Research Journal of Agriculture and Environmental Management. Vol. 4(3), pp. 141-148, March, 2015
Available online at http://www.apexjournal.org
ISSN 2315 - 8719© 2015 Apex Journal International

Full Length Research

Land Suitability Evaluation for Cereal and Pulse Crops Using Geographical Information System in East Amhara Region, Ethiopia

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Accepted 4 February, 2015

This study was carried out to spatially evaluate land suitability for maize (*Z. mays* L.), wheat (*T. aestivum* L.), soybean (*G. max* L.) and chickpea (*C. arietinum* L.) crops in the East Amhara Region, Ethiopia based on FAO guidelines. Geographical Information System (GIS) was used to develop land suitability map. Land characteristics (LC) and cropland use requirements (LUR) used as criteria for crop suitability analysis were soil depth, soil texture, available phosphorus, organic carbon, pH and slope. Surface soil samples at 0-30 cm depth from different soil types were collected and analyzed in the soil laboratory of Amhara Design and Supervision Works Enterprise (ADSWE). Crop suitability map was made by matching between reclassified LC with crop LUR using GIS model builder. The results indicated that the largest portion of the region 232 ha (85.8% and 321.69 ha (8.04%) were highly suitable for maize and wheat, respectively. However, the land use suitability analysis indicated that the largest portion of the region (2380 ha (59.5%), 1880 ha (47%), 1459.32 ha (36.48%) and 1464.12 ha (36.60%) were unsuitable for chickpea, soybean, maize and wheat production, respectively due to due to soil depth, texture, drainage, pH, soil organic matter and slope factors.

Key words: Chickpea, GIS, Maize, Soybean, Suitability, Wheat

INTRODUCTION

Agriculture is the basis for the economy of Ethiopia. It accounts for the employment of 90% of its population, over 50% of the country's gross domestic product (GDP) and over 90% of foreign exchange earnings (Ethiopian Central Agricultural Census Commission (ECACC) 2002). Irrespective of this fact, production system is dominated by small-scale subsistence farming system largely based on low-input and low-output rain-fed agriculture. As the result farm output lags behind the food requirement of the fast growing population. The high dependency on rain-fed farming in the dry lands of Ethiopia and the erratic rainfall require alternative ways of improving agricultural production.

Ethiopian agricultural sector has a proven potential to increase food supplies faster than the growth of the population (Davidson, 1992). Crop production plays a vital role in generating surplus capital to speed up the overall socio-economic conditions of the farmers. However, the country is unable to feed its people.

Sustainable agriculture would be achieved if lands be categorized and utilized based upon their capacity (FAO, 1993). Thus, land evaluation is essential to assess the potential and constraints of a given land parcel for agricultural purposes (Murphy and Riley, 1962) using satellite data. The GIS system contains a set of procedures that facilitate the data input, storage, manipulation and analysis, and data output to support decision making activities (Grimshaw , 1994). To date, the FAO guidelines on the land evaluation system (FAO, 1976, 1983). are widely accepted for the evaluation. The value of land quality is the function of the assessment and grouping of land types into orders and classes in the framework of their fitness. Generally, land suitability is categorized as suitable (S) and not suitable (N). Whereas, S features

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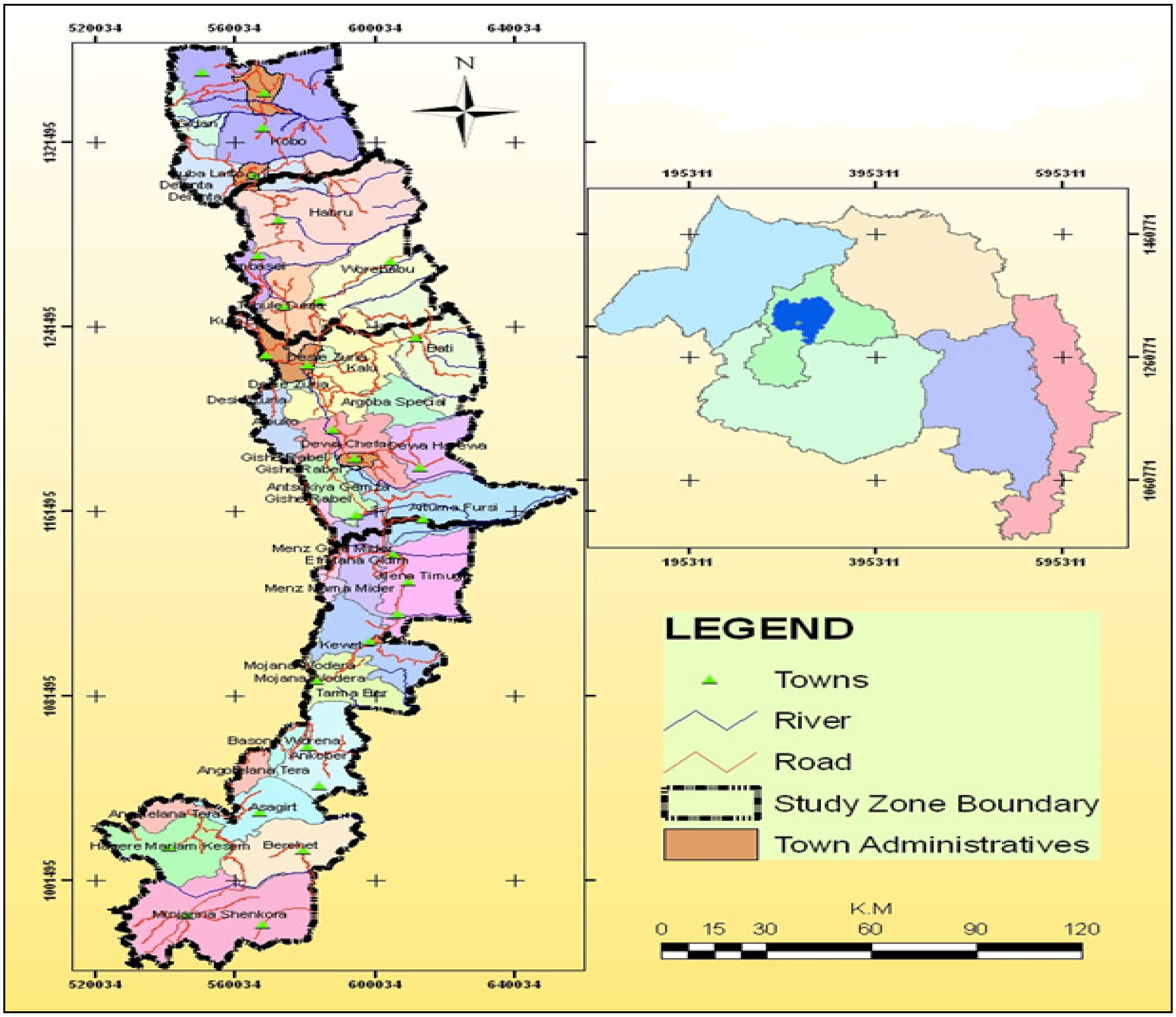

Figure 1. Map of East Amhara Region.

lands suitable for use with good benefits, N denotes land qualities which do not allow considered type of use, or are not enough for suitable outcomes (FAO, 1985, 1993.

Under the present situation, where land is a limiting factor, it is impractical to bring more area under cultivation to satisfy the ever growing food demand (Fischer et al., 2002). In other hand, the rapid population growth has caused increased demands for food while soil erosion and extensive deforestation continue (Fresco et al., 1992). Therefore, successful agriculture is required for sustainable use of soils that significantly determine the agricultural potential of an area. Land suitability evaluation for maize, wheat, chickpea and soybean crops were not yet done in the region. This calls for a need to conduct detailed studies at region level for use in crop suitability analysis. Hence, the main objective of the study were to spatially evaluate the suitability of the selected crops using GIS tools thereby identify the potential to expand the selected cereal and pulse crops cultivation in East Amhara Region, Ethiopia.

MATERIALS AND METHODS

Description of the Study Region

The present study region, East Amhara, with total area of 4,000 ha is geographically located between 963873 and 1363639 north and 519535 to 656864 m east UTM (Figure 1). The altitude is ranging from 580 to 3960 m.a.s.l. The study region has mean annual rainfall varying from 476 to 1930 mm. The major agro climatic zones (ACZ) categorized in to four traditional agro ecological zones as Wurch, Dega, Woynadega and Kola with 0.64, 16.25, 46.28 and 36.83%, respectively. The major farming system is mixed mode of production. However, the living standard of the farming community is still at subsistence level meanwhile the productivity of

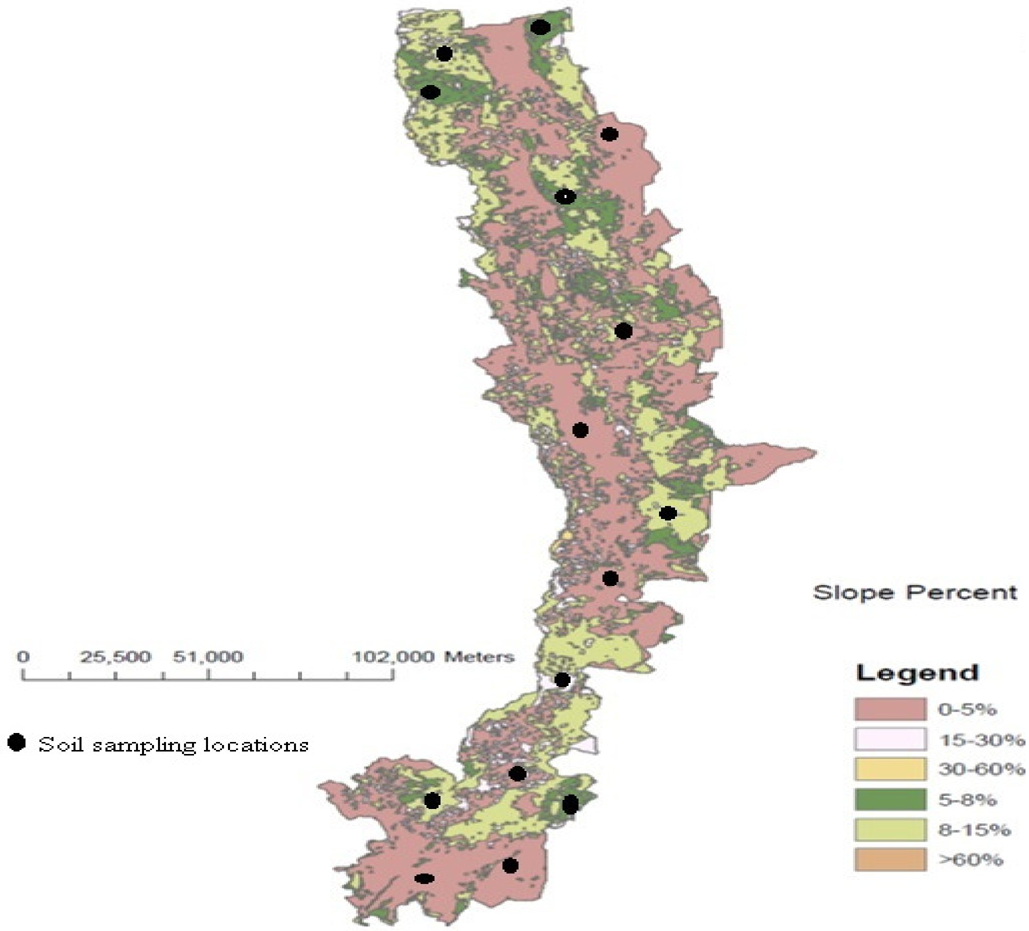

Figure 2. Soil sample locations along slope category

land is seriously declining due to miss and under utilization of natural resources.

Surface Soil Sampling

The watershed was stratified into six slope classes as there is strong relation between slope and soil types and their characteristics(FAO, 1998). Based on soil color, texture and slope, major soil types and their boundaries were identified, stratified and delineated by auguring by intensive traversing. A total of 15 disturbed soil samples from surface horizons were collected and analyzed (Figure 2). Spatial soil characterization was made at scale of 1:25,000 based on the information obtained from field soil surface description and laboratory analysis result. Several auger observations were taken by Edelman auger at surface layer (0-30 cm) and bulked into 15 composite soil samples for surface soil characterization and crop suitability evaluation purposes (Figure 2). Surface soil samples from different soil types were collected and analyzed in the soil laboratory of Amhara Design and Supervision Works Enterprise (ADSWE).

Soil Analysis

The soil samples collected from surface were air dried at room temperature and ground to pass through sieves. Soil pH was measured potentiometrically using a digital pH meter in the supernatant suspension of 1:2.5 (soil: water). Soil texture was determined by the hydrometer method as described in (Bouyoucos, 1962) where hydrogen peroxide was used to destroy OM and using sodium hexa-metaphosphate as dispersing agent. Then, hydrometer readings after 40 seconds and 2 hours were used to determine the silt plus clay and clay particles in suspension, respectively, whereas the percent of silt was calculated from the difference. Soil textural classes were determined following the textural triangle of USDA system as described by Rowell (1997). Soil pH was measured potentiometrically using a digital pH meter in the supernatant suspension of 1:2.5 (soil: water ratio). The OC content was analyzed following the wet digestion method described by Walkley and Black (1934) which involves digestion of the OC in the soil samples with potassium dichromate in sulphuric acid solution. The Kjeldahl procedure was followed for the determination of TN by oxidizing OM with concentrated sulphuric acid and

Table 1. Soil laboratory results and characterization.

Soil depth (cm)	Textural class	pH_{H2O}	TN (%)	AVP (ppm)	OC (%)
>150	Silty clay loam	4.64	0.1	2.69	221.12
>150	Silty clay loam	4.03	0.5	2.34	239.38
>150	Heavy clay	4.24	0.2	2.46	94.17
>150	Heavy clay	3.77	0.1	2.18	89.95
>150	Heavy clay	3.90	0.1	2.26	47.91
>150	Heavy clay	4.24	0.1	2.46	88.76
>150	Heavy clay	4.10	0.3	2.38	43.23
>150	Heavy clay	4.57	0.2	2.65	83.57
>150	Heavy clay	3.97	0	2.3	38.19
>150	Loam	4.44	0.1	2.57	100.94
>150	Loam	3.70	0.1	2.15	96.10
>150	Heavy clay	4.30	0.2	2.5	74.14
>150	Heavy clay	3.77	0.1	2.18	74.43
>150	Heavy clay	4.64	0.1	2.69	30.56
>150	Clay	3.83	0.3	2.22	97.37

converting the nitrogen in the organic compounds into ammonium sulphate during the oxidation (Bremner and Mulvaney, 1982). Available P was determined by Bray II method in which available P was determined by shaking the soil sample with extracting soil solution of 0.3 N ammonium fluoride in 0.1N hydrochloric acid as described by Bray and Kurtz (1945). The available P extracted then was measured by spectrophotometer (Rossiter and van Wambeke, 1996).

Land Suitability Evaluation and Classification

The crop land utilization types ((maize (*Z. mays* L.), wheat (*T. aestivum* L.), soybean (*G. max* L.) and chickpea (*C. arietinum* L.)) were selected through discussion with the key informant farmers and development agents. When crop selection was carried out, area coverage, importance of the crops in the livelihood of the concerned community, suitability of soils and agro-climatic conditions of the study region were considered. The crop land use requirements (LURs) were also selected based on agronomic knowledge of local experts and (FAO, 1998) guideline. Crop environmental requirements database developed in excel computer program with the database file format as classifier tables arranged from to values against the suitability classes. Digital data of selected land characteristics (LCs) of the region and classifier tables for crop LURs were properly encoded to the Microsoft Office Excel sheet as database file to be used in ArcGIS for spatial analysis. The LCs were reclassified based on crop LURs.

The evaluation criteria used to address the suitability of the selected crop LUTs in the study region were soil depth, texture, drainage, pH and SOM, slope and LGP factors were rated based on FAO land evaluation system using (FAO, 1976; 1983) guidelines. A Land suitability classification at present condition was made in an area of 4000 ha by matching between reclassified LCs of the region with crop LURs using GIS model builder (Figure 3). The model builder uses maximum limitation method so that the most limiting climatic or soil parameter dictates the final level of suitability (Sys et al., 1991; Van Diepen et al., 1999).

RESULTS AND DISCUSSION

The factors influencing chickpea, soybean, maize and wheat yields and their suitability are soil depth, texture, av P, pH, organic carbon and slope factors, etc (FAO, 1998). The study has produced potential land suitability map of the East Amhara Region that will allow growing the right cereal cash and pulse crops at the right site for optimum yield and optimum return to investment for each crops. Tables 2 and 3 and Figures 4 and 5 showed that 232 ha (85.8% and 321.69 ha (8.04%) were highly suitable for maize and wheat, respectively. However, the land use suitability analysis indicated that the largest portion of the region (2380 ha (59.5%), 1880 ha (47%), 1459.32 ha (36.48%) and1464.12 ha (36.60%) were, respectively unsuitable due to soil depth, texture, pH and SOC and slope factors for, chickpea, soybean, maize and wheat production. The study revealed that GIS technique was found to be most essential tool for the crop land suitability evaluation of the region. It was clear that the same parcel of land was suitable for all crops bringing competing nature of crop LUTs. To validate the variations observed in the spatial analysis, other empirical research need to be carried out. The current limiting factors for all

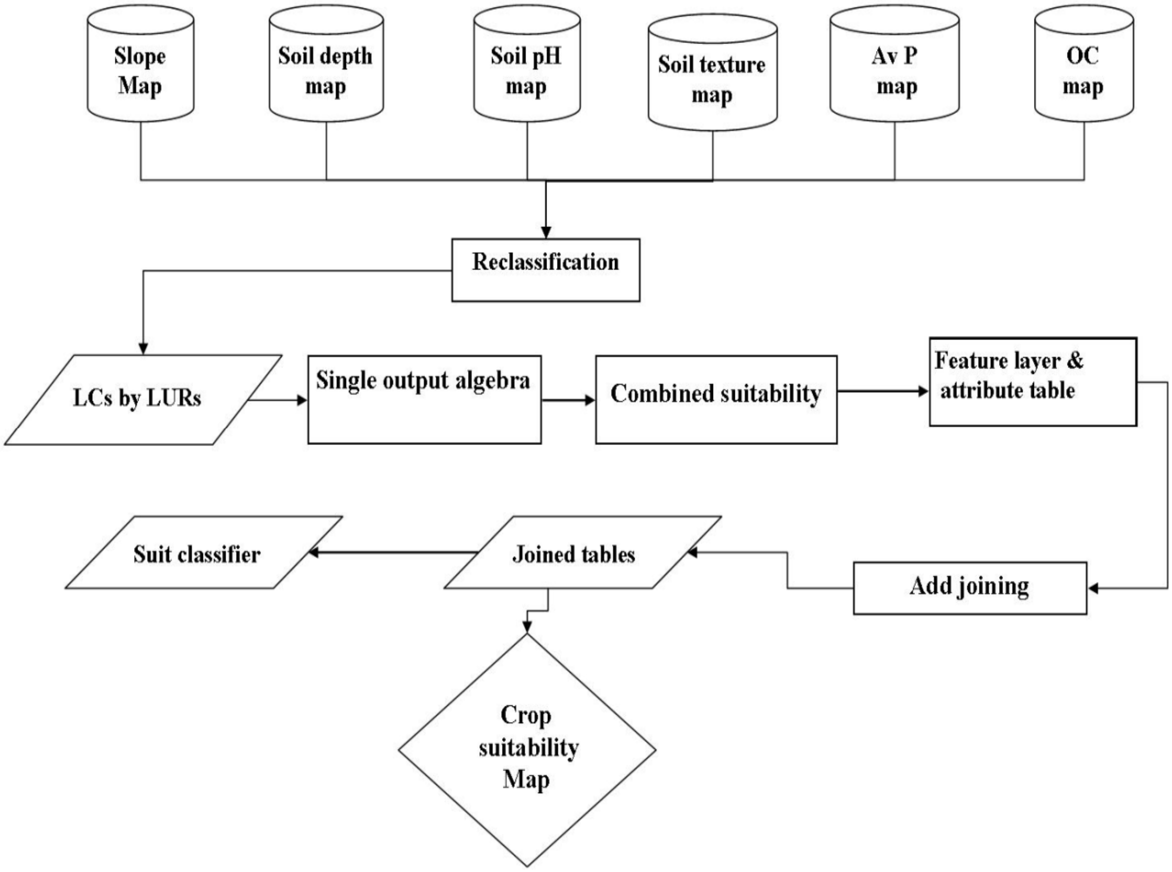

Figure 3. Model used in the study.

Table 2. Suitability of physical suitability, limitations and proportional area of maize and wheat.

No.	Suitability Subclass	Maize		Wheat	
		Area (ha)	Cover (%)	Area (ha)	Cover (%)
1	N	1459.32	36.483	1464.12	36.603
2	S1	232.08	5.802	321.68	8.042
3	S2e	0.12	0.003	1.24	0.031
4	S2k	109.76	2.744	666.76	16.669
5	S2m	608.4	15.21	409.2	10.23
6	S2n	193.16	4.829	82.36	2.059
7	S2r	133.44	3.336	516.56	12.914
8	S2t	169.96	4.249	11.68	0.292
9	S2z	9.08	0.227	4.32	0.108
	Subtotal for moderately suitable land	1223.92	30.598	1692.12	42.303
10	S3k	156.8	3.92	1.24	0.031
11	S3m	119.84	2.996	215.32	5.383
12	S3n	698.24	17.456	268.52	6.713
13	S3r	2.8	0.07	2.32	0.058
14	S3t	1.24	0.031	0.48	0.012
15	S3z	105.84	2.646	34.24	0.856
	Subtotal for marginally suitable land	1084.76	27.119	522.12	13.053

Table 3. Suitability, limitations and proportional area of chickpea and soybean.

No.	Class	Limitations	Chickpea		Soybean	
			Area (ha)	Cover (%)	Area (ha)	Cover (%)
1	N	LGP	244	6.1	80	2
2	N	Slope	1456	36.4	684	17.1
3	N	Soil depth	96	2.4	408	10.2
4	N	slope	112	2.8	380	9.5
5	N	SOM	44	1.1	92	2.3
6	N	Soil texture	128	3.2	84	2.1
7	N	pH	300	7.5	152	3.8
	Subtotal for unsuitable land (N)		2380	59.5	1880	47
8	S2	LGP	288	7.2	228	5.7
9	S2	Slope	348	8.7	396	9.9
10	S2	Soil depth	52	1.3	100	2.5
11	S2	slope	180	4.5	108	2.7
12	S2	SOM	84	2.1	140	3.5
13	S2	pH	44	1.1	96	2.4
	Subtotal for moderately suitable land (S2)		996	24.9	1068	26.7
14	S3	LGP	168	4.2	364	9.1
15	S3	Slope	84	2.1	260	6.5
16	S3	Soil depth	96	2.4	152	3.8
17	S3	slope	116	2.9	88	2.2
18	S3	SOM	52	1.3	84	2.1
19	S3	Soil texture	56	1.4	104	2.6
20	S3	pH	52	1.3	1052	26.3
	Subtotal for marginally suitable land (S3)		624	15.6		

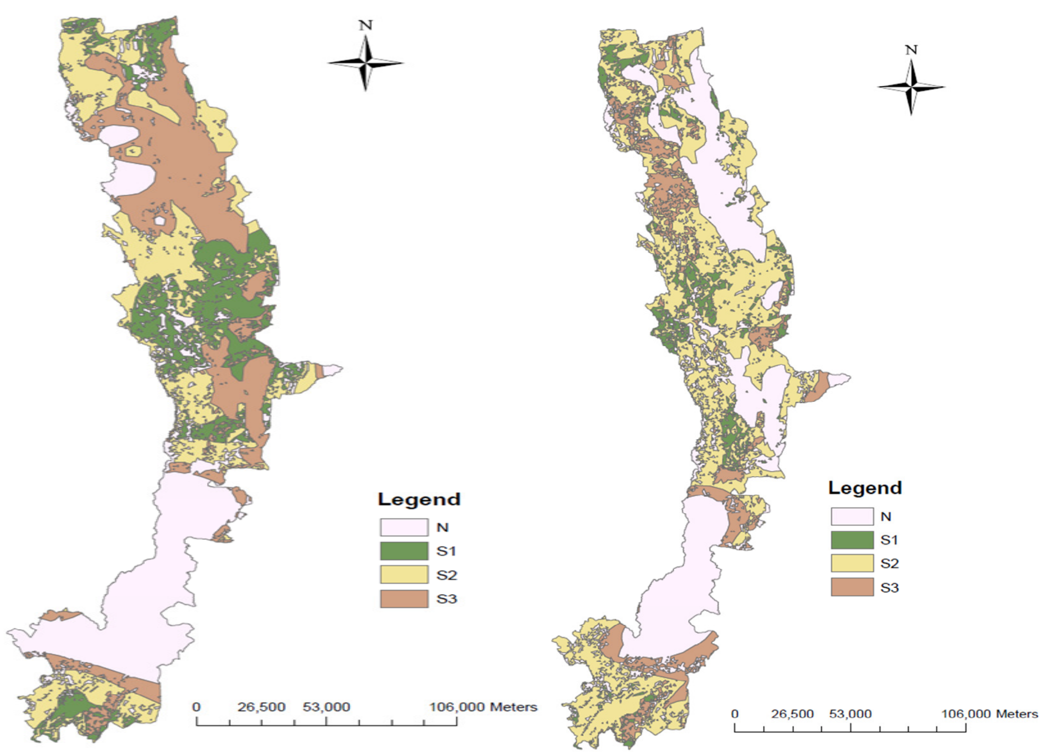

Figure 4. Maize (left) and Wheat (right) suitability Map.
Note: N for unsuitable; S1 for highly suitable; S2 for moderately suitable and S3 for marginally suitable

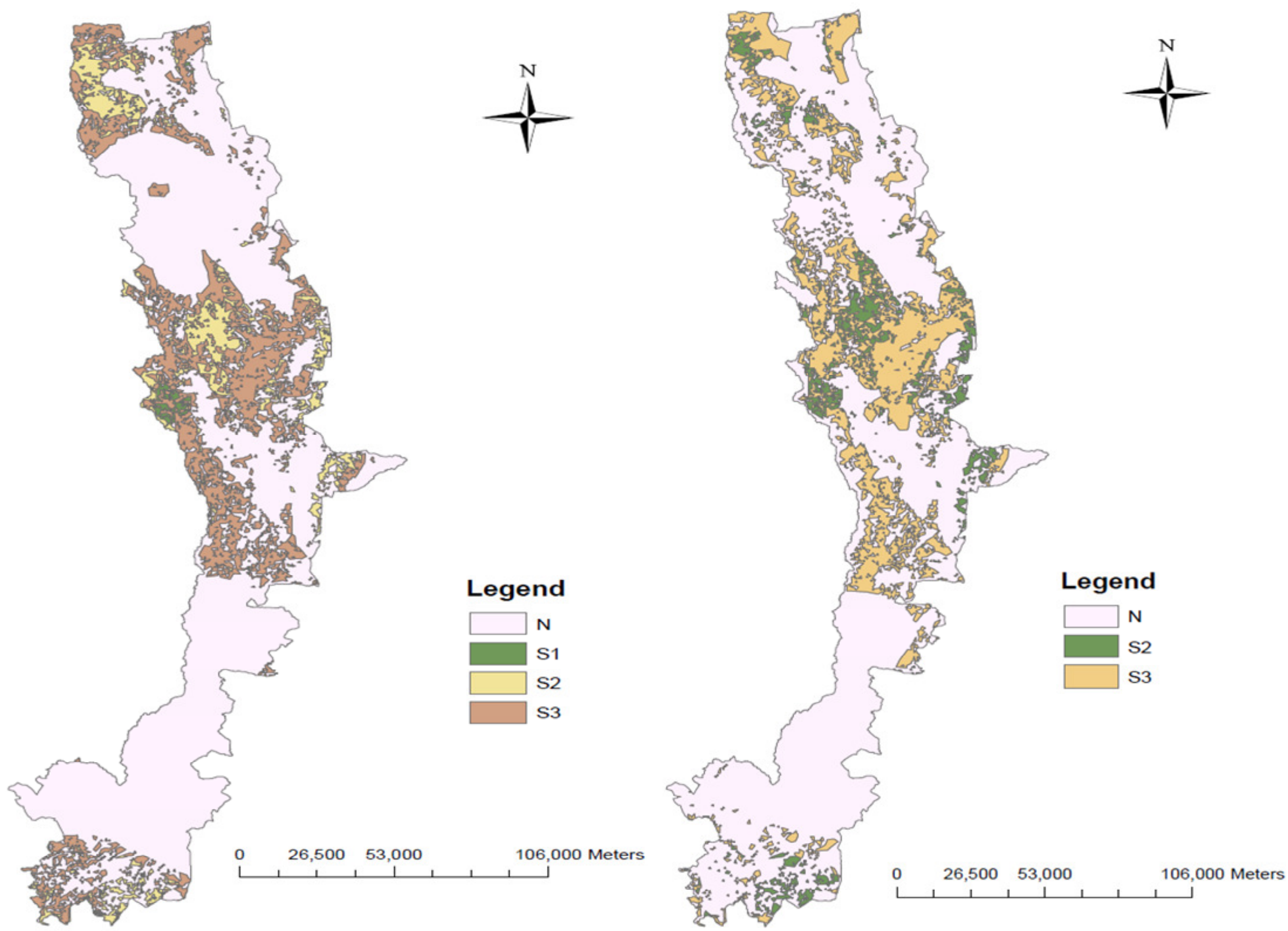

Figure 5. Chickpea (left) and Soybean (right) Suitability Maps.

crop suitability were soil texture and soil depth limitations. Decision-making regarding selection of crop LUTs and mitigation measures to alleviate the identified crop production limitations could also be include socio-economic evaluation (Ceballos-Silva and Lopez-Blanco, 2002). It is found that the increasing degree of limitation decreases the suitability and productivity.

Conclusions

The study revealed that GIS technique was found to be essential tool for the crop land suitability evaluation. The study has delineated areas and produced potential land suitability map of the watershed that will allow growing the right cereal and pulse crops at the right site for optimum yield and optimum return to investment for each crops. It was clear that the main limiting factor for crop suitability in the area were soil pH, texture, soil depth, and slope limitations. However, suitability for growing crop is not only limited by the selected edaphic constraints but also socioeconomic factors which should be incorporated for further study.

ACKNOWLEDGEMENTS

This study was part of the Capacity Building for Scaling up of Evidence-Based Best Practices in Agricultural Production in Ethiopia (CASCAPE) project on increasing agricultural productivity in Ethiopia. The CASCAPE project is funded by the Dutch Ministry of Foreign Affairs through the Embassy of the Kingdom of The Netherlands in Addis Ababa, Ethiopia. The Amhara Design and Supervision Works Enterprise (ADSWE) are also acknowledged for permitting the analysis of the soil samples in its laboratory.

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