Land capability classification and suitability assessment for selected crops in Gateno watershed, Ethiopia

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Cogent Food & Agriculture (2018), 4: 1532863
SOIL & CROP SCIENCES | RESEARCH ARTICLE

Land capability classification and suitability assessment for selected crops in Gateno watershed, Ethiopia

Gebrehana Girmay¹*, Workat Sebnie¹ and Yonas Reda¹

Abstract: The aim of the study was to evaluate the capability and suitability of the land for rain-fed major crop production. The study was conducted in Woleh Kebele of Sekota Woreda Wag-Himira administration zone in Ethiopia. In this study area, four homogeneous land units were identified based on topography. Soil survey was conducted on each land unit to observe the physical and chemical properties of the soil. The soil property analysis results indicate that the area is highly susceptible to erosion and low fertility that limit the land capability for various cultivated lands. The land capability assessment was undertaken based on USDA criteria. The results showed that three land unit maps were rated as capable for rain-fed crop production, whereas the fourth land unit was not capable due to permanent limitations associated with slope and soil depth. The land suitability assessment for rain-fed major crops was performed by using the maximum limitation method. The results showed that three land unit maps were marginally suitable for wheat and faba bean and not suitable for barley, due to poor soil fertility, slope, and high erosion. The potential land suitability results showed that 7.05% of land is highly suitable for barley and wheat but moderately suitable for faba bean, 25.04% moderately suitable for barley and wheat but marginally suitable for faba bean, 58.65% marginally suitable for barley and wheat but not suitable for faba bean, and 9.3% not suitable. The land suitability of the area can be enhanced by implementing appropriate

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PUBLIC INTEREST STATEMENT

In Ethiopia, national economic development is highly dependent on agriculture. Wheat, barley, maize, teff, and sorghum are major cereals and faba bean and pea are major pulses, which are essential for the national economy. Currently, most of these crops are cultivated in less suitable and degraded areas due to mismanagement of the land, shortage of fertile land, and pressing demand for food. Accordingly, low productivity has become a challenge in most parts of the semi-arid lowland area of North Ethiopia. This work evaluates the land capability and suitability of mostly the hilly terrain in Ethiopia. It is important to modify the land use and select and grow crops based on land suitability to get better crop production and to alleviate land degradation.
interventions such as soil and water conservation, improving soil fertility, and agronomic practices.

**Subjects:** Agriculture; Agriculture and Food; Soil Conservation Technology; Agronomy; Conservation – Environment Studies

**Keywords:** land capability; land suitability; land unit map; Gateno major crops

1. **Introduction**

Worldwide, the quantity of agricultural land is diminishing, and most part of the land has been degraded as irreversible and has become unsuitable for agricultural production (Verheye, 2008). Land evaluation is the basis for sustainable land resource scheduling and managing since it assists us to know whether the resources are degraded or improved in quality (Dumanski et al., 2010; Mohana, Mariappan, & Manoharan, 2009). The land capability is determined by different land characteristics such as the types of soil, which is critical for productivity, fundamental geology, topography, and hydrology. These characteristics limit the extent of land accessible for various purposes (Bizuwerk, Peden, Taddese, & Getahun, 2005). The final aim of land capability classification is to predict the agricultural capability of the land development units in utility of the land resources (Sys, Van Ranst, & Debaveye, 1991). FAO (1993) defines land suitability as “the fitness of a given parcel of land for specific uses”. As a result, land assessment is done to determine the specific land use for a specific location and classify the limiting factors for a specific crop production (AbdelRahman, Natarajan, & Hegde, 2016; Mu, 2006). The evaluation of land suitability depends on land capability as well as other factors such as land quality, proximity to different accesses, landowners, customer demand, and economic values (Counsel, 1999). Ethiopia’s economic development is greatly dependent on agricultural production since agriculture constitutes 46.6% of the national gross domestic product (CSA, 2008). Expansion of cultivated areas to compensate for low yields and exploitation of soils without restoration of soil fertility are common features in semi-arid lowland area of North Ethiopia, which is not sustainable. The principal purpose of agricultural land suitability assessment is to predict the potential and limitations of the land for crop production (Pan & Pan, 2011). Geographic Information Systems (GIS) techniques have been used to identify spatially and evaluate the physical land capability and suitability. They have been proved to be helpful and successful tools in studying, mapping, processing, and presenting certain problems (Abdel-Motaleb, 1997). For this reason, the assessment of land characteristics for the present and potential capability and suitability of crop production are necessary. Therefore, the objective of this study was to assess the capability and suitability of the land for rain-fed major crops in Gateno watershed, Ethiopia.

2. **Materials and methods**

2.1. **Description of the study area**

Gateno watershed is situated 720 km north of Addis Ababa and is approximately 15 km southeast of Sekota town adjacent to the Sekota-Lalibelle highway. The study was conducted in Woleh Kebele of Sekota Woreda Wag-Himira administration zone in Ethiopia. The coverage of the study area is 823.8 ha, which is located at 39°0’25” to 39°2’50” E longitudes to 12°31’0” to 12°32’35” N latitudes (Figure 1). The study area was characterized by a unimodal rainfall pattern, which extends from late June to late August or early September, where crops are cultivated in the summer season. As shown in Figure 2, eight years (2010–2017) data obtained from the Combelcha Meteorology Agency indicate that the study area has a mean annual rainfall of 675 mm and the mean minimum and maximum annual temperatures are 10°C and 22°C, respectively. The altitude of this study area ranges from 2100 to 2410 m a.s.l. According to Dejene (2003), the climatic zone classifications in Ethiopia are based on the altitude, rainfall, average annual temperature, and length of growing season; the study area belongs to dry semi-arid lowland.
3. Identification and characterization of land unit maps

Land unit is a unit of lands that have similar characteristics. In this study area, the land unit is classified into four homogeneous land unit maps (LUMs) based on topography (Table 1), in accordance with Ethiopia land use guideline (MOA/LAUD, 2012). The slope was extracted from the Digital Elevation Model using ARCGIS 10.2.1. The land unit maps were used as a guide in the field survey (Figure 3).

Measurements and soil samples are a re-interpretation of field observation and soil analysis (Table 2). Based on the measurement of the slope check by clinometers, the study area was found to be flat, sloppy, hilly, and steep sloppy, and the coverage area was 28.18%, 21.68%, 25.12%, and 25.01%, respectively.
Table 1. Topography distribution and area coverage of land unit maps

| Land unit maps | Slope | Topography distribution | Area (ha) |
|----------------|-------|--------------------------|-----------|
| LUM1           | 0–8   | Flat                     | 58.123    |
| LUM2           | 8–15  | Sloppy                   | 206.28    |
| LUM3           | 15–30 | Hilly                    | 483.165   |
| LUM4           | >30   | Steep sloppy             | 76.302    |
| **Total**      |       |                          | **823.8** |
Table 2. Soil characteristics of land unit map of study area

| Land units | Slope % | Soil depth (cm) | Texture | Stoniness % | Past erosion | Drainage | pH 1:1.25 | EC ds m⁻¹ | OC % | OM % | TN % |
|------------|---------|----------------|---------|-------------|--------------|----------|-----------|----------|------|------|------|
| LUM1       | 0-8     | 101            | C       | 15          | Mo           | WM       | 5.6       | 0.16     | 1.22 | 2.09 | 0.052 |
| LUM2       | 8-15    | 68             | SiL     | 35          | Sev          | Well     | 5.4       | 0.2      | 0.87 | 1.5  | 0.053 |
| LUM3       | 15-30   | 47             | CL      | 48          | Sev          | Well     | 5.5       | 0.21     | 0.6  | 0.94 | 0.058 |
| LUM4       | >30     | 23             | L       | 50          | VSev         | Well     | 5.7       | 0.15     | 0.53 | 0.91 | 0.042 |
4. Determination of soil physical and chemical properties
The soil samples were collected from each land unit, and soil profiles were opened to measure soil depth and drainage conditions. Besides, representative soil samples from a depth of 0 to 20 cm were collected to examine the soil physical and chemical properties. For the determination of total N and organic carbon (OC), a 0.5-mm sieve was used. Analysis of the physicochemical properties of the soil samples was performed based on the standard laboratory procedures. Particle size distribution was analyzed by using the ratio method. Soil pH was determined in H$_2$O using the 1:2.5 soils to solution ratio using a combined glass electrode pH meter (Carter and Gregorich, 2006). Total N was analyzed by the Kjeldahl digestion and distillation procedure, electrical conductivity by Sahlemedin and Taye (2000), whereas OC and organic matter (OM) were determined by the wet combustion method of Walkley and Black as outlined by Van Ranst et al. (1999).

SiL = silt loam; L = loam; CL = clay loam; L = loam; LUM = land unit map; MW = moderately well drained; VSev = very severe; Sev = severe; Mo = moderate.

5. Land capability and suitability evaluation
The land characteristics used in capability rating systems can impose limitations to the use of land through their effects on productivity and management and in the production of hazards (Figure 4); because land features are important to determine the capability (Rowe, Howe, Alley, & Authority, 1981).
Land capability classification was done based on inherent soil characteristics, land features, and environmental factors that permanently limit land use (Table 3). It was also undertaken based on the capability or limitations (United States Department of Agriculture [USDA] 2014). The land qualities and characteristics used for capability and suitability evaluation in this study are climate, soil characteristics, and topography. In accordance with the US Soil Resources & Conservation Service, which consists of matching (maximum limitation method) land characteristics against crop requirements and assigning a suitability rate for each land characteristic, land capability evaluation for the major crops produced in the study area was performed. The major crops grown in the study area (barley, wheat, and faba bean) were identified by focus group discussion with the watershed team and community. The selection of these crops was based on their dominance (area coverage) and economic importance in the area.

Climatic and land parameters were assigned to each factor affecting the suitability for each crop. Land use requirements of each crop were established using FAO (1976, 1983), FAO/UNDP (1984) and Sys et al. (1991). Generally, in the study area, the land unit map of soil nutrient level classifications and ratings was determined based on Cottenie (1980), Tekalign (1991), Jones (2003), and Hazelton and Murphy (2007). The crop requirements were compared with climate (temperature and rainfall) and landform attributes such as depth, slope, surface stoniness, and drainage, and with soil parameters such as texture, EC, pH, TN, OC, and OM. The soil characteristic values were matched with crop requirements for each land unit map.

6. Results and discussion

6.1. Land quality analyses

Textural class of the area was coarse (loam) to fine (clay). The soil depth ranges from shallow (23 cm) to deep (101 cm), stoniness coverage ranges from 15% to 50%, past erosion occurred from moderate to very high, and there was no any drainage problem. Besides, the soil properties of the study area were organic matter (OM) content (<2.09%), OC (<1.22%), and total nitrogen (0.058%) which indicated very low fertility status (Murphy, 1968 and Tekalign, 1991). According to Murphy’s (1968) and Tekalign’s (1991) pH classification method, the soil laboratory analysis results showed that the soil pH of the area was moderately (medium) acidic. The chemical soil analysis showed that it has low electrical conductivity (EC) (<0.21 ds m$^{-1}$) indicating that the area was free from salt.

6.2. Land capability classification

Based on USDA and Gizachew and Ndoo (2008), land capability classes IIet, IIIe, and IVLs were capable for crop cultivation with some limitations of slope (L), erosion (e), texture (t), and soil fertility (s). Therefore, these land unit maps required intervention in integrated soil fertility management and soil and water conservation practice like contour cropping, strip cropping, grass strips, alley cropping waterways, cutoff drains, and moisture harvesting structures (USDA, 2014). LUM4 has severe limitations related to slope (>30%), soil depth (<25 cm), and stoniness (68%) coverage. Hence, VIL was completely not capable for crop production, but can be suitable for perennial crops or forage production with rehabilitation activities and forestry with care and proper conservation plantation and area enclosure (Tesfay, Biedemariam, Haqazi, & Gebretinsae, 2017). Three land unit maps were capable for rain-fed crop production, whereas LUM4 was incapable due to slope, soil depth, erosion, and stoniness; as a result, out of the total area (823.8 ha), 9.26% was not suitable for rain-fed crop production. The result supported by Tesfay et al. (2017) reports that out of the total study area, 11.89% was not capable for rain-fed cultivated land in semi-arid lowland area of North Ethiopia.

6.3. Land suitability evaluation

Climatic suitability: The average growth length of barley, wheat, and faba bean was 90–120, 100–130, and 100–120 days, respectively (Raemaekers, 2001). The study area was characterized by a unimodal rainfall pattern, which extends from June to mid-September with a mean annual rainfall of 675 mm. The total growth period of the area was 115 days. The results indicated that
Table 3. Land capability parameters and thresholds (Gizachew & Ndoo, 2008)

| Parameters                        | Land capability class |
|-----------------------------------|-----------------------|
|                                   | I (0-8)    | II (8-16)   | III (16-30) | IV (30-50) | V (>50) | VI (>50) | VII (>50) |
| Slope (L) %                       | 0-8        | 8-16        | 16-30       | 30-50      | >50     | >50      | >50       |
| Erosion (e)                       | No sign to slightly | Moderate | High | Very high | Extremely high |
| Stoniness (% area coverage)       | 0-40       | >40         | >40         | >40        |
| Soil depth (cm)                   | >60        | 45-60       | 15-45       | <15        | >15     |
| Soil drainage                     | Never saturated | Rarely saturated | Saturated for short period | Saturated for long period |
| Soil texture (t)                  | L, LS, SL  | SL, SCL     | SC, SCL     | SC, SCL    | Any     |
| Organic carbon (%)                | >1         | 0.8-1       | 0.6-0.8     | 0.4-0.6    | 0.2-0.4 |
| Carbonates (%)                    | <25        | 25-40       | >40         |
| pH                                | 5.5-7.9    | 4.5-5.5     | ><4.5 or >8.4 | <4.5 or >8.4 |

L = loam; SL = sandy loam; LS = loamy sand; Si = silt; SCL = sandy clay loam; SL = silty loam; CL = clay loam; SiC = silty clay; SC = sandy clay; S = sand; C = clay.
the agroclimatic characteristic of Gateno watershed was highly suitable for both barley and wheat and moderately suitable for faba bean for the rain-fed crop cultivation in the area (Table 4). The climatic suitability for faba bean was limited by rainfall due to its mean annual rainfall requirement (Nahusenay & Kibebew, 2015).

6.4. Soil and landscape suitability evaluation

The results of the soil and landscape suitability evaluation showed that LUM1 is marginally suitable (S3) for wheat and faba bean, but not suitable (N) for barley for rain-fed crop production. LUM2 is marginally suitable (S3) for faba bean and not suitable (N) for both barley and wheat for rain-fed crop production in the land unit. LUM3 is only marginally suitable (S3) for wheat and not suitable (N) for both barley and faba bean. The limiting factors of the land units are presented in Table 5. Because of one or more limitations of the land qualities fall in to highly, moderately, or marginally suitable class for the selected major crops.

6.5. Overall land suitability evaluation

LUM1 was found to be well-drained, deep soil and less stony as compared to LUM2 and LUM3 (Table 6). However, erosion, climate, and soil fertility are common problems in all topographic positions (LUMs). Currently, LUM1 is marginally suitable (S3) for wheat and faba bean, but not suitable (N1) for barley for rain-fed crop production, the main cause of the area that amplified erosion and low fertility such as OC, OM and total nitrogen.

Hailu, Kibret, and Gebrekidan (2015) also reported that OM content and total nitrogen were found to be the limiting factors for wheat and barley crop production. It is improved by applying appropriate soil and water conservation, integrated soil fertility management, agro-forestry as well as agronomic practices such as intercropping and crop rotation (Tesfay, 2017; USDA, 2014). LUM2 was, compared to LUM1, very sloppy, had moderate soil depth, and was moderately stony. LUM2 is marginally suitable (S3) for faba bean and not suitable (N) for both barley and wheat for rain-fed crop production in the land unit. The limiting factors are erosion and topography (slope).

Soil fertilities (OM content (1.5%) and total nitrogen (0.053%)) and soil depth. Hailu et al. (2015) also reported that OM content and total nitrogen were found to be the limiting factors for wheat and barley crop production. Therefore, applying appropriate soil and water conservation, integrated soil fertility management, agro-forestry as well as agronomic practices such as Grass strip; alley cropping; combination of grass strip and bunds; Fanya Juu + waterways, cutoff drains (USDA (United States Department of Agriculture), 2014). It enhanced to moderate suitability (Tesfay et al., 2017). LUM3 result showed that it is only marginally suitable (S3) for wheat and not suitable (N) for both barley and faba bean. The limiting factors are climate, topographic position; shallow soil, severe erosion, and high cover surface stoniness. Similar to this, Nahusenay and Kibebe (2015) have reported that climate, fertility (OM, total N, and available P), rooting conditions (depth), physical (stoniness), and topography occur to be limiting factors for faba bean rain-fed crop production. The management option and the conservation measure of the study area improve the suitability of land units, particularly for marginally and not suitable lands. Alemu et al. (2013) reported that soil conservation measures are playing an important role in enhancing the

### Table 4. Climatic suitability for the major crops

| Climate characteristics          | Factor value | Land utilization type |
|----------------------------------|--------------|-----------------------|
| Growing season mean TO           | 16           | Wheat: S1, Barley: S1, Faba bean: S1 |
| Total growing season rainfall (mm) | 675          | Wheat: S1, Barley: S1, Faba bean: S2 |
| Overall climatic suitability     | S1           | Wheat: S1, Barley: N, Faba bean: S2 |

S1 = highly suitable; S2 = moderately suitable.
| Land quality/characteristics | LUM1 | LUM2 | LUM3 |
|-----------------------------|------|------|------|
| Wheat | Barely | Faba bean | Wheat | Barely | Faba bean | Wheat | Barely | Faba bean |
| Topography | | | | | | | | |
| Slope (%) | S1 | S1 | S1 | S2 | S2 | S2 | S3 | S3 |
| Altitude (m) | S1 | S1 | S1 | S1 | S1 | S1 | S1 | S1 |
| Wetness (w) | | | | | | | | |
| Drainage | S1 | S1 | S1 | S1 | S1 | S1 | S1 | S1 |
| Flooding | | | | | | | | |
| Physical characteristics (s) | | | | | | | | |
| Textural class of soil | S1 | S1 | S1 | S1 | S1 | S1 | S1 | S1 |
| Soil depth (cm) | | | | | | | | |
| Surface stoniness | | | | | | | | |
| Fertility status (f) | | | | | | | | |
| H:O | S3 | S2 | S3 | S3 | S3 | S3 | S3 | S3 |
| Soil organic matter (%) | S1 | S1 | S1 | S2 | S2 | S2 | S3 | S3 |
| Soil organic carbon (%) | S1 | S1 | S1 | S2 | S2 | S2 | S3 | S3 |
| Total nitrogen (%) | | | | | | | | |
| Salinity and alkalinity (n) | | | | | | | | |
| Electrical conductivity (dS m⁻¹) | | | | | | | | |
| Overall rating of soil and landscape | S3 | S3 | S3 | N | S3 | S3 | S3 | S3 |

LMU = land mapping unit; S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N = not suitable.
Table 6. Overall land suitability evaluation for LUMs

| Crop type | LUM | Climate suitability | Topography | Soil physical | Soil chemical | Erosion status | Wetness | Level of suitability |
|-----------|-----|---------------------|------------|---------------|---------------|----------------|---------|---------------------|
|           | 1   | S1                  | S1         | S1            | N1            | S2 (e)         | S1      | S1                  |
| Barley    | 2   | S1                  | S1         | S3 (e)        | S2 (t)        | S2 (e)         | S1      | S1                  |
|           | 3   | S1                  | S1         | S3 (e)        | 53 (t)        | S3 (e)         | S1      | S1                  |
| Wheat     | 1   | S1                  | S1         | S1            | S3 (f)        | S3 (e, f)      | S1      | S1                  |
|           | 2   | S1                  | S1         | S3 (e)        | S2 (t)        | S3 (e, f)      | S1      | S1                  |
|           | 3   | S1                  | S1         | S3 (e)        | 53 (t)        | S3 (e, t, s, f)| S1      | S1                  |
| Faba bean | 1   | S2 (c)              | S1         | S2 (e)        | S1            | S3 (c, e, f)  | S2 (c)  | S2 (c)              |
|           | 2   | S2 (c)              | S1         | S3 (e)        | S2 (t)        | S3 (c, e, t, s, f)| S2 (c) | S2 (c)              |
|           | 3   | S2 (c)              | S1         | S3 (e)        | 53 (t)        | S3 (c, e, t, s, f)| S2 (c) | S2 (c)              |

LMU = land mapping unit. Limitation factors: c = climate (amount of rainfall); e = erosion; f = fertility (OM, total N, and OC); s = physical (stoniness); t = topography (altitude/elevation).
ecosystem services in the form of improving the suitability of the soils for most crops. Consequently, different soil and water conservation measures are important to reduce further degradation.

7. Conclusion
Based on land capability or limitation, the study area is grouped into two such as capability of agricultural land (class II covers an area of 7.05% and the limiting factors are erosion and texture; class III covers 25.04% and the limiting factor is erosion; class IV covers 58.65% and the limiting factors are slope and stoniness; class V covers 9.3% and the limiting factors are slope, stoniness, soil depth, and erosion) of the total area. According to FAO (1976, 1983, 1984), soils of the study area are classified from the suitability point of view: suitable or not suitable. The results of the soil and landscape suitability evaluations are topographic position, erosion, low soil fertilities, and surface stoniness the limiting factors of land suitability. Some of the limitations are the results of anthropogenic activities related to inappropriate land use. Because one or more limitations of the land qualities fall into highly, moderately, or marginally suitable class for the selected major crops. The current land suitability of the study area can be enhanced by applying appropriate interventions such as soil and water conservation, integrated soil fertility management, moisture harvesting structures, and agronomic practices.

Funding
The authors received no direct funding for this research.

Competing interest
The authors declare no competing interests.

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Citation information
Cite this article as: Land capability classification and suitability assessment for selected crops in Gateno watershed, Ethiopia, Gebrehana Girmay, Workat Sebnie & Yonas Reda, Cogent Food & Agriculture (2018), 4:1532863.

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## Table A1. Land suitability ratings for agroclimatic characteristic requirements for rain-fed (barley, wheat, and faba bean) crops

| LUT   | Rating | Rainfall (mm) | Temperature (°C) | LGP (day) | Frost (months)                      |
|-------|--------|---------------|------------------|-----------|-------------------------------------|
|       |        |               |                  |           |                                     |
|       | S1     | 0             | 400–650          | 16–18     | 120–135                             | None                              |
|       |        | 1             | 500–750          | 14–18     | 110–155                             | None in Oct. to Nov., slight in Dec. |
|       |        | 2             | 300–400 or 750–850 | 12–14 or 18–20 | 90–110 or 155–180                  | None in Oct., slight in Nov. to Dec. |
|       |        | N1            | 150–200 or 1000–1250 | 8–10 or 22.5–28 | <75 or >230                       | Any frost in Oct., severe in Nov., Dec. |
|       |        | N2            | 40               | 8–10 or 27–30 | 80 or >230                         | Any frost in Oct., severe in Nov., Dec. |
|       | S2     | 2             | 250–350 or 1250–1500 | 12–15 or 20–25 | 100–120 or 155–180                 | None in Oct., slight in Nov. to Dec. |
|       |        | S3            | 250–200 or 1500–1750 | 10–12 or 25–27 | 80–100 or 180–230                 | Slight in Oct. to Dec.             |
|       | N1     | 4             | 200–500           | 17.5–20   | 135–155                             | None                              |
|       |        | 2             | 400–600           | 15–20     | 130–180                             | None in Oct. to Nov.              |
|       |        | 2             | 300–400 or 600–1000 | 12.5–15 or 20–24 | 100–130 or 180–265                | None in Oct. to Nov., slight in Dec. |
|       |        | 3             | 250–300 or 1000–1200 | 10–12.5 or 24–27 | 75–100 or 265–305                  | None in Oct., slight in Nov. to Dec. |
|       | N2     | 4             | 250–500           | 8–10 or 27–30 | <75 or >305                        | Slight in Oct. to Dec.            |
|       |        | 2             | 60               | 8–10 or 27–30 | 75–100 or 265–305                  | Slight in Oct. to Dec.            |

Source: Adapted from FAO (1976, 1983), FAO/UNDP (1984), Sys et al. (1991; 1993), and Teshome and Verehye (1994). LGP = length of growing period.
Table A2. Land suitability ratings for physical characteristic requirements for rain-fed (barley, wheat, and faba bean) crops

| LUT   | Rating | Slope % | Elevation (m) | Drainage     | Flood | Texture | Stoniness ° | Depth (cm) |
|-------|--------|---------|---------------|--------------|-------|---------|-------------|------------|
|       |        |         |               |              |           |         |             |            |
| Barley S1 | 0      | 100     | 0-4           | 2000-3000    | Good   | C < 60s, Ca, SiCs, SiCL, Si, SiL, CL | 0-3         |
|        | 1      | 95      | 4-8           | -            | Moderate | F0      | C < 60v, SC, C > 60s, L | 3-15       |
|        | S2     | 2      | 85            | 8-16         | 1500-2000 or 3000-3300 | Imperfect/good | F0 | C > 60v, SCL | 15-35     |
|        | S3     | 3      | 60            | 16-24        | 3300-3800 | Poor and aeric | F1 | SL, Lfs | 35-55     |
|        | N1     | 4      | 40            | 24-30        | <1500 or >3800 | Poor but drainable | F2 | - | 10-25     |
|        | N2     | 25     | >30           | -            | -         | Poor not drainable | F3+ | Cm, Si, Ls, F, F, s, s | >55       |
| Wheat S1 | 0      | 100     | <2            | 2000-2600    | Good   | F0      | C < 60s, Ca, SiCs, SiCL, Si, SiL, CL | 0-3         |
|        | 1      | 95      | 2-8           | -            | Moderate | -       | C < 60v, SC, C > 60s, L | 3-15       |
|        | S2     | 2      | 85            | 8-16         | 1500-2000 or 2600-3000 | Imperfect/good | F1 | C > 60v, SCL | 15-35     |
|        | S3     | 3      | 60            | 16-30        | 3000-3300 | Poor and aeric | F2 | SL, Lfs | 35-55     |
|        | N1     | 4      | 40            | <1500 or >3300 | Poor but drainable | - | - | 10-20     |
|        | N2     | 25     | >30           | -            | Poor not drainable | F3+ | Cm, Si, Ls, F, F, s, s | >55       |
| Faba bean S1 | 0 | 100 | 0-4 | 2100-2400 | Good | F0 | C < 60s, SiCs, SCl, CL, Si, SiL | 0-3         |
|        | 1      | 95      | 4-8           | 2000-3000    | Moderate | -       | C < 60s, SC, C < 60v, L, SCL | 3-15       |
|        | S2     | 2      | 85            | 8-16         | 1800-2000 or 3000-3200 | Imperfect/good | - | C > 60v, SL, Lfs, LS | 15-35     |
|        | S3     | 3      | 60            | 16-24        | 1500-1800 or 3200-3400 | Poor and aeric | F1 | Ls, F, s | 35-55     |
|        | N1     | 4      | 40            | 24-30        | <1500 or >3400 | Poor but drainable | - | - | 20-50     |
|        | N2     | 25     | >30           | -            | Poor not drainable | F2+ | Cm, Si, cm, s | >55       |

Source: Adapted from FAO (1976, 1983), FAO/UNDP (1984), Sys et al. (1991, 1993), and Teshome and Verehye (1994). Textural range: Cm = massive clay; SiCm = massive silty clay; C + 60,v = fineclay, vertical structure; C + 60,s = fine clay, blocky structure; C-60,v = clay, vertical structure; C-60,s = clay, blocky structure; SiCs = silty clay, blocky structure; SiCL = silty clay loam; CL = clay loam; Si = silt; SiL = silt loam; SL = sandy loam; L = loam; SCL = sandy clay loam; SL = sandy loam; Lfs = loamy fine sand; LS = loamy sand; LcS = loamy coarse sand; F = fine sand; S = sand; cS = coarse sand; Co = clay, oxisol structure.
Table A3. Land suitability ratings for soil chemical characteristic requirements for rain-fed (barley, wheat, and faba bean) crops

| LUP       | Rating | pH – H₂O   | Soil OC (%) | Total N (%) | Avail. P₁ (mg kg⁻¹) | EC (dS m⁻¹) | CaCO₃ (%) | Gypsum (%) | Cations²⁺ (cmol (+) kg⁻¹) | CEC | PBS (%) | EPS (%) |
|-----------|--------|------------|-------------|-------------|---------------------|-------------|-----------|------------|-------------------------|-----|---------|---------|
| Barley    | S1 0   | 7–7.5      | >2.0        | >0.2        | 0–8                 | 3–20        | 0–3       | >8         | >24                    | >80 | 0–15    |
|           | 1 95   | 6.2–8.0    | 1.2–2       | 0.15–0.2    | >10                 | 8–12        | 3–5       | 5–8        | 24–16                  | 50–80 | 15–25   |
|           | S2 2   | 6.2–5.8 or | 0.8–1.2     | 0.1–0.15    | 5–10                | 12–16       | 5–10      | 3.5–5.0    | <16 (⁺)                | 35–50 | 25–35   |
|           | 3 60   | 5.8–5.5 or | 0.4–0.8     | <0.1        | 3–5                 | 16–20       | 40–60     | 10–20      | 2.0–3.5                 | <16 (⁺) | <35    | 35–45   |
|           | N1 4   | <5.5 or >8.5| 0.4–0.8     | <0.1        | 3–5                 | >25         | >60       | >20        | <2                     | -    | >65     |
|           | N2 25  | -          | -           | -           | >25                 | >60         | >20       | <2         | -                      | -    | -       |
| Wheat     | S1 0   | 6.5–7.5    | >2.5        | 1–3         | 20–30 or 0–3        | 3–5         | 5–8       | 24–16      | 50–80                  | 15–25 |
|           | 1 95   | 6.2–8.0    | 1.5–2.5     | >0.2        | >10                 | 1–3         | 20–30 or 0–3 | 3–5 | 5–8        | 24–16 | 50–80 | 15–25   |
|           | S2 2   | 6.5–6.6 or | 1.0–1.5     | 0.15–0.2    | 5–10                | 3–5         | 30–40     | 5–10       | 3.5–5.0                 | <16 (⁺) | 35–50 | 25–35   |
|           | 3 60   | 5.6–5.2 or | 0.5–1.0     | 0.1–0.15    | 3–5                 | 5–6         | 40–60     | 10–20      | 2.0–3.5                 | <16 (⁺) | <35    | 35–45   |
|           | N1 4   | <5.2 or >8.5| 0.5–0.8     | 0.08–0.1    | 3                | 6–10        | -         | -          | -                      | -    | -       |
|           | N2 25  | -          | <0.08       | -           | >10                 | >60         | >20       | <2         | -                      | -    | >65     |
| Faba bean | S1 0   | 6.0–7.0    | >2.0        | >0.2        | 0                   | 0–6         | 0.1       | >5         | >24                    | >80 | 0–2     |
|           | 1 95   | 5.6–7.6    | 1.2–2       | 0.15–0.2    | 0–1                 | 1–6         | 0.1–0.5   | 3.5–5.0    | 24–16                  | 50–80 | 2–5     |
|           | S2 2   | 5.6–5.4 or | 0.8–1.2     | 0.1–0.15    | 5–10                | 1–1.5       | 12–20     | 0.5–1      | 2.0–3.5                 | <16 (⁺) | 35–50 | 5–8     |
|           | 3 60   | 5.4–5.2 or | <0.8        | <0.1        | 3–5                 | 1.5–2       | 20–25     | 1–3        | <2                    | <16 (⁺) | <35    | 8–12    |
|           | N1 4   | <5.2        | -           | <3          | -                   | -           | -         | -          | -                      | -    | -       |
|           | N2 25  | >8.2       | -           | >2          | >25                 | >3          | -         | -          | -                      | -    | -       |

Source: Adapted from FAO (1976, 1983), FAO/UNDP (1984), Sys et al. (1991, 1993), and Teshome and Verehye (1994). ¹Olsen method analysis; ²sum of cations; PBS = % base saturation; EPS = exchangeable sodium percentage.
