorological Agency only for a few recent years.

Reference evapotranspiration was estimated following CropWat Version 8.0 for Windows based on FAO Penman-Monteith method.

2.4. Description and Characterization of Land Mapping Unit

Identification of the land mapping units (LMUs) was based on slope, soil depth and soil texture. The entire study area was categorized into three slopes, four soil depths and two textural classes. Seven representative pedons (A-1 to A-7) were opened across the study area. The pedons were classified according to WRB (IUSS Working Group, 2006) as Haplic Cambisols, Vertic Luvisols, Mollic Leptosols and Mollic Vertisols (Table 1). The pedons were further categorized into five LMUs: 1Ac, 1Bc, 1El, 2Cc and 3Cl (Figure 3) for the purpose of land suitability evaluation. The first number and the last small letter in the LMU designation indicate the slope (1= 0.0-1.0, 2= 1.0-2.0 and 3= 2.0-5.0%) and texture (c= clay and l= loam), respectively, whereas the middle capital letters indicates the soil depth (A= >150, B= 100-150, C= 50-100 and E= <30 cm) (Table 1).

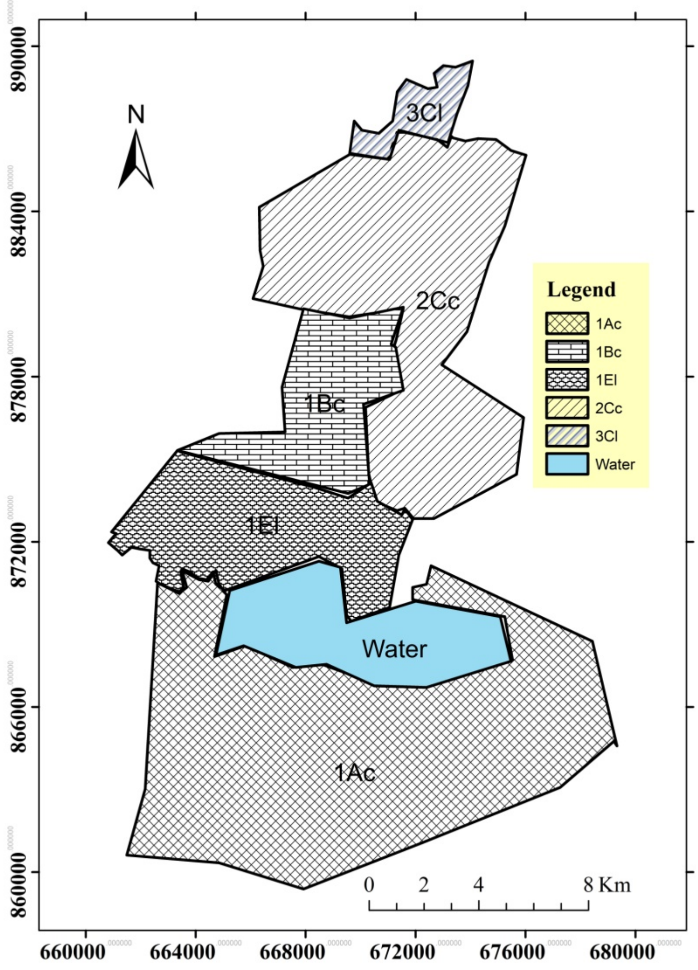

Figure 3. Mapping units of the study area

Table 1. The identified mapping units and their area coverage in the soils of Abobo area

Mapping unit	Slope (%)	Soil depth (cm)	Texture	Area		Soil classification
				ha	%	
1Ac	0-1.0	>150	Clay	12,117.2	45.3	Mollic Vertisols
1Bc	0-1.0	100-150	Clay	2,552.6	9.6	Mollic Vertisols
1El	0-1.0	<30	Loam	3,677.6	13.8	Mollic Leptosols
2Cc	1.0-2.0	50-100	Clay	7,698.1	28.8	Vertic Luvisols
3Cl	2.0-5.0	50-100	Loam	674.4	2.5	Haplic Cambisols

2.5. Land suitability Evaluation and Mapping

The land suitability classification was made following the methods of FAO (FAO, 1976; 1983; 2007). Automated Land Evaluation System (ALES) (Rossiter & Van Wambeke, 2000) was employed for the evaluation. The suitability map for each considered land utilization type was made using ArcGIS 9.3. The boundaries of the *kebeles* (the smallest administrative unit) in the study area were delineated using digital map of Gambella region, which was used as a base for soil survey and physical land suitability mapping. Hand held GPS was used for geo-referencing soil pedon and augering points.

2.6. Estimation of production potential

Radiation-temperature limited yield, simulated rainfed yield and expected land-determined yield were estimated following the FAO model (Van Ranst, 1991):

$$Y_m = 0.36 * bgm * KLAI * Hi / (1/L) + (0.25 * ct) \qquad (2.1)$$

where Y_m = radiation-temperature limited yield (kg dry matter ha^{-1}), bgm = maximum gross biomass production rate (kg CH_2O ha^{-1} day^{-1}), KLAI = correction factor for leaf area index below 5 (m^2m^{-2}), Hi = harvest index (fraction of total net biomass that is economically useful), L = length of crop growth cycle (days) and ct = respiration coefficient (ct = 0.0108 (0.044 + (0.0019*t) + (0.001*t2)), where t is mean daily temperature)

$$Ya = Y_m * (1 - ky * (1 - (ETa / ETm))) \quad (2.2)$$

where Ya = rainfed (moisture-limited) yield, Y_m = radiation-temperature limited yield, Ky = yield response factor, ET_a = actual evapotranspiration and ET_m = maximum evapotranspiration.

$$ExYo = Ya * Index(SL) \quad (2.3)$$

where ExYo = expected land-determined yield at optimum management, Ya = rainfed yield and index (SL) = parametric index of a land unit based on soil and landscape constraints.

Parametric approach (Storie's method of calculation) was used for ratings and soil index calculation (Van Ranst, 1991):

$$SL = A * [B / 100 * C / 100 * D / 100 * E / 100 * F / 100] \quad (2.4)$$

where SL = soil index, A = rating of profile development, B = rating for texture, C = rating for soil depth, D = rating for color/drainage condition, E = rating for pH/base saturation, F = rating for the development of the A horizon.

3. Results and Discussion

3.1. Description and Characterization of Land Mapping Unit

3.1.1. Land mapping unit 1Ac

This unit refers to imperfectly drained soils occurring on level land form (0.2 to 0.5 % slope) covering 12,117.2 ha. These soils are very deep (>150 cm) and had black (10YR 2/1) moist surface color. The unit has clay texture with moderate medium to coarse angular blocky structure and friable, sticky and plastic moist and wet consistence, respectively. Currently, most of the area is covered with forest and grass.

The pH (H_2O) values of the unit ranged from 6.0 to 6.2, which was slightly acidic (Horneck *et al.*, 2011). Based on the rating established by Tekalign (1991), the unit had medium status of organic carbon (2.10 to 2.15 %), total nitrogen (0.17 to 0.19 %) and medium status of available phosphorus (4.98 to 5.12 mg kg^{-1}), according to Jones (2003) ratings. But according to Hazelton and Murphy (2007) ratings, it had high status of CEC (35.10 cmolc kg^{-1}) and base saturation (83 to 85 %). The EC and ESP values varied from 0.11 to 0.16 dS m^{-1} and 0.3 to 0.6 %, respectively.

3.1.2. Land mapping unit 1Bc

This unit refers to moderately drained soils occurring on nearly level terrain (0.5 to 1.0 % slope) covering 2,552.6 ha. These soils are deep (100 – 150 cm) and had very dark gray (10YR 3/2) moist surface color. The unit has clayey texture with moderate medium to coarse angular blocky structure and firm, sticky and plastic moist and wet consistence, respectively. In this unit of land the forest and grazing lands have diminished due to the expansion of cultivated land.

The pH (H_2O) values of the unit ranged from 5.4 to 5.6 and categorized under moderately acidic (Horneck *et al.*, 2011). The unit had medium contents of organic carbon (1.88 to 1.95 %) and medium contents of total nitrogen (0.15 to 0.16 %) as per Tekalign (1991) ratings. But it had high contents of available phosphorus (15.96 to 16.43 mg kg^{-1}), CEC (30.15 to 31.18 $cmol_c$ kg^{-1}) and base saturation (74 to 77 %) based on the ratings of Jones (2003) and Hazelton and Murphy (2007), respectively. On the other hand, the values of EC and ESP varied from 0.10 to 0.16 dS m^{-1} and 0.3 to 0.7 %, respectively.

3.1.3. Land mapping unit 1El

This unit refers to well drained soils occurring on nearly level terrain (0.5 to 1.0 % slope) covering 3,677.6 ha. These soils are very shallow (0 – 30 cm) and had very dark grayish brown (10YR 3/2) moist surface color. The unit has clay loam texture with moderate fine to medium granular structure and friable, sticky and slightly plastic moist and wet consistence, respectively. The unit was dominated by forest and grazing land as compared to the cultivated land.

The pH (H_2O) values of the unit ranged from 6.6 to 6.9, which were slightly acidic to neutral as per Horneck *et al*. (2011) ratings. According to the ratings established by Tekalign (1991), the unit had medium contents of organic carbon (2.44 to 2.62 %), medium contents of total nitrogen

(0.19 to 0.22 %) and medium contents of CEC (23.54 to 24.59 $cmol_c$ kg^{-1}) as per Hazelton and Murphy ratings (2007). But it had high contents of available phosphorus (50.61 to 54.01 mg kg^{-1}), and base saturation (79 to 81 %) as per the ratings of Jones (2003) and Hazelton and Murphy (2007), respectively. The values of EC and ESP varied from 0.14 to 0.18 dS m^{-1} and 0.5 to 0.7 %, respectively.

3.1.4. Land mapping unit 2Cc

This unit refers to well drained soils occurring on very gently sloping terrain (1 to 2 % slope) covering 7,698.1 ha. These soils are moderately deep (50 – 100 cm) and had dark brown (10YR 3/3 moist surface color. The unit has clayey texture with weak fine granular structure and friable, sticky and plastic moist and wet consistence, respectively. This unit of land was dominated by cultivated land as compared to the forest and grazing land.

The pH (H_2O) values of the unit ranged from 6.5 to 6.8, which is within the preferred range for most crops. The unit had low to medium contents of organic carbon (1.37 to 1.67 %) and medium contents of total nitrogen (0.12 to 0.13 %) as per Tekalign (1991) ratings. But it had high contents of available phosphorus (41.13 to 49.03 mg kg^{-1}), CEC (36.74 to 38.16 $cmol_c$ kg^{-1}) and base saturation (72 to 75 %) in accordance with the ratings of Jones (2003) and Hazelton and Murphy (2007), respectively. Considering the values of EC and ESP, the values varied from 0.13 to 0.18 dS m^{-1} and 0.2 to 0.5 %, respectively.

3.1.5. Land mapping unit 3Cc

This unit refers to well drained soils occurring on gently sloping (2 to 5 % slope) covering 674.4 ha. These soils are moderately deep (50 - 100 cm) and has clay loam texture with moderate very fine to medium granular structure and friable, sticky and plastic moist and wet consistence, respectively. The unit was dominated with grazing land as compared to forest and cultivated land.

The pH (H_2O) values of the unit ranged from 5.8 to 6.0, which were moderately acidic (Horneck *et al.*, 2011). According to the ratings established by Tekalign (1991), the unit had medium contents of organic carbon (1.63 to 1.72 %) and medium contents of total nitrogen (0.13 to 0.15 %). But it had high contents of available phosphorus (25.43 to 27.04 mg kg^{-1}), CEC (25.4 to 25.49 $cmol_c$ kg^{-1}) and base saturation (63 to 69 %) as per the ratings of Jones (2003) and Hazelton and Murphy (2007), respectively. Similar to other units, these soils were non saline and non sodic.

3.2. Agro-climatic Analysis and Suitability Evaluation

The length of growing period (LGP) was calculated to be 179 days, indicating all the considered land utilization types are within the specified LGP (Figure 4). The growing period in the study area begin on April 21 and end on October 20. The beginning and end of the humid period are May 20 and October 4, respectively.

The result of the study revealed that the agro-climatic situation of the study area is moderately suitable (S2) for the considered varieties of cotton, maize and sorghum, whereas it is marginally suitable (S3) for upland rice, total growing period rainfall being the most limiting factor (Table 2). The moderate suitability is due to the longer LGP. According to Teshome (1994), there are four broad maturity groups: (1) very short maturing (60/75-90 days), (2) short maturing (90-120/130 days), (3) medium maturing (120/130-180 days), (4) long maturing (180-210 days), and (5) very long maturing crops (>210 days). Based on this categorization, the LGP of the study area is most suits for medium maturing crops varieties. On the other hand, the considered crops varieties which grown in the study area are characterized under short maturing, which has an implication in attaining agro-climatic production potential. Therefore, choosing the varieties with relatively longer LGP within the existing crops varieties and developing crops varieties which fit the LGP of the area would help in attaining the agro-climatic production potential of a given crop.

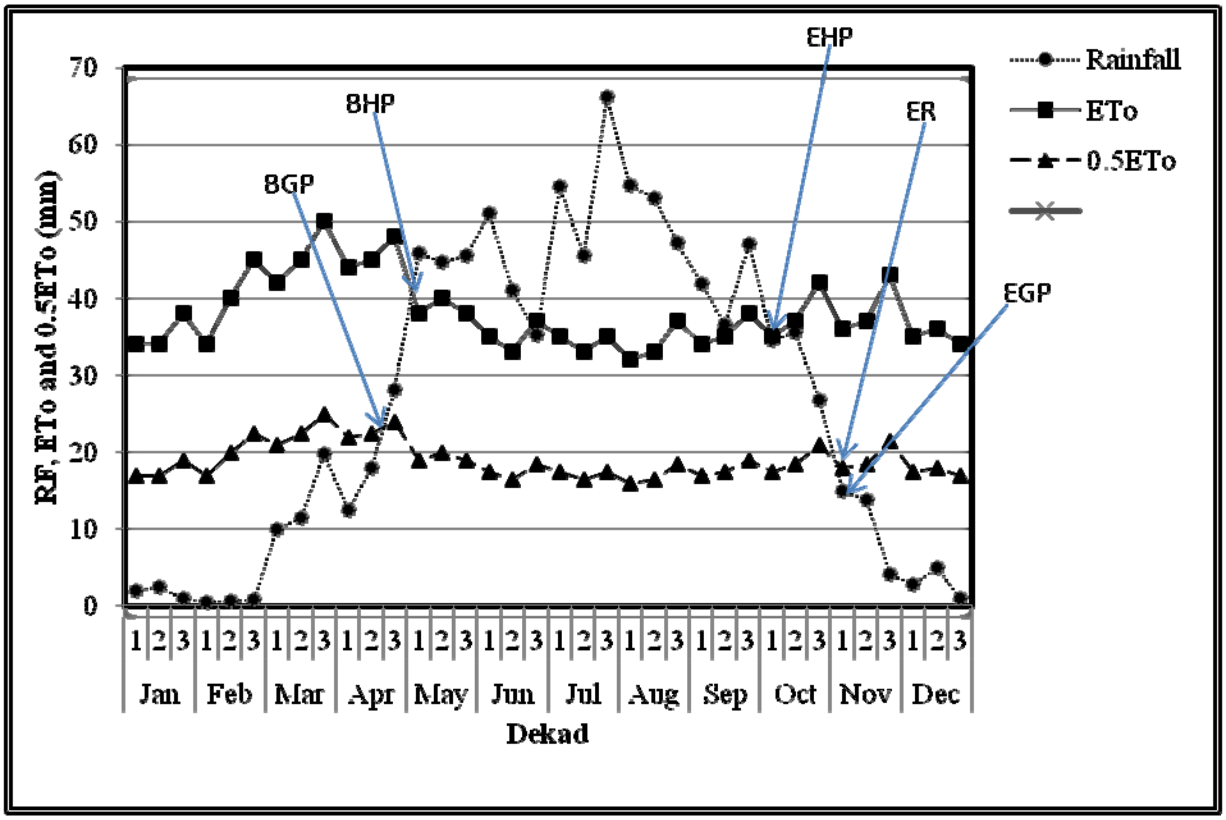

Figure 4. Length of growing period of Abobo area, south-western Ethiopia; BGP= Beginning of growing period, BHP= Beginning of humid period, EHP= End of humid period, ER= End of rains and EGP= End of growing period.

Table 2. Agro-climatic suitability using maximum limitation method

Climatic characteristics	Land utilization type								
	Cotton (days)		Maize (days)			Upland rice (days)			Sorghum (days)
	120[a]	120[b]	112[c]	116[d]	90[e]	120[f]	120[g]	120[h]	90[i]
Mean growing period temperature (^{0}C)	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of growing period (days)	S2	S2	S2	S2	S2	S2	S2	S2	S2
Total growing period rainfall (mm)	S1	S1	S1	S1	S1	S3	S3	S3	S1
Overall climatic suitability	S2	S2	S2	S2	S2	S3	S3	S3	S2

Cotton varieties: [a]Deltapay, [b]Gedera; maize varieties: [c]Abobako, [d]Gusawo, [e]local; rice varieties: [f]Nerica-3, [g]Nerica-4, [h]Superica-1; sorghum variety: [i]Gambella 1107

3.3. Soil and Landscape Suitability Evaluation

Land mapping unit (LMU) 1Ac is marginally suitable (S3) for the considered maize and sorghum varieties, and non suitable (N) for cotton and upland rice varieties due to wetness limitation. Land mapping unit 1Bc is moderately suitable (S2) for all considered LUTs, fertility (nitrogen) being major limitation (Table 3). On the other hand, LMU 1El, which has shallow soil depth, is not suitable (N) for maize and cotton varieties. But it is moderately (S2) and marginally suitable (S3) for sorghum and upland rice varieties, respectively (Table 3).

Mapping unit 2Cc and 3Cl are marginally suitable (S3) for all LUTs; fertility of the soil being major limitation, particularly nitrogen is the most limiting factor in those units (Table 3 and Figure 5-8).

Table 3. Soil and landscape suitability evaluation using maximum limitation method

	Land utilization type			
	Cotton	Maize	Upland rice	Sorghum
Mapping unit	120 days	90-116 days	120 days	90 days
1Ac	N (w)	S3 (w)	N (w)	S3 (w)
1Bc	S2 (n)	S2 (n)	S2 (n)	S2 (n)
1El	N (r)	N (r)	S3 (r)	S2 (r)
2Cc	S3 (n)	S3 (n)	S3 (n)	S3 (n)
3Cl	S3 (n)	S3 (n)	S3 (n)	S3 (n)

Limitations: w = wetness; n = fertility; r = root depth

3.4. Overall Suitability Evaluation

Land mapping unity 1Ac with an area of 12,117.2 ha (45.3%) is marginally suitable (S3w) for the considered maize and sorghum verities, and not suitable (Nw) for cotton and upland rice varieties (Figure 5-8). Land mapping unit 1Bc with an area of 2,552.6 ha (9.6%) is moderately suitable (S2m,n) for cotton, maize and sorghum, and marginally suitable (S3m) for upland rice (Table 4). Land mapping unit 1El, which cover 3,677.6 ha (13.8%), is moderately suitable (S2m,r) for sorghum, marginally suitable (S3m,r) for upland rice, and not suitable (Nr) for the considered maize and cotton varieties (Table 4 and Figure 5-8).

Table 4. Physical suitability evaluation for the mapping units using maximum limitation method

	Land utilization type							
	Cotton 120 days		Maize 90-116 days		Upland rice 120 days		Sorghum 90 days	
LMU	Actual	Potential	Actual	Potential	Actual	Potential	Actual	Potential
1Ac	N (w)	S2 (m)	S3 (w)	S2 (m)	N (w)	S3 (m)	S3 (w)	S2 (m)
1Bc	S2 (m,n)	S2 (m)	S2 (m,n)	S2 (m)	S3 (m)	S3 (m)	S2 (m,n)	S2 (m)
1El	N (r)	N (r)	N (r)	N (r)	S3 (m,r)	S3 (m,r)	S2 (m,r)	S2 (m,r)
2Cc	S3 (n)	S2 (m)	S3 (n)	S2 (m)	S3 (m,n)	S3 (m)	S3 (n)	S2 (m)
3Cl	S3 (n)	S2 (m)	S3 (n)	S2 (m)	S3 (m,n)	S3 (m)	S3 (n)	S2 (m)

LMU = land mapping unit; limitations: w = wetness; n = fertility; r = root depth; m = moisture

Land mapping unit 2Cc with an area of 7,698.1 ha (28.8%) and LMU 3Cl with an area of 674.4 ha (2.5%) are marginally suitable (S3n) for cotton, maize and sorghum, and (S3m,n) for upland rice.

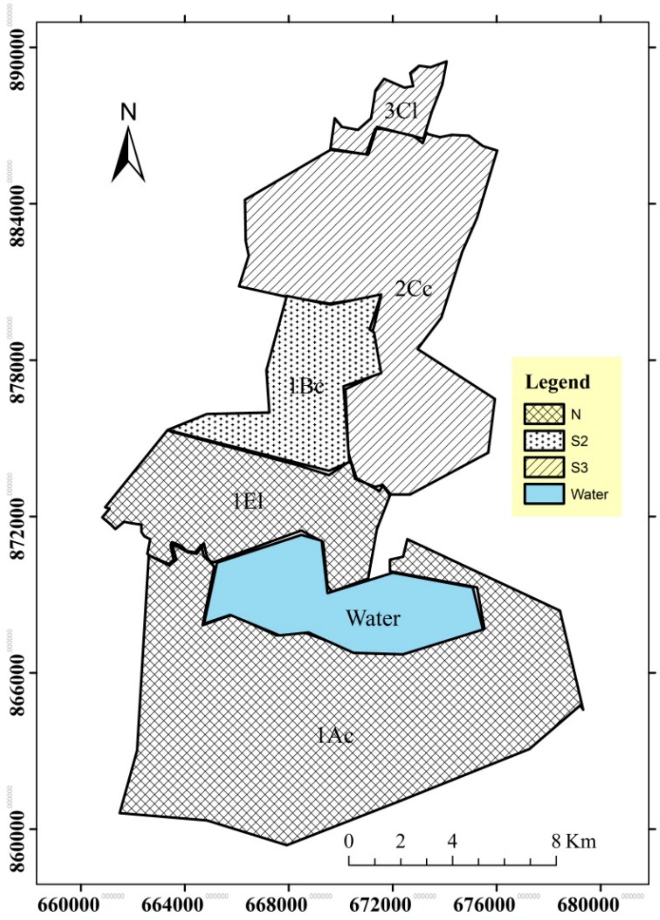

Figure 5. Land suitable evaluation map for cotton.

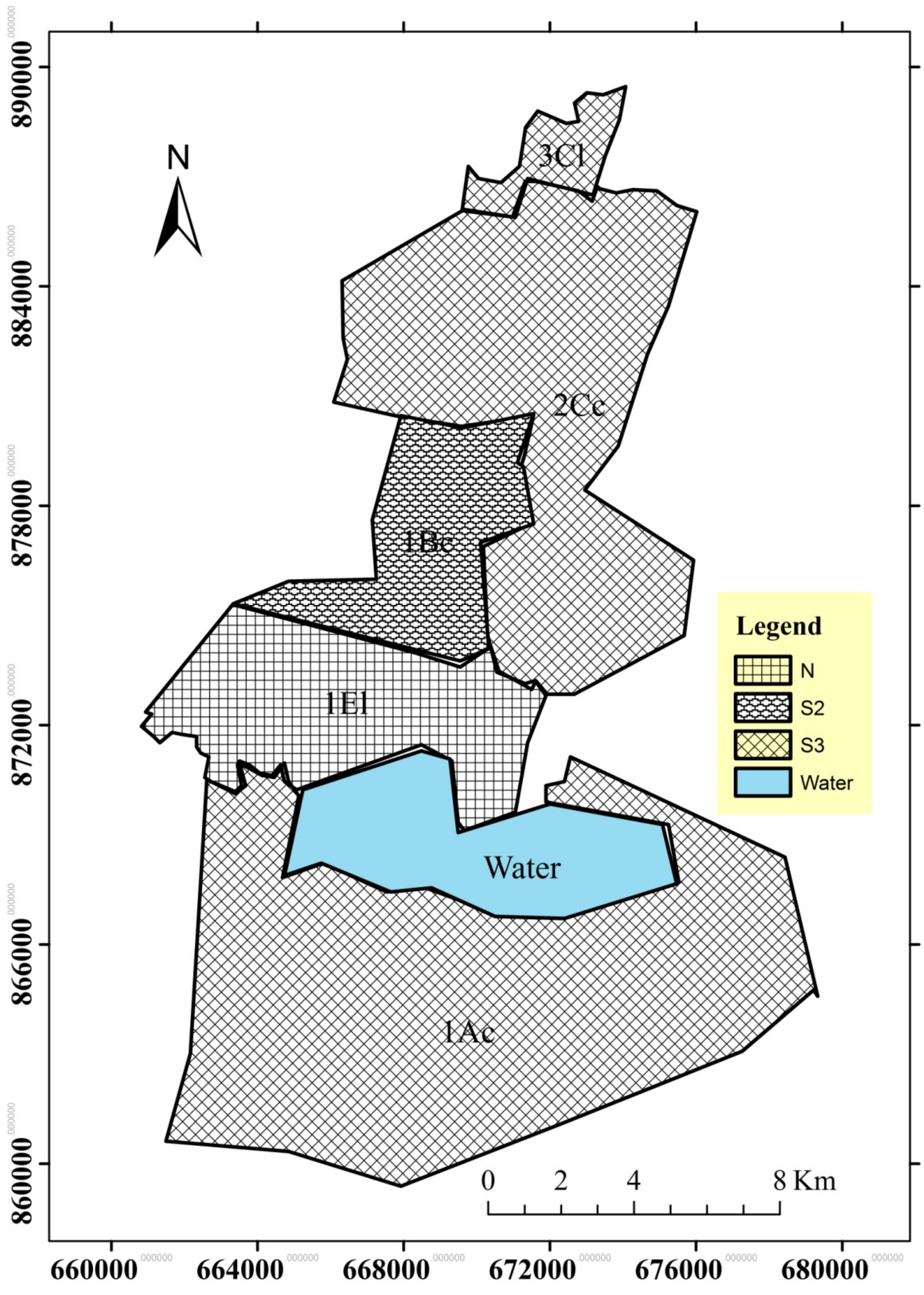

Figure 6. Land suitability evaluation map for maize.

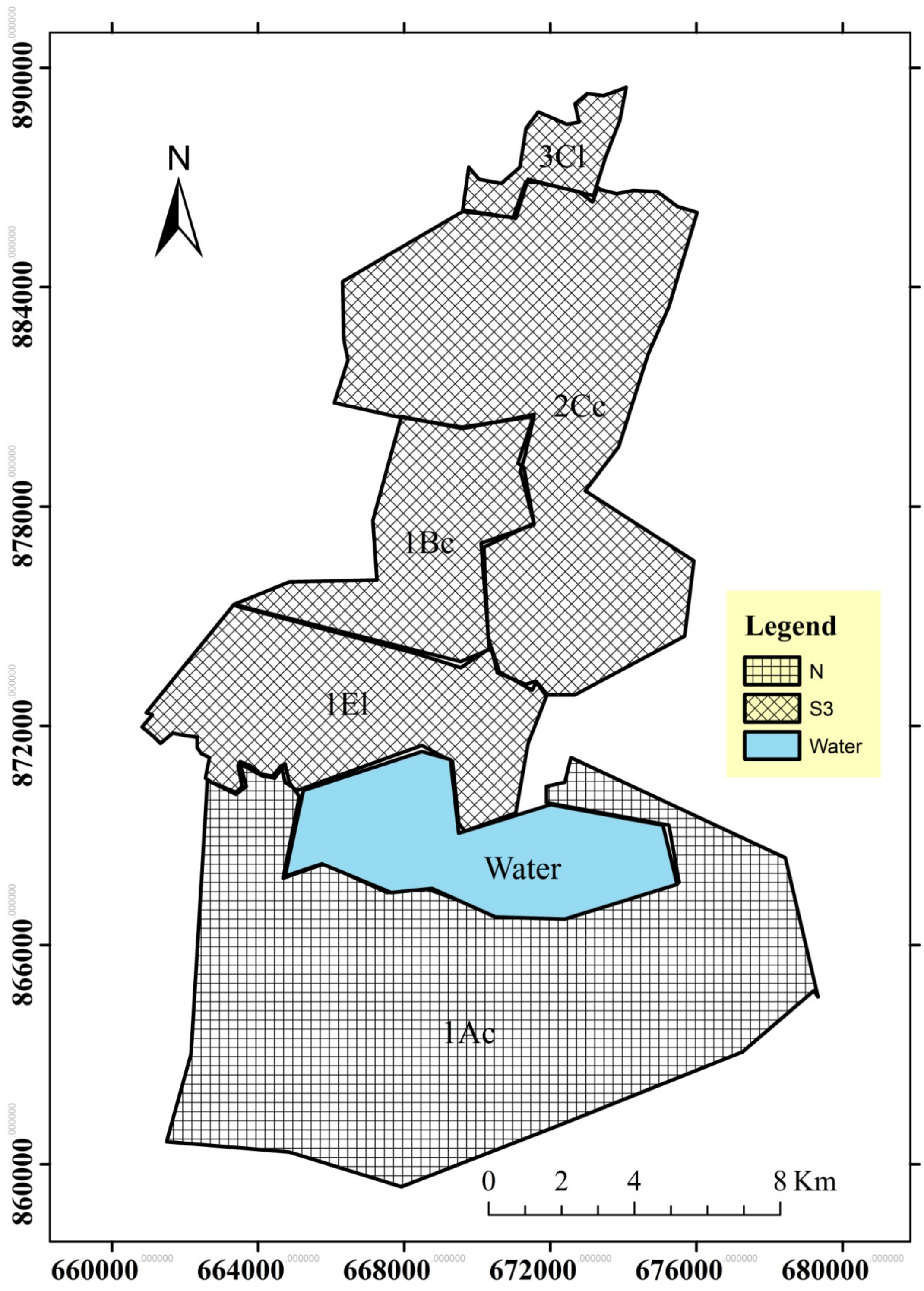

Figure 7. Land suitability evaluation map for upland rice.

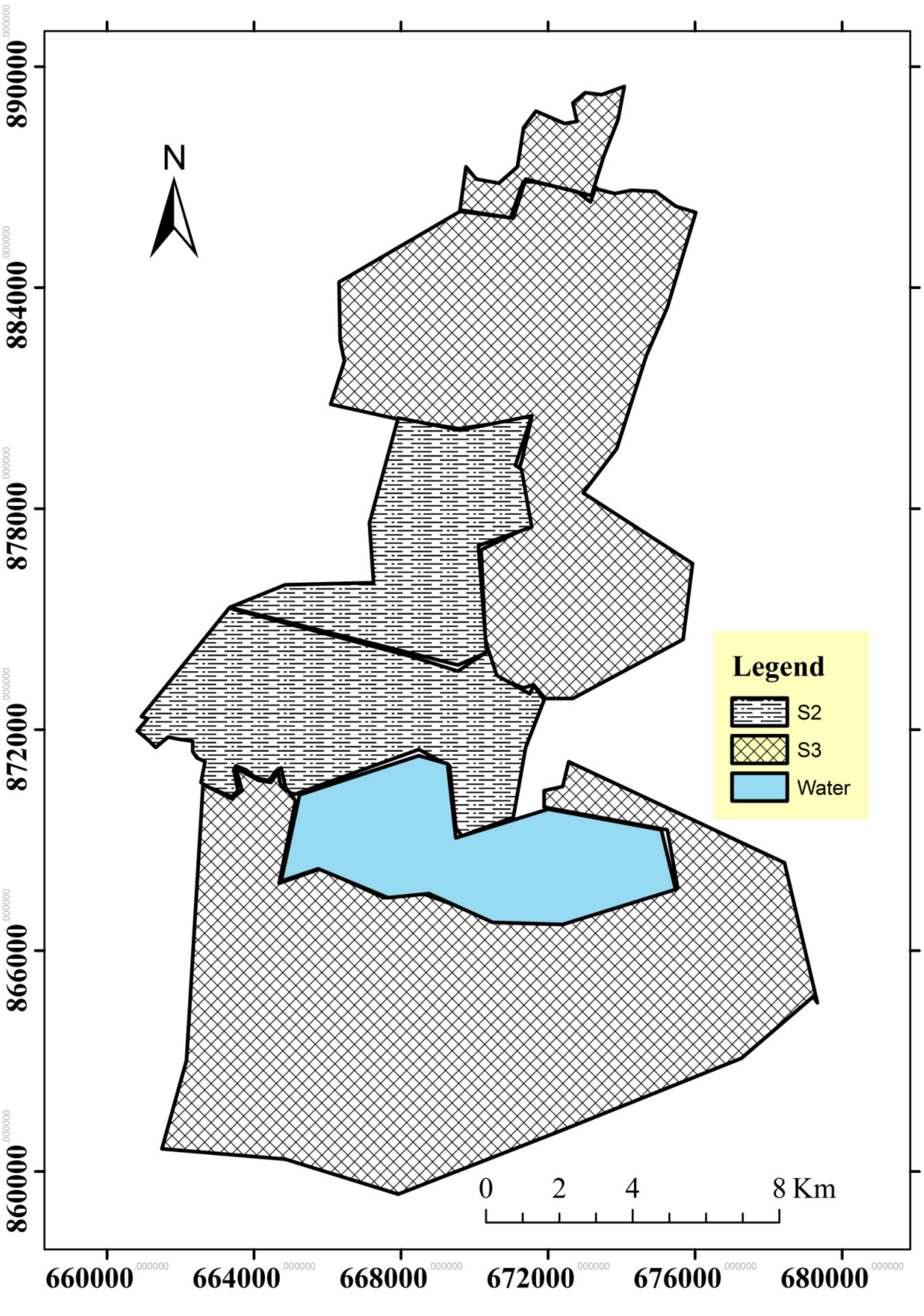

Figure 8. Land suitable evaluation map for sorghum.

3.5. Yield Gap Analysis

Radiation-temperature limited yield, simulated rainfed yield and expected land-determined yield were estimated using Equations 2.1, 2.2 and 2.3, respectively and the results presented accordingly.

3.5.1. Potential Production

Radiation-temperature limited yield of cotton, maize, upland rice and sorghum are presented in Table 5. Based on FAO model (Van Ranst, 1991), cotton, maize, upland rice and sorghum production potentials were 2,645, 6,409, 4,774 and 4,194 kg ha^{-1}, respectively. According to the ECSA (2007), the average yield of maize and sorghum for Gambella region were 2,150 and 1,429 kg ha^{-1}, respectively, which showed about 66% deviation from the potential yields. The radiation-temperature limited yields of cotton, rice and sorghum were beyond the ranges (1.5 to 2, 1.5 to 2.5 and 2.5 to 3.5 ton/ha, respectively) of good commercial yields, which were established by Sys *et al* (1993). However, the potential yield of maize was within the ranges (6 to 9 ton grain/ha) of good commercial yields (Table 5). The radiation-temperature limited yield of maize was lower in comparison with the result obtained from central Ethiopia by Teshome (1994). The reason might be the relatively higher mean temperature of the growing months and the difference in LGP of the crop varieties. Teshome (1994) observed high simulated yields for temperature ranges of about 15^0C to 20^0C, declining sharply for study stations with temperatures exceed 23^0C.

Table 5. Rate of gross biomass production (bgm), total net biomass production (Bn) and potential yield of maize, upland rice, sorghum and cotton in Abobo area

Crop	bgm (kg CH_2O ha^{-1} day^{-1})	Bn (kg CH_2O ha^{-1} day^{-1})	Yield (kg/ha)
Cotton	405	27,993	2,645
Maize	554	18,312	6,409
Upland rice	489	15,913	4,774
Sorghum	535	16,775	4,194

3.5.2. Water-limited production

The analysis of simulated rainfed yield revealed that maize and upland rice yield could be reduced by 7.32 to 12.09% and 6.01 to 11.16%, respectively (Table 6) in comparison with the corresponding potential yield. However, yield differences were not recorded for cotton and sorghum. The reason might be due to their water utilization efficiency. Van Ranst (1991) concluded that some crops react on a water deficit with an increase in water utilization efficiency, as in sorghum species, while other crops may decrease their water utilization efficiency, as in maize. In reference to their ETc, sorghum has lowest values (3.00 to 3.46 mm/day) followed by cotton (3.33 to 4.24 mm/day), upland rice (4.1 to 5.24 mm/day) and maize (3.81 to 5.71 mm/day), respectively, which suggest difference upon water limitation impact.

Table 6. Simulated rainfed yield of cotton, maize, upland rice and sorghum

Land mapping unit	Land utilization type			
	Cotton	Maize	Upland rice	Sorghum
1Ac	2,645	5,960	4,487	4,194
1Bc	2,645	5,960	4,487	4,194
1El	2,645	5,960	4,487	4,194
2Cc	2,645	5,634	4,241	4,194
3Cl	2,645	5,960	4,487	4,194

3.5.3. Expected land-determined yield

Expected land-determined yields of cotton, maize, upland rice and sorghum (at optimum level of management) range from 1,018 to 2,142, 2,295 to 4,828, 1,727 to 3,634 and 1,615 to 3,397 kg/ha, respectively (Table 7). Expected land-determined yields estimated under optimum level of management may be obtained only by farmers who use high inputs (Teshome, 1994). In addition to soil and landscape limitations, actual yields obtained by farmers are determined by local socio-economic or specifically by management level of the farm.

Table 7. Expected land-determined yield of the land utilization types across the land mapping units

	Land utilization type			
Land mapping unit	Cotton	Maize	Upland rice	Sorghum
1Ac	1,785	4,023	3,029	2,831
1Bc	2,142	4,828	3,634	3,397
1El	1,018	2,295	1,727	1,615
2Cc	1,695	3,960	2,718	2,688
3Cl	1,526	3,439	2,589	2,420

Conclusion

In this study, five LMUs (1Ac, 1Bc, 1El, 2Cc and 3Cl) and four land utilization types (cotton, maize, upland rice and sorghum) were considered. The land suitability evaluation results showed that the maximum limiting factors were soil depth, wetness and soil fertility. For shallow soil depth (LMU 1El), adapting shallow root crops is preferable. On the other hand, for LMU 1Ac, which has wetness limitation, drainage is necessary to utilize its optimum potential. The other limiting factor was soil fertility, mostly nitrogen. To alleviate such limitation and to use the LMUs in sustainable manner, soil organic matter management by integrating chemical fertilizers is essential. With regards to climatic situation, the moderately limiting factor was LGP, relatively longer than the growing cycle of the considered land utilization types. It is therefore advisable to develop or search crop varieties which best fit the LGP of the area. On the other hand, yield gap analysis also performed and the result revealed difference in radiation-temperature limited yield, simulated rainfed yield and expected land-determined yield for the considered LUTs. The differences might mainly be induced due to water limitation, soils and landscape attributes. This suggests use of supplementary irrigation and soil management which mainly focus on improving and maintaining soil OM and practicing integrating soil fertility management to optimize and sustain production.

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