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ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
SCHOOL OF EARTH SCIENCES
REMOTE SENSING AND GEOINFORMATICS

Assessment of the Spatial Distribution of Wild and Cultivated *Ensete ventricosum* in Ethiopia Using Geospatial Tools

***Dissertation submitted for Partial Fulfillment of the Requirements for
The Award of the Degree of Master of Science in Remote Sensing and
Geoinformatics***



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May, 2017

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**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES FOR PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR DEGREE OF MASTER OF
SCIENCE IN REMOTE SENSING AND GEO-INFORMATICS**

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This is to certify the thesis prepared by Meron Awoke entitled as “Assessment of the Spatial Distribution of Wild and Cultivated *Ensete ventricosum* in Ethiopia Using Geospatial Tools” is submitted in partial fulfillment of the requirements for the degree of master of science in Remote Sensing and Geo-informatics compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

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DECLARATION

I, hereby declare that the thesis entitled “**Assessment of the Spatial Distribution of Wild and Cultivated *Ensete ventricosum* in Ethiopia Using Geospatial Tools**” has been carried out by me under the supervision of **Dr. BinyamTefaw**, School of Earth Sciences, Addis Ababa University from the year 2016–2017 as a part of Master of Science program in Remote Sensing and Geo-informatics. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

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Abstract

Ensete ventricosum varieties are important for agricultural and economic developments of Ethiopia. However, little information is documented on the existing characteristics of ensete and distribution of different ensete varieties across different agro-ecological zones. Hence, analyzing the spatial distribution of these species at spatial and temporal scale is of great importance for resource management and conservation planning. This study is attempted to identify, map and model the distribution of wild and cultivated *Ensete ventricosum* (ensete) with respect to land cover, climate, natural vegetation cover and agroecological zones. For this purpose, geospatial data analysis and MaxEnt modeling techniques were used to map the probabilistic distribution of both wild and cultivated varieties. About 26 environmental factors were utilized as variables for distribution and modeling these includes 19 bioclimatic variables, DEM, LU/LC, vegetation, agro-ecology and soil type, and 192 cultivated and 20 wild ensete species records. Besides, Pearson correlation analyses were undertaken for 26 environmental variables to reduce highly correlated variables. The MaxEnt modeling has proven to be very effective at determining habitat use and species distributions for a variety of species and localities. The average test Area under curve (AUC) for the replicate runs was 0.842, and the standard deviation was, 0.046 and AUC 0.760 with standard deviation of 0.101 for cultivated ensete and wild ensete, respectively. Out of the determinants, the annual rainfall (15.7%) and LU/LC (53.7%) were the most important environmental variables that highly affected the distribution of cultivated and wild ensete, respectively. In addition, about 1.55% of the study area was covered by primarily hotpot areas of cultivated and 3.6% is for wild ensete. The probabilistic distribution of cultivated ensete is higher in the southern region, some part of Oromia region, and little areas of southern and eastern parts of Amhara region, whereas wild ensete is spatially highly distributed in Tigray and Benshangul Gumuz regions in addition to areas that cultivated ensete is distributed. In terms of agroecological zones, ensete is dominant to tropical sub-humid areas and tropical cool humid areas, typically at higher elevations (highlands), and areas having high rainfall and low temperature.

Keywords: MaxEnt modeling, AUC, *Ensete ventricosum*, Geospatial data analysis

Acronyms

AEZ	Agroecological zones
ASCII	American Standard Code for Information Interchange
AUC	Area under Curve
CSV	Comma Separated Values
DEM	Digital elevation model
EROS	Earth Resources Observation and Science
GIS	Geographic information system
GTopo30	Global Topographic 30 arc-second
LULC	Land use land cover
ROC	Receiver Operating Curve
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission
SDM	Species Distribution Model
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System

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1. Introduction

1.1. Background

Agriculture is the mainstay of Ethiopia's economy, which supports more than 85% of the population. This sector directly or indirectly forms an important component of the livelihoods of more than 70 million for food and as a source of income. ensete is categorized under highland mixed farming system from the four major agricultural systems in Ethiopia; it is one of the major sources of food and income in southern part of Ethiopia with high production. Different ethnic groups in southern region use ensete in different ways, but the main ones are the Gurage, Sidama, Gamo, Hadiya, and Wolayta. (Chiche, 1995)

Ensete ventricosum commonly known as ensete is a plant which closely resembles the banana plant, and used for human food, fiber, animal forage, construction materials, and medicine. It is a monocropic perennial herb of the family Musaceae originated in Ethiopia and cultivated only in its native indigenous farming systems of South and South-Western Ethiopia. The genus of this species is distributed widely in Africa and Southeast Asia, its main centre of distribution being in the cooler and drier parts of tropical and stability of the farming system itself (Cheesman, 1947). *Ensete ventricosum* is arguably the most important crop contributing to food security and rural livelihoods for about one fourth (~20 million people) of Ethiopian population. Currently, ensete cultivation covers over 300,000 ha of land, one of the largest for perennial food crops in the Country. The ensete farming system is cultivated as perennial plantation in homesteads in association with other companion crop species like coffee and chat growing in main agricultural land (Olango *et al.*, 2014).

According to Alemu and Sandford, (1991) different variables affect the growth and distribution of ensete including management, type/cultivar, soil type and fertility, amount and distribution of rainfall, and altitude of the area. It reaches up to 10.300 m in height and the girth at the fattest point can be up to 4 m. This crop is not affected by excess rain or by drought, as it has been witnessed during the famines of the 1980s and it is called as “a tree against hunger” (Brandt *et al.*, 1997). Previous studies have attempted to characterize and analyze the production of ensete but the species distribution has rarely been explored. Thus, mapping the spatial distribution of

this species using geospatial tools and MaxEnt modeling is crucial for the management and other studies of the *Ensete ventricosum* in Ethiopia.

1.2. Statement of the Problem

Agricultural sector is the basis for the entire socio-economic structure of Ethiopia. However, changing environmental factors have led to crop failures, which pose a critical risk for agricultural productivity and food security in general and production of cultivated and wild ensete in particular. Many studies were undertaken in Ethiopia regarding on *Ensete ventricosum* distribution in specific areas. However, the characterization of Ensete crop regarding their spatial distribution at temporal and spatial scales have not yet been studied. In addition, there is inadequate information regarding the existing characteristic of ensete and distribution of different ensete types across different agro-ecological zones and natural vegetation types in Ethiopia.

1.3. Research Questions

The main research questions that have to be addressed in this study are:

- What are the landscapes, environmental and climatic factors that affect the presence of wild and cultivated *Ensete ventricosum*?
- What are the factors governing the distribution of wild and cultivated *Ensete ventricosum* in Ethiopia?
- What are the potential hotspots areas for wild and cultivated *Ensete ventricosum*?

1.4. Objective

1.4.1. General Objective

The general objective of this study was to identify, map and model the distribution of wild and cultivated *Ensete ventricosum* (ensete) with its respective natural vegetation cover and agroecological zones using Geospatial data analysis and MaxEnt modeling.

1.4.2. Specific Objectives

The specific objectives of the study were;

- To characterize *Ensete ventricosum* based on the agroecological zones, natural vegetation, land-use/land-cover, soil type, elevation and climate condition of Ethiopia,

- To identify potential hotspots areas for wild and cultivated *Ensete ventricosum* using MaxEnt modeling.

1.5. Significance of the study

Ensete ventricosum plays great role in the food security of Ethiopia. It's a staple food for significant Ethiopian population. It has several environmental, nutritional and socio-cultural importance. Because of this, it is vital and necessary to study the factors that affect *Ensete ventricosum*. Maps of species distributions are required for many aspects of environmental research, resource management, and conservation planning. These include biodiversity assessment, food security plans, habitat management, and restoration, species and habitat conservation plans and predicting the effects of environmental changes on species and ecosystems. The outcome generated from this study will provide basis to identify the distribution and hotspot areas of ensete also wild and cultivated *Ensete ventricosum* are characterized with respect to different factors were: natural vegetation, agroecological zone, land-use/land-cover, soil type, elevation and climate of the country.

1.6. Scope and limitation of the study

The scope of this study is limited to analyze the spatial distribution of ensete in Ethiopia. This assessment is limited by fragmented information and course resolution of land-use/land-cover, soil type, and bioclim data of the study area from worldclim.

1.7. Thesis outline

This thesis is organized in six chapters and associated appendixes. The **first chapter** is an introduction that includes back ground, statement of the problem, research questions and objectives, significance and scope of the study as well as the overall thesis outline. **Chapter two** covers the review of the main related facts from reference sources and review of earlier studies related to *Ensete ventricosum*. **Chapter three** gives a general description of the study area. This includes location, geography, topography, climate, and land use/land cover of the study area. It's also covers materials and methods of the study. Model input data, and methods of data analysis are presented in detail. **Chapter four** deals with results and discussions of the study. Conclusions and Recommendations of the thesis work are discussed in **Chapter five**. Finally,

appendices in the form of Tables and Figures to serve as supporting documents to this thesis are attached.

2. Literature Review

2.1. Agricultural system in Ethiopia

Over 85 % of the Ethiopian population depends on agriculture for livelihood. The agricultural sector contributes slightly more than half of the country's Gross Domestic Product. Almost all of the foreign exchange earnings of the country come from the export of agricultural products; many of the raw materials used by the country's factories and industries come from agriculture. The potential for sharply increased agricultural development is high, both for crop and livestock production, and thus the country's sustained development depends above all on the achievement of steady progress in agricultural output and production efficiency.

According to Getahun Amare, (1978), the major agricultural systems of Ethiopia are categorized in to four classes namely, highland mixed farming system, low plateau and valley mixed agriculture, Pastoral livestock production of the arid and semi-arid zones, and commercial agriculture.

A) Highland mixed farming system

In this farming system, intensive multiple crop production is integrated with livestock production. This farming system is typically found in areas of higher elevations, usually above 2000 m but some areas farm in areas of above 1500 m altitude. Here, the annual precipitation, especially during the long growing season (June-September) is sufficient to grow annual crops. The crop production aspect of this mixed farming system is characteristically diversified and intensive and employs multiple cropping with limited inter-cropping. Farms are generally permanent and/or semi-permanent and the individual holdings are usually under 5 ha. Continuous cropping is made possible by a crop rotation in which several years of cereal production alternates with a legume crop as a means of maintaining soil fertility in addition to the customary pen-manuring with livestock excreta. The production system, particularly in crop production, is labor-intensive: family labor is the major production input and the farming operation is so designed that all members of the household participate throughout the year, thus fulfilling both social and economic status and food needs of the members of the peasant family (Getahun Amare, 1977). Diversity of crops grown for food, cash or other purposes is high,

largely because of diversified agro-climates, natural resources (genetic resource diversity) and diverse socio-cultures. ensete crop is categorized under this class.

B) Low plateau and valley mixed agriculture

Related or similar to the mixed farming system of high plateau described above is the sedentary agriculture of the intermediate or low highlands, mountain foothills and upper valleys, often at altitudes of 1500-2000 m at 450-800 mm annual rainfall isohyets. Here, both crops and livestock are produced but the diversity of crops grown and the degree of integration of crop and livestock production is less pronounced. Sorghum (low altitude type) and maize dominate the crop production with some oil crops, wheat and tef (*Eragrostis tef*). The livestock is often taken out of the cropping zone during the growing season and returned after crops are harvested to be fed on crop residues. Except for the river valleys, much of the area is of broken topography and general ecological degradation-resulting from overgrazing, deforestation for firewood and charcoal production and bad crop farming practices-is a common feature. Despite the physical dominance of crop farming, livestock production is economically significant as year-to-year yields are highly variable.

C) Pastoral livestock production of the arid and semi-arid zones

Pastoral agriculture is common in the lowlands of Ethiopia, which completely encircle the country. It is physically dominant as it covers a vast area although the total livestock produced is still less than that produced in the mixed farming system of the highlands. This system occurs below 1500 m elevation where annual rainfall is <4500 mm. In the more arid zone, nomadic and semi-nomadic pastoral livestock production dominates, with camels and goats as important constituents. In the semi-arid zone, semi-nomadic or semi-sedentary livestock production dominates: cattle and sheep may be more important, but more often all four classes of animals are well represented. There is often some corral cropping (i.e. crop growing in the livestock corrals), usually maize. Water shortage is a major production constraint, particularly in the arid zone, and thus both water and range development and management are important elements of improved livestock production on a sustained basis.

D) Commercial Agriculture

Scattered within the farming systems and zones described above is commercial agriculture (crop or livestock), which is of recent origin and largely the result of government subsidies in the form of tax-free agricultural machinery and fuel as well as tax 'holidays' of five years for larger investments in agriculture. These are intensive farms such as the dairy farms near urban centres, irrigated crop farms (sugar cane, cotton, tobacco) and plantation crops (coffee, tea) and citrus and other tropical fruits in river basins. They may be extensive such as the mechanized rain-fed farms of the lowlands (sorghum, sesame, cotton)

2.2. Origin and History of *Ensete ventricosum* in Ethiopia

It may be difficult to delineate details origin of ensete cultivation and its temporal-spatial dimensions. However, available ethno-historical and archeological sources indicate that ensete is considered as wild crop in East Africa. *Ensete ventricosum* is widely spread in a wild state in Africa from Cameroon to East Africa and Transvaal (South Africa), and cultivated in Ethiopia (Purseglove, 1972). It grows as food crop only in Ethiopia and that restricted to southern Ethiopia. Trends in ensete plant cultivation as a food source have also been changing so that in some formerly ensete dominated areas other cereal crops have come to play major roles (Zerihun Doda, 2006). According to Westphal (1976), the high land of Kefa, which is the humid corner of southwest Ethiopia, is the natural center of distribution of ensete. Ancient group of people first cultivated ensete in the Bako Highlands in Gamo Gofa and the Gimira and Maji areas in Kefa. Other studies have revealed that the Ethiopian highlands as the primary center of the origin for ensete cultivation. It is an indigenous crop to Ethiopia, where primarily cultivated as a staple food though wild ensete varieties were reported to be found in other African and Asian countries (Tadessa Daba and Masayoshi Shigeta, 2016). Based on the review of previous studies, *Ensete ventricosum* plantation in Ethiopia as a food crop has long history. Many scientists of different disciplines have developed theories that assume ensete domestication in Ethiopia since 10,000 years ago. Early scholars considered the indigenous hunter/gatherers of southern Ethiopia may be the first ones to cultivate *Ensete ventricosum*.

2.3. Economic and Socio-Cultural Values of ensete

People in the south and south western parts of the country are not only depending on ensete for food and cash, but also consider it as part of their cultural heritage. They have a strong attachment to the crop and the land. Many farming households grow ensete for economic as well as non-economic purposes. The ensete plant can also be sold in some cases and the processed products like kocho and bulla are sold anytime in the rural markets and towns. Therefore, it is an immediate cash income source for a family to buy their daily needs (Tadessa Daba and Masayoshi Shigeta, 2016). It is observed that ensete is the only staple food of people of the southwest Ethiopia. Although in the main ensete makes up the dominant strand in the livelihood and socio-cultural system of the peoples, emphasizing this issue too much underplays the reality. Painting a picture of the people who know nothing else besides the ensete plant and eat nothing besides kotcho is highly inappropriate and misinformed (Zerihun Doda, 2006). ensete has cultural values during wedding and funeral ceremonies. During wedding, ensete leaves can be used on tables for serving food and as skirts for women in some cases in addition to being the major food for the ceremony.



Figure 2.1: Homestead cultivation of ensete (A), wild ensete around Ari (B).

2.4. Importance of *Ensete Ventricosum*

ensete is plant of which every single part is used. There are a variety of purposes of *Ensete ventricosum*. It's suitable for sustainable agricultural systems due to its contribution to soil fertility. In addition, ensete can easily be stored without the need for refrigeration and is available throughout the year. It can be accessed at any time when there is food shortage and other crops fail as a result of drought, diseases or other factors. ensete represents 65% of the total crop production in the southern regions of Ethiopia. Productivity is very high compared to other crops but varies depending on edaphic factors, altitude, cultural practices and climatic conditions (Genet Birmeta, 2004).

According to Peveri, (2005), ensete is categorized based on their functions:

- ❖ The building function: ensete is used to cover the roofs or the house's walls, to baste materials, to make ropes, mats, bags, ropes and sieves.
- ❖ The economic function: the leaves of the plant, and the strong fibers which are extracted from it, are important articles of barter, an integral part of the inter-tribal trade, and goods through which to get money.
- ❖ The domestic function: the stems and central nervatures, once dried, feed the fire; the pulp extracted from these parts can be used as a duster or a brush, as a pillow or a nappy for children, as a support for pots; the fresh leaves are used as serving dishes or as a protective covering inside the pits where the ensete is fermented or to pave the ground where the processing of the plant takes place.
- ❖ The protective function: the fresh leaves wrap kocho, honey, tobacco, butter, bread, crops, but also, in the past, the new born babies; they cast a shadow over the other crops or men, screening them from the light of the sun, the wind, the rain; they allow the packaging and therefore the transport of objects and goods to the local markets; the ensete plants surround the house providing security, primarily in the form of a supply of close and always available food.
- ❖ The dietary function, but for animals as forage: since the plant contains a lot of water and is quite resistant to drought, some specimens of ensete are cut down to feed the animals especially in the dry season when the grass is spare.

- ❖ The healing (Medication) function: specific clones and parts of the ensete are used for therapeutic purposes, both for humans and animals, to treat fractures and broken bones, problems related to childbirth - for example, as an aid to release the placenta, for diarrhea and as a means of birth control - for abortion.

2.5. Difference between wild and cultivated *Ensete Ventricosum*

Wild *Ensete ventricosum* grows in a number of countries in central and east Africa, including Congo, Mozambique, Uganda, Tanzania and Zambia. Wild *Ensete ventricosum* occur in highlands of Ethiopia (1100–3100 m a. s. l.) in the southern part. The distribution is very restricted; the wild populations grow mainly around the city of Bonga (Keffa administrative region) and in a smaller area by the Omo river (Gamo-Gofa administrative region), in habitats ranging from dense forests to open shrub land, or along riverbanks. Areas where wild ensete grows are often not suitable for human settlements; human interference still prevails through the raising of domestic animals and cutting of trees and shrubs (Genet Birmeta, 2004).

Cultivated *Ensete ventricosum* grows in a wider area when compared to wild ensete which, comprising the central, south and southwestern parts of Ethiopia, but mainly at higher altitudes ranging from 1500 to 3100 m. According to Pankhurst (1996), ensete cultivation in Ethiopia may have started around the 15th century, south of Ghibe River. However, historical evidence regarding the origin and domestication of crops is seldom completely trustworthy.

ensete is mainly grown by the southern and southwestern peoples, though some areas in the Oromia region grow who ensete too. At present, most of these areas are part of the Southern Nations, Nationalities and Peoples which is considered to be a Region of the home of ensete agriculture (Alemu K, and Sandford S. (1991).

Ensete ventricosum was previously cultivated only in the south and south-western parts of Ethiopia, but the previous droughts have led to the expansion of ensete cultivation to other parts of the country. A wide adaptation within the species to altitude, soil and climate has allowed widespread cultivation in western Bale, south-western Oromia including south and east Shewa, Jima, Illubabor and Welega (Shank, 1994). *Ensete ventricosum*, the only known wild species in Ethiopia, is concentrated in the southern Highlands, but also grows in the central and northern highlands around Lake Tana, the Simien Mountains, and as far north as Adigrat and into southern Eritrea (Brandt *et al.*, 1997).

According to Brandt *et al.*, (1997), wild ensete grows at altitudes of 1200–1600 m above sea level while domesticated ensete is cultivated at altitudes of 1100–3100 m above sea level. The optimal conditions for ensete cultivation occur at 2000–2750 m with 1100–1500 mm rainfall, a temperature range of 10–21°C and a relative humidity of 63–80% .Lack of sufficiently high humidity is more limiting for good growth. ensete often grows best in acidic, heavy clay soils that retain high levels of organic matter when manure. Figure 2.2 indicate ensete growing areas of Southern Ethiopia and its Ethnic groups.

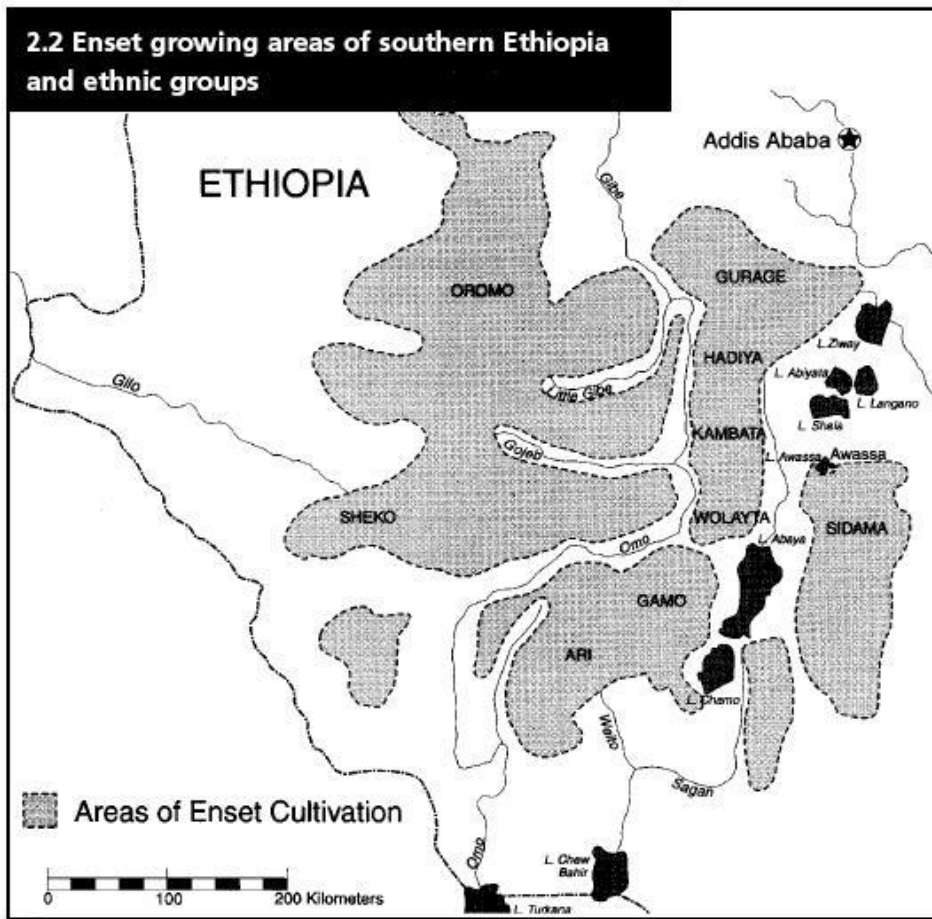


Figure 2.2: ensete growing areas of southern Ethiopia and its ethnic groups (Source: Brandt *et al.*, 1997).

2.6. Remote Sensing and GIS approaches for mapping distribution of species

Remote sensing (RS) and Geographical Information System (GIS) techniques are becoming increasingly important in many fields. The potential of modern RS is to identify areas of high

biodiversity, prediction of species distribution and modeling species responses to environmental and anthropogenic changes (Turner *et al.*, 2003). Geospatial tools play a great role in order to map the potential distribution of a species with species distribution models.

One potentially cost effective approach in identifying potential occurrences of species is to predict their distribution using remotely sensed data and knowledge of ecology and environmental tolerances. Remote sensing technology has received considerable interest in the field of biological invasion in the recent years. The key requirement in species mapping is delineation of spatial extent to understand the severity of species (Reddy, 2015).

Remote sensing and GIS are important tools separately and in combination with models for modeling species distribution. GIS can be used to model the spatial distribution of species based on the niche concept. Different GIS map layers describing the environmental conditions of the study area can be used to extract the variables that determine their distribution (Pallaris, 1998). Application of GIS systems to explore the biodiversity and potential distribution of crop species have successfully been implemented, with the result of producing maps indicating areas of favorable environmental conditions for their growth and distribution (Jones *et al.*, 1997).

2.7. MaxEnt Model

The most common strategy for estimating the actual or potential geographic distribution of a species is to characterize the environmental conditions that are suitable for the species, and to identify where suitable environments are distributed in space. Species distribution models are models that associate species concurrence at known locations with information on the environmental characteristics of those locations (Elith and Leathwick, 2009). The environmental conditions that are suitable for a species may be characterized using either a mechanistic or a correlative approach. Mechanistic models aim to incorporate physiologically limiting mechanisms in a species tolerance to environmental conditions (Pearson, 2007).

Phillips *et al.*, (2004), proposed the use of maximum entropy to model species geographic distributions. The maximum entropy method for modeling species distribution involves using a collection of known localities of the species as sample data along with relevant environmental factors to model the distribution of that species within a known geographic extent. Maximum entropy or MaxEnt (Phillips *et al.*, 2006), a machine-learning method, has been very effective in SDM studies with presence-only data, particularly with small sample sizes however, its

performance degrades when used for extrapolation (Franklin, 2010). It can be misleading when a species is not in equilibrium with the environment or when there is an historical or biotic barrier preventing it from occurring in suitable habitat. Presence-only data are most appropriate for predicting potential distribution (Jimenez *et al.*, 2008). MaxEnt is influenced by biased sampling distributions. However, this bias can be reduced by targeting background locations from sampled areas (Phillips *et al.*, 2009).

2.8. Previous studies on MaxEnt Modeling

Many studies were undertaken using MaxEnt modeling in different geographical locations. For instance, VanGils *et al.*, (2012) used MaxEnt to model the distribution of endemics at fine resolution in Majella national Park. Stepwise Maximum Entropy model was generated per endemic to achieve the most parsimonious result at an area under the curve 0.8 and MaxEnt confirmed its strengths also at fine resolutions and, in addition, showed to be robust across predictor layers at both resolutions. Pollock, (2015) also used MaxEnt model to identify local scale tree species richness in California. Species richness predictions met the 0.7 AUC benchmark and their test data closely mirrored the ROC plot. Clark *et al.*, (2014) assessed current and projected suitable habitats for tree-of-heaven along the Appalachian Trail using MaxEnt modeling and incorporating NASA's remote sensing data and modeling capacities from the Terrestrial Observation and Prediction System (TOPS). Their results predicted a 48% increase in suitable area over the study area, with significant expansion along the northern extremes of the Appalachian Trail.

3. Area Description and General Methodology

3.1. Description of the Study Area

3.1.1. Geographic Location

Ethiopia lies within the zone of sub Africa country in the Horn of Africa ($32^{\circ}42'_{-}48^{\circ}12'E$ longitude and $3^{\circ}24'_{-}15^{\circ}00'N$ latitude). It is bordered by Eritrea to the north, Djibouti and Somalia to the east, Sudan and South Sudan to the west, and Kenya to the south (Fig 3.1). The country covers about 1.13 million km^2 . The highlands > 1500 m above sea level constitute around 45% of the total area, where $>80\%$ of the Ethiopian population (Gebeyehu, 2003).

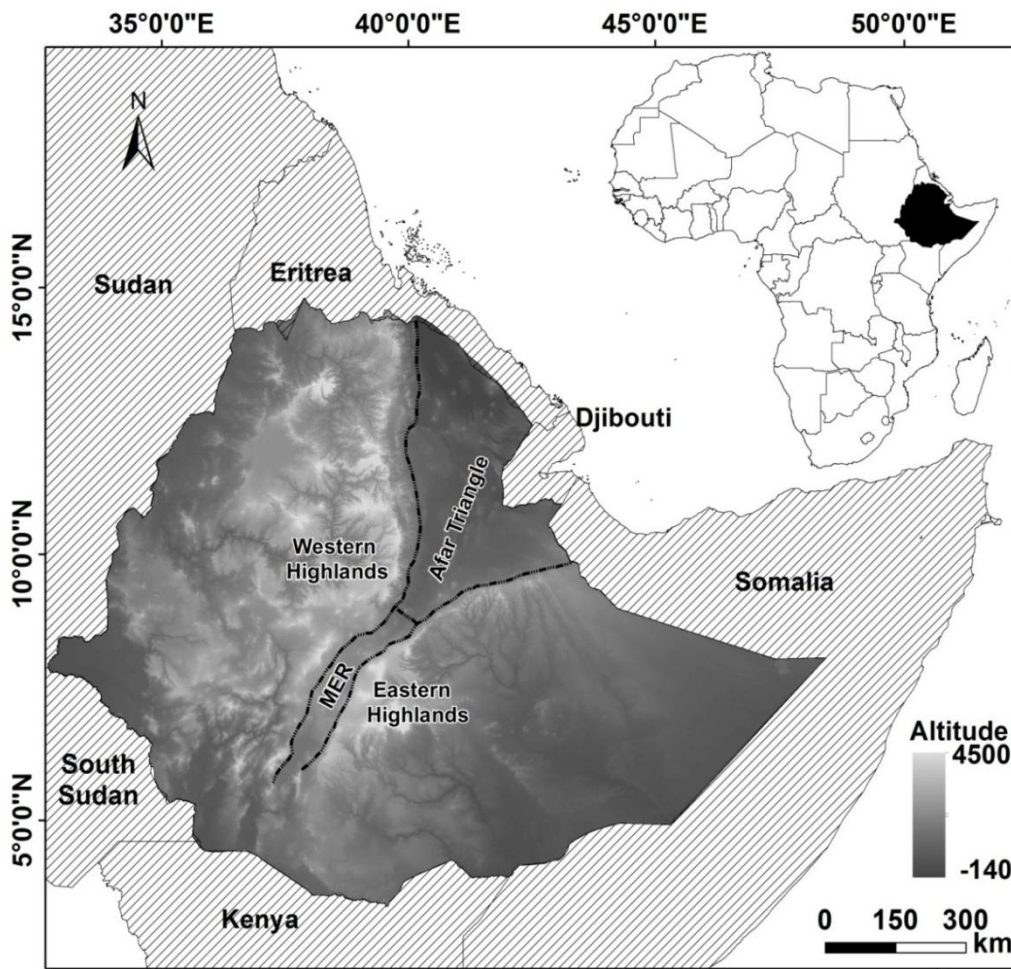


Figure 3.1: Location map of the study area.

3.1.2. Climate

Ethiopia has a wide range of climatic features suitable for different agricultural production systems. Temperature and rainfall are the most important climatic factors for agricultural production in Ethiopia. Rainfall in Ethiopia is related with an altitude that determines the distribution of climatic factors and land suitability. This influences the crops to be grown, rate of crop growth, natural vegetation types and their species diversity (Alemayehu, 2006). Middle and higher altitudes (above 1500 m) receive higher rainfall than lowlands, except the lowlands in the west where rainfall is high. Generally, average annual rainfall of areas above 1500 m exceeds 900 mm. In the lowlands (below 1500 m), rainfall is erratic and averages below 600 mm. There is strong inter-annual variability of rainfall all over the country. Temperatures range from the mean annual 34.5 °C in the Danakil Depression, while minimum temperatures fall below zero in the upper reaches of Mountain Ras Degen (4620 m) with a mean of less than 0 °C (FAO, 1984).

3.1.3. Topography

Ethiopia has a high central plateau that varies from 1,290 to 3,000 m above sea level; with the highest mountain reaching 4,533 m. Elevation is generally highest just before the point of descent to the Great Rift Valley, which splits the plateau diagonally. The great Ethiopia Rift Valley separates the western and the eastern highlands; and these highlands gradually descend to the lowland areas in the east, west, and south of the country. Much of the country consists of high plateau and mountain ranges, which are dissected by numerous streams and rivers. Among the biggest river basins are Blue Nile, Awash, Baro, Omo, Tekkeze, Wabe Shebelle and Genale (Osman *et al.*, 2001).

3.1.4. Land-use/land-cover

Ethiopia is characterized by great diversity in terms of natural resource endowments. In principle, favorable environmental conditions, i.e. fertile soils, good climatic conditions, and a high diversity of fauna and flora, are capable of supporting large number of humans and livestock. However, most of these resources are dwindling due to high population growth, the increasing pressure on natural resources, and lack of adequate resource management policies and enforcement.

The current land-cover significantly departs from the potential vegetation, mainly due to anthropogenic influences that dramatically change land use across the country. Natural forest cover has decreased to 2.4% of its original size (Tedela and Lemma, 1998), while woodlands and savannahs are either utilized as pastures or have been converted into agricultural lands. In addition, grasslands are in general highly degraded due to overgrazing or plugging wherever climatic conditions permit cultivation. In the western Ethiopian highlands, 95% of the land is cultivated, whereas the average for Ethiopia is only 45%. This is caused by the large extent of land that is unsuitable for cultivation, such as the Afar Triangle or Somaliland (Shiferaw and Holden, 1999). These areas are generally utilized by nomadic pastoralists. The majority of the population is therefore concentrated in the highlands and the fertile south-western regions, where environmental conditions favor cultivation.

3.2. Materials

Different materials and software's were used based on the relevance to different activities and processes towards the accomplishment of the research. The softwares used for this study are; ArcGIS 10.3, ERDAS IMAGINE 2010, Microsoft excel and MaxEnt modeling. The Geographic Positioning System (Garmin) was used to collect the spatial locations of *Ensete ventricosum* in different part of the region.

3.3. Data collection

Primary and secondary data were collected from different sources (Table 3.1). Prior to the primary data collections, based on the findings of the previous research works, Woredas/ zones was identified where *Ensete ventricosum* were grown extensively. Field data collections were then undertaken in *Ensete ventricosum* cultivated areas for one month. From the randomly selected woredas, about 192 well-defined and distributed ground control points (GCP's) were collected using a global positioning system (GPS) as shown in Figure 3.4. Wild ensete locations data (n=20) were obtained from Addis Ababa University National Herbarium specimen.

Table 3.1: List of spatial and meteorological data used for this study.

Data	Resolution	Year	Source
DEM	1km		Global 30-arc-second(Gtopo 30)
LULC	30 m	2008	Ethiopia Mapping Agency(EMA)
Soil type		1984	FAO
Climate data	1km		http://www.worldclim.org/bioclim
Agroecological data	1km	2010	(Choice H, 2010)
Vegetation data	5 km	2010	(Friis, I.,Sebsebe Demissew., and Breugel, P. V. 2010).

During the field work, important information about the soil type, elevation and climate aspects, which determine the suitability for both cultivated and wild ensete were collected from farmers, development agents and experts. These data were helpful for the study in terms of characterization of *Ensete ventricosum* (Figure 3.2)





Figure 3.2: Cultivated ensete intercropping with coffee and chat (A), data collection during field work (B), Cultivation of ensete on farm land around Masha woreda (C).

3.4. Overall conceptual framework of the study

The following methodologies were applied in order to address the objectives of the study (Figure 3.3). The geographic information system and remote sensing were coupled to map the spatial distribution of cultivated and wild ensete in Ethiopia. Different GIS functions were implemented to investigate the relation between cultivated and wild ensete with respect to land-use types, altitude, slope, aspect, soil type, natural vegetation, and precipitation for different agroecological zones. ArcGIS and ERDAS IMAGINE software were employed to analyze the spatial data. The MaxEnt model were then used to identify hotspot areas with high potential for conservation of wild and cultivated *Ensete ventricosum* using spatial data as input. The general work flow of the study is given in (Figure 3.3.)

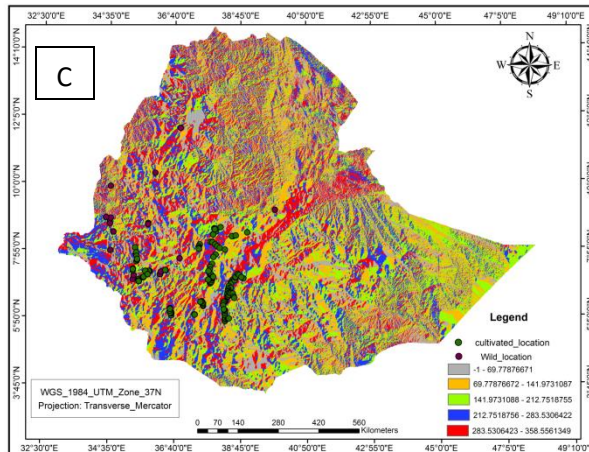
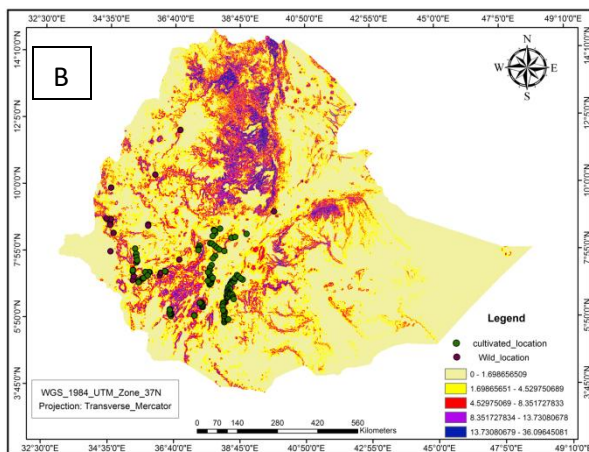
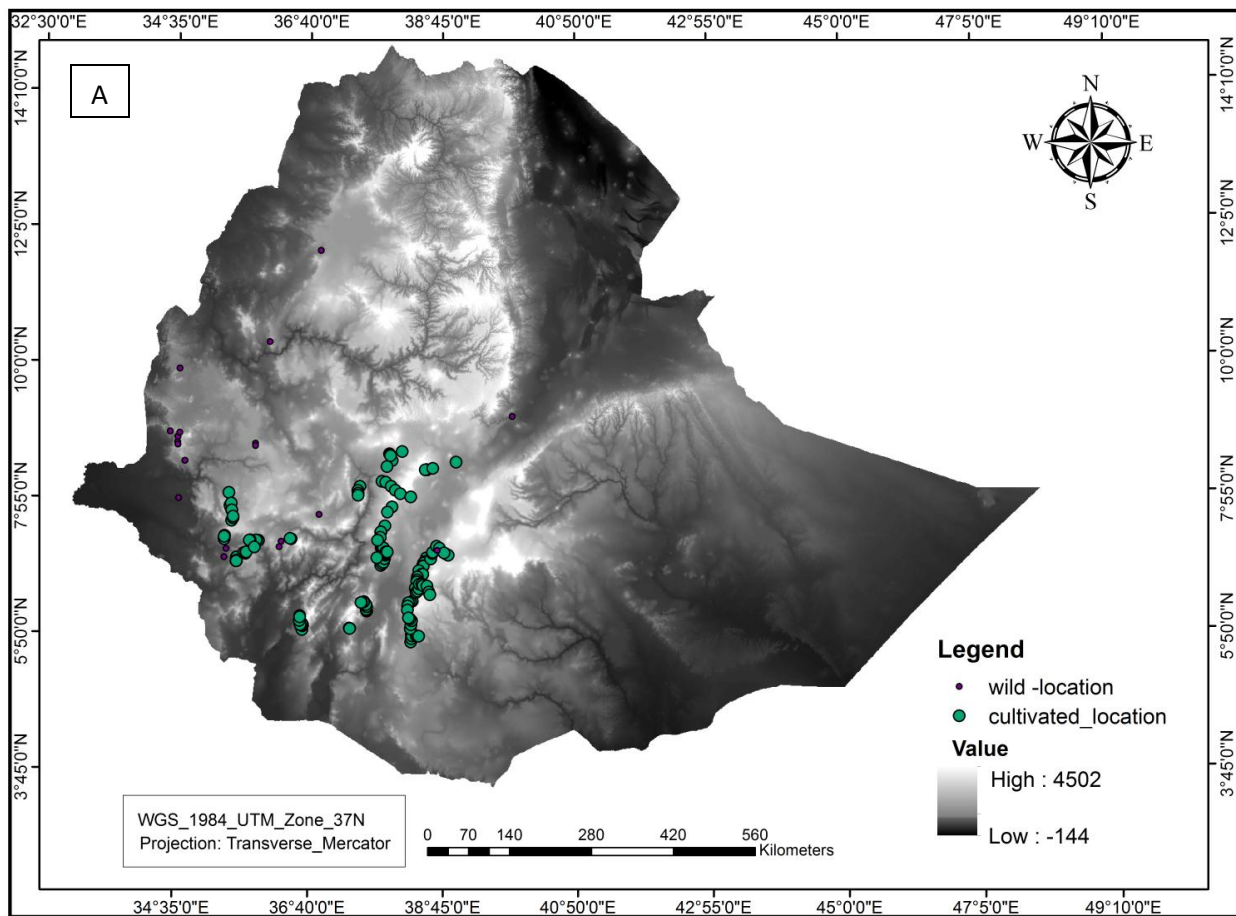


Figure 3.4: DEM (A), slope (B) and aspect (C) map of Ethiopia.

3.5.2. Climate data

Climatic data were obtained from WorldClim database at 1 km spatial resolution. This database consists of a set of 19 global climatic layers generated by the interpolation of global climatic data such as average and seasonal temperature and precipitation records from 1950 to 2000. The 19 bioclimatic variables that define general trends, seasonality and extremes were considered biologically more meaningful than simple monthly or annual averages of temperature and precipitation in defining a species distribution modeling (Kumar *et al.*, 2009). These data were used in MaxEnt species distribution modeling and related ecological modeling techniques as an input (Figure 3.5).

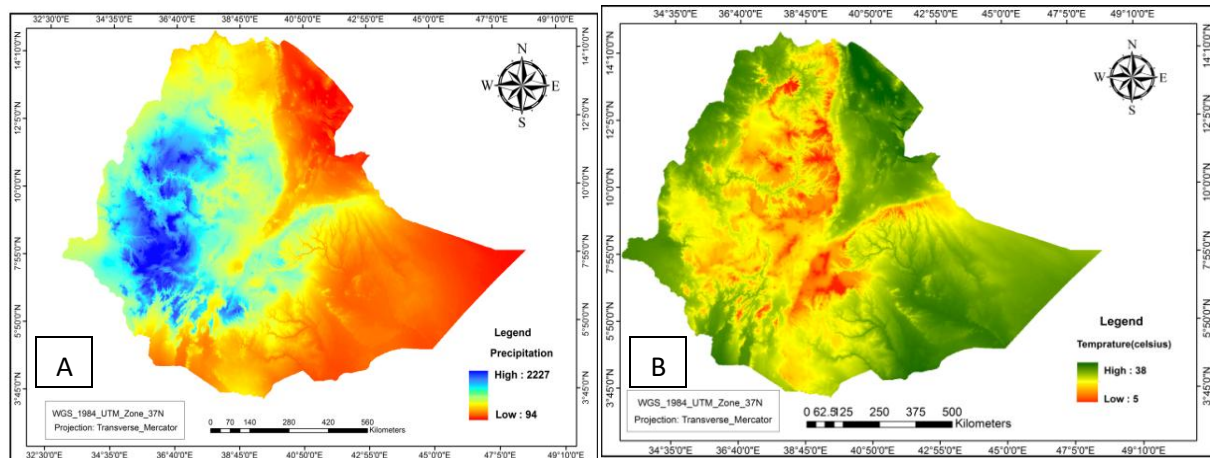


Figure 3.5: Precipitation (A) and temperature (B) map of Ethiopia.

3.5.3. Soil data

Soil data were another spatial input data required by MaxEnt model. Soil data were obtained from FAO 1984. The FAO classification system was used in this study because this classification system considers wide ranges of topographic and climatic factors, parent material and land-use that result in extreme variability of soils (FAO, 1984). According to FAO soil classification, 35 soil types were identified throughout the country (Figure 3.6).

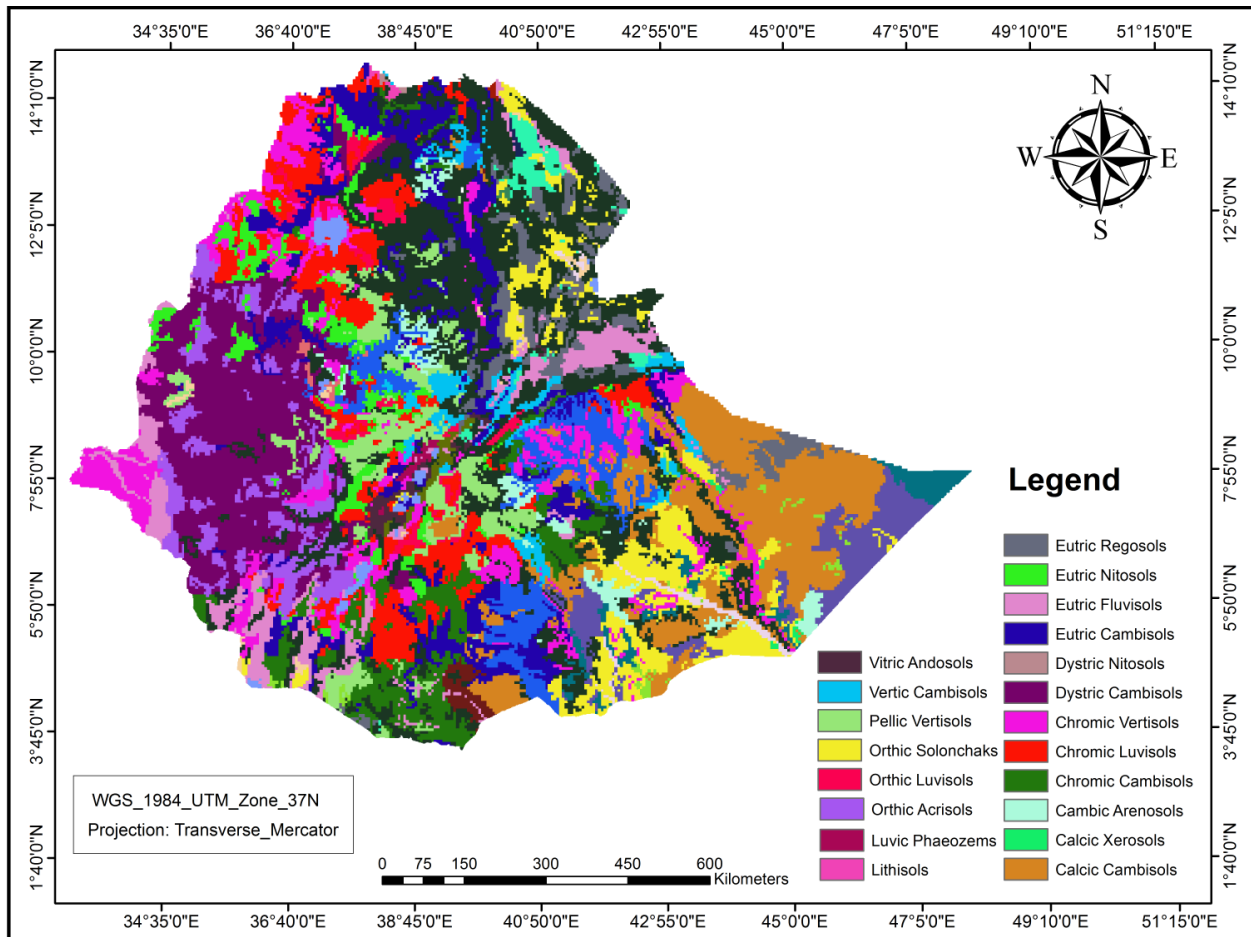


Figure 3.6: Soil types of Ethiopia.

3.5.4. Agroecological zone map

Agroecological Zoning (AEZ) refers to the division of an area of land into smaller units, which have similar characteristics related to land suitability, potential production and environmental impact (FAO, 1996). At a regional scale, AEZs are influenced by latitude, elevation, and temperature, as well as seasonality, and rainfall amounts and distribution during the growing season. The resulting AEZ classifications for Africa have the following three dimensions: major climate zone, moisture zones and highland/lowland (Choice, 2010). Agroecological zone of Ethiopia was classified based on Choice, (2009) classification system. Accordingly, there are eight agroecological zones of Ethiopia (Figure 3.7).

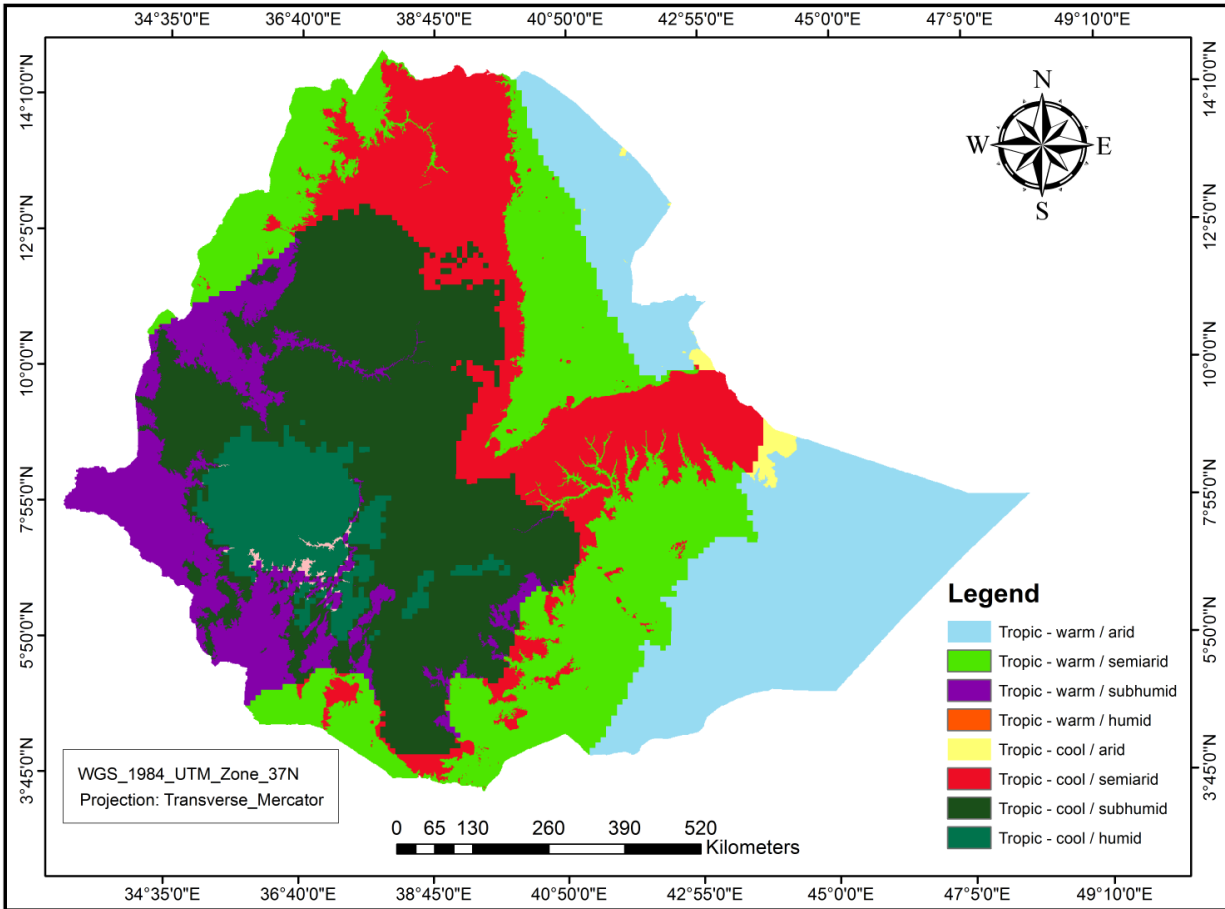


Figure 3.7: Agroecological zones of Ethiopia.

3.5.5. Potential vegetation

Ethiopia is one of the tropical countries with diverse flora and fauna. Potential vegetation is dependent on many variables such as, topography, climate, soil, and geology of the rock (Friis *et al.*, 2010). According to Friis *et al.*, (2010), Potential vegetation of Ethiopia is classified in to 14 classes (Figure 3.8).

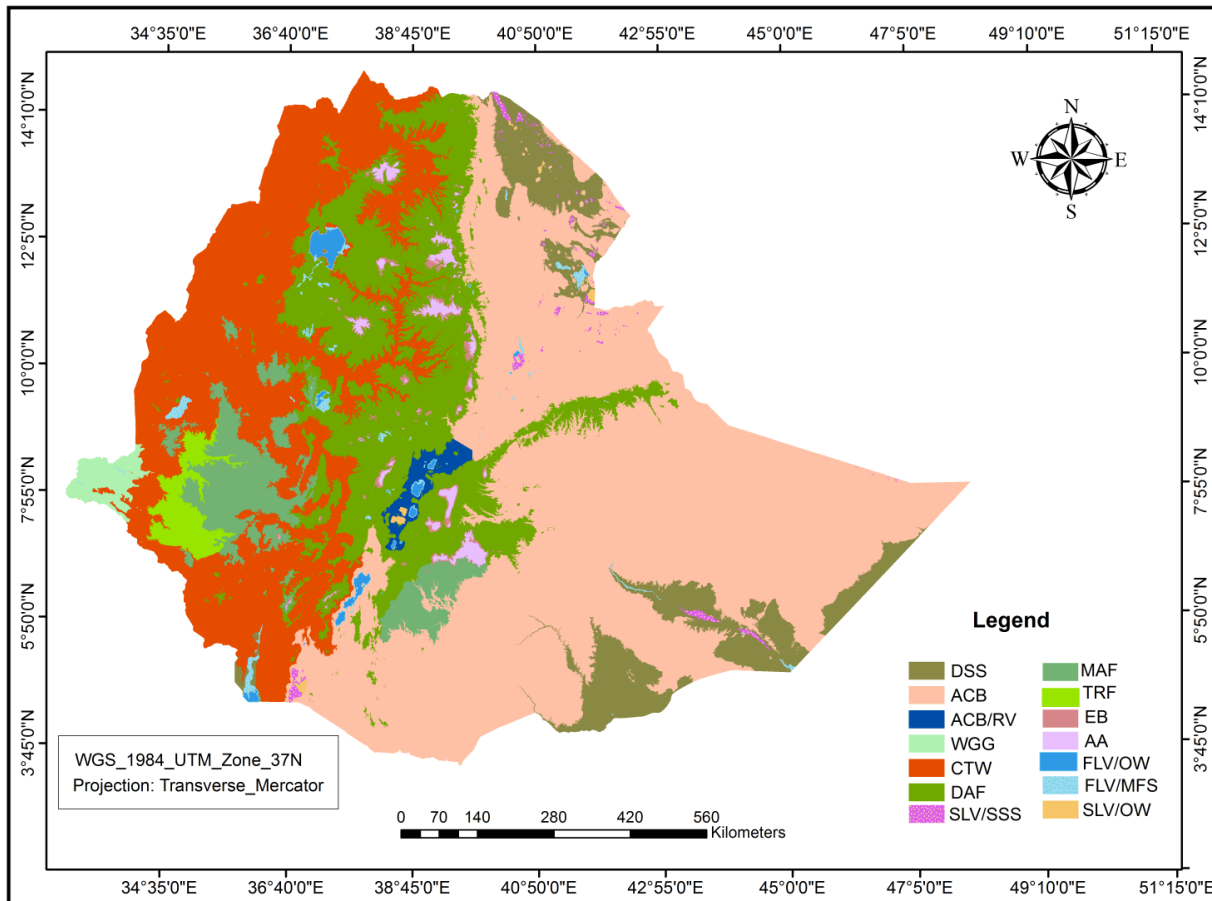


Figure 3.8: Potential vegetation types of Ethiopia.

Table 3.2: Legend Description of Figure 3.8.

Label	Description
SLV/OW	Salt lake open water vegetation
SLV/SSS	Salt pans, saline/brackish and intermittent wetland and salt lake shore vegetation
DSS	Desert and semi-desert scrub land
ACB	Acacia-commiphora wood land and bush land proper
ACB/RV	Acacia wooded grass land of Rift land
WGG	Wooded grass land of the western Gambela region
CTW	Combretum-Terminalia wood land and wooded grass land
DAF	Dry vegetation Afro-mountain forest and grass land complex
MAF	Moisture ever green Afro-mountain Forest
TRF	Transitional rain forest
EB	Ericaceous Belt
AA	Afro-alpine vegetation
FLV/OW	Fresh water lakes- open water vegetation
FLV/MFS	Fresh water marshes and swamps, floodplains and lake shore vegetation

3.5.6. Land-use/land-cover map

Land-use/land-cover map of Ethiopia was obtained from the Ethiopian Mapping Agency. Land cover maps were developed for green house gases inventories to provide baseline data for land-use/land-cover change and forestry (LULUCF) sector. The land-cover maps were developed from LandSat Imagery (30 m by 30 m) resolution using supervised classification. Accordingly, 15 classes of land-use/ land-cover were identified (Figure 3.9).

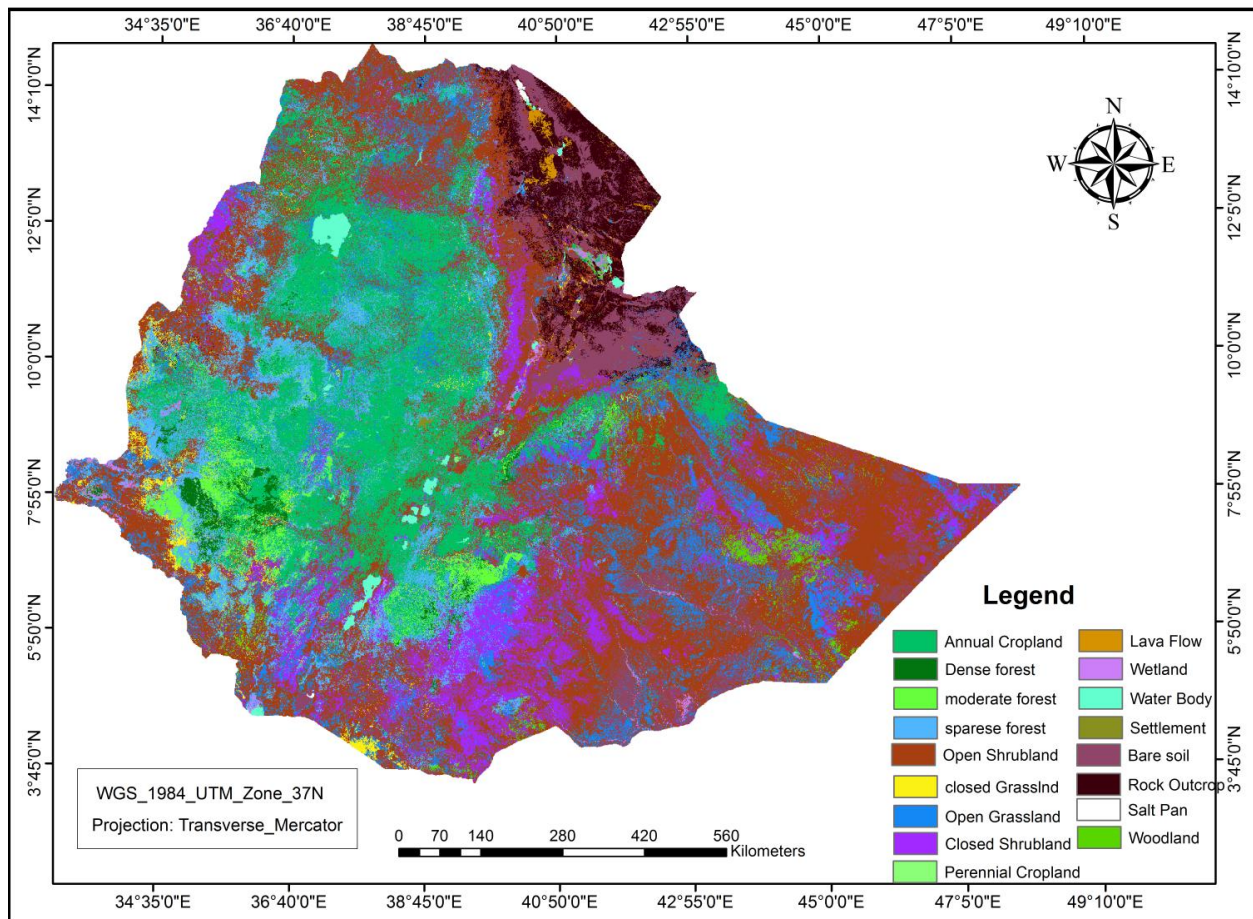


Figure 3.9: Land-use/land-cover map of Ethiopia.

3.6. MaxEnt model

3.6.1. General

The species occurrence records and environmental variables are the two important datasets required for MaxEnt modeling. The geographic points (i.e. coordinates) of *Ensete ventricosum* observation were collected as species occurrence records. The environmental variables that

contain continuous or categorical values were also collected. Climatic variables and topographical data (DEM, slope, and aspect) are categorized as continuous data whereas soil, Agroecology, vegetation, land use land cover and soil type are categorized values. This classification was adapted for the study and given to model based on the required formats. For instance, species occurrence data were put in to the model as a comma separated values (Csv) and environmental variables as a raster Arc/Info ASCII Grid format (Pearson, 2007).

3.6.2. MaxEnt Model Input

A) Species occurrence data

MaxEnt requires that the presence data is in a comma delimited value text file that contains three fields, at a minimum, that identify the species, the X-coordinates and Y-coordinates. The X and Y-coordinate values for each datum point were added to the attribute table of the original presence point dataset. The values for each environmental variable were also added to the attribute table for each sample point. The addition of the environmental variable values ensured that MaxEnt would run more efficiently because it would not have to go through each environmental raster to determine the values for each sample presence point (Phillips *et al.*, 2006). Once the pertinent data were added to the attribute table, it was converted to a comma delimited text file (csv).

B) Environmental variable data

MaxEnt requires that each of the environmental variables is stored in ASCII grid format with all raster sharing the same exact cell size and the same exact geographic extent. It is possible to set up MaxEnt once the presence-only data and the environmental variable raster are in the proper format (Appendix 1).

3.6.3. Input Data preprocessing

Prior to MaxEnt modeling, all environmental data layers were pre-processed to conform a uniform spatial extent, resolution and geographical projection, and converted into grid format and projected to the WGS_1984_UTM_Zone_37N. The data layers were extracted by mask using the Ethiopia boundary. The data layers were then resampled to a 1km cell size using resample tool under raster processing to ensure that cell alignment agreed perfectly between data layers. Minor processes such as creating slope or aspect surfaces are not described.

To proceed with MaxEnt modeling, data that were used as input into the application were pre-processed to meet strict requirements. Presence only (species) data were matched with X-Y coordinate data that coincides with the environmental raster data, and these data were then exported into a comma separated value (csv) format. These tasks were accomplished using the Excel spreadsheet program. In addition, in the environment of ArcGIS, all raster environmental layers were covered exactly as the same extent with bioclimatic variables. After this step (co-registration), the raster data were exported into an ASCII grid format. The overall pre-processing steps followed in this study are indicated in Figure 3.10.

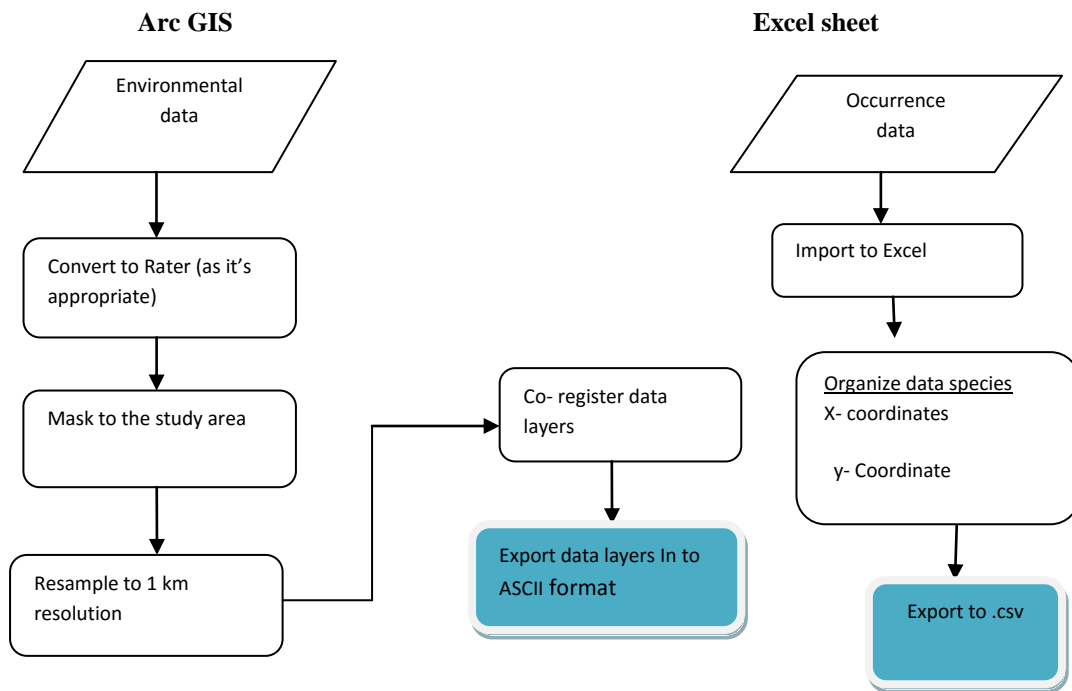


Figure 3.10: Pre-processing using ArcGIS and excel sheet.

3.6.4. Mapping the spatial distribution of *Ensete ventricosum* species using MaxEnt model

In order to predict the probabilistic distribution of *Ensete ventricosum* at a coarse resolution (1 km), MaxEnt model was used in this study. A total of 26 environmental variables were used for modeling purpose including 19 bioclimatic variables, DEM, LULC, vegetation, and Agrologic and soil type. These variables were chosen based on their biological relevance to plant species distributions and other habitat modeling studies. Attempts were also made to match the projections, grid cell size, and spatial extent of all environmental variables with bioclimatic

variables using ArcGIS 10.3. This was crucial to ensure consistency across all the layers that cause errors in the model result. All maps were projected to WGS_1984_UTM_Zone_37N (WGS84 datum) with a grid cell size of 1km. Categorical data (LULC, vegetation, agroecology and soil type) were resampled to 1km spatial resolution using the nearest neighbor resampling techniques. The overall workflow of MaxEnt model is indicated in Figure 3.11.

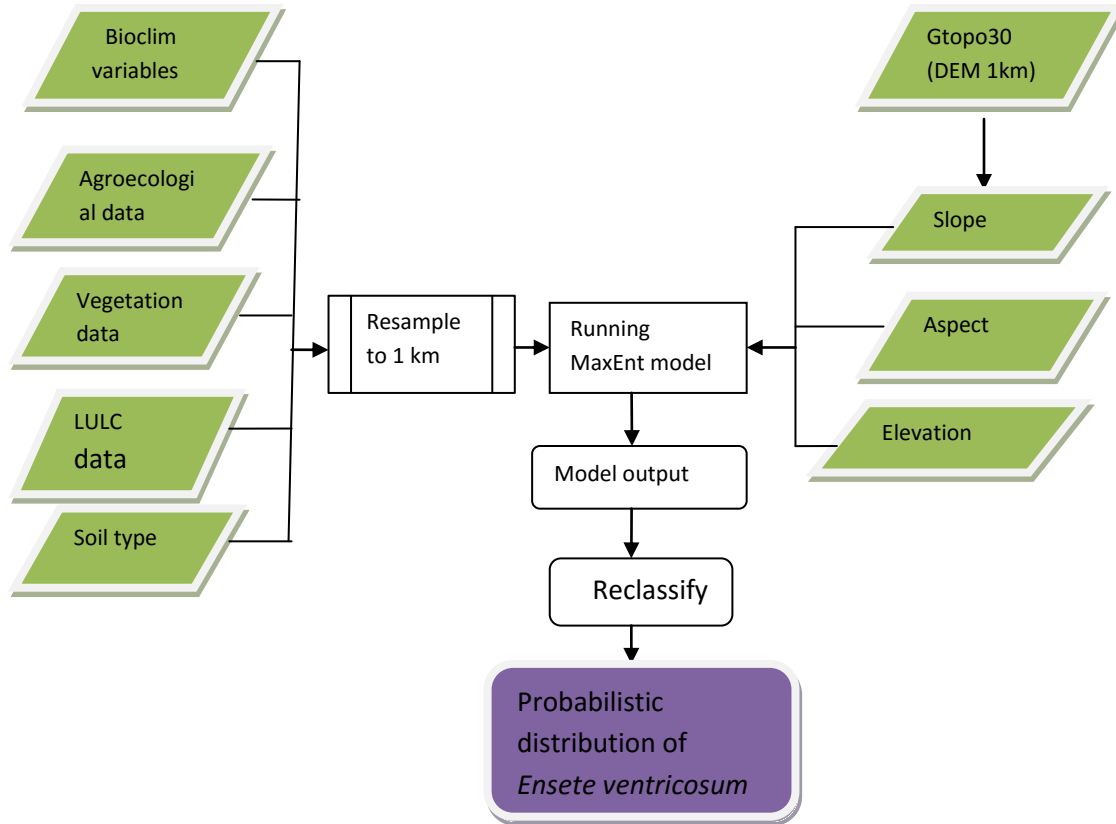


Figure 3.11: The general work flow for MaxEnt model.

Geospatial tools and MaxEnt modeling was successful and efficient to map the distribution of species. This permitted a large enough area to be mapped based on the collected locations in order to give a representative distribution of the species modeled in the study (Reddy *et al.*, 2015). The final cultivated ensete probability distribution was a product of 10 bootstrap replicate runs. Each run used 125 presence records used for training, 14 for testing. (n = 192) and 10,112 background points and presence points. In the case of wild ensete, four presence records used for training, two for testing and 10,006 points was used to determine the MaxEnt distribution (background points and presence points) of wild ensete.

3.6.5. Determining spatial auto correlated environmental variables

To reduce the potential of model over parameterization, correlation analysis (Pearson) of the 26 environmental variables were performed. Pearson correlation coefficients were calculated for every pair-wise combination of topographic and land-cover environmental variables as well as bioclimatic variables. Besides, the ground control point (192 for cultivated and 16 for wild ensete), data were checked whether the distance between the presence records were at least 5km apart so as to avoid pseudo replication.

Correlation analyses were performed using Microsoft excel data analysis tool. Before the correlation analysis, random points were generated for all variables by data management tool in ArcGIS 10.3. Correlation Matrix is the one that involves the relationship between one dependent and many independent variables. Correlation measures the strength of the linear relationship between variables. A correlation of zero shows that there is no linear association between the two variables. A correlation of 1 (-1) shows that there is an exact positive (negative) linear association between the two variables (Mikias, 2014).

3.6.6. Selection of variable importance

MaxEnt uses two different methods to estimate variable importance. The first method implemented by MaxEnt creates a table using data gathered during the training of the model that summarizes the environmental variable contribution to the model and the permutation importance (Kailihiwa, 2015). Another method that MaxEnt used to determine variable importance is the jack-knife test. The jack-knife test trains the model removing each environmental variable to calculate which variable causes the largest decrease in the model's gain.

3.6.7. Model performance evaluation and analysis

Model Performance can be measured by looking at the Area under Curve (AUC) in the MaxEnt results. The AUC created for MaxEnt models shows how well the model is able to distinguish presence from random. The value for the AUC ranges from 0 to 1, the closer the value of the AUC to 1 is the better the fit of the model (Phillips *et al.*, 2005). A result 0.5 is believed to be the result of a random sampling, while a score of one is considered perfect. Value of AUC indicating the following degrees of predictive accuracy: >0.90 = very good; AUC: 0.70-0.90 = good, AUC:

<0.70 = uninformative (Swets, 1988). To analyze the graphic results, the averaged ASCII file must convert to raster in ArcGIS using Conversion tools. This has to be processed as a “Float” (Dowling, 2015).

3.7. Characterization of *Ensete ventricosum*

Based on the location and from the MaxEnt output results, both wild and cultivated ensete were characterized according to the factors that determine the growth and distribution of *Ensete ventricosum*. Those factors were altitude, climate, soil type, agroecological zones, natural vegetation and land-use/land-cover. Characterization of ensete drought tolerance species is a vital issue in clarifying the role of ensete in Ethiopian food security (Brandt *et al.*, 1997).

3.8. Hotspot areas selection

Hotspot areas are locations where ensete is highly distributed across the study area. Hotspot area selection was undertaken according to the probabilistic distribution of both wild and cultivated *Ensete ventricosum*. The higher and the medium probabilistic distributions were selected and classified based on the output of MaxEnt modeling. The hotspot areas classified as primarily hotspot area, secondary hotspot area, and none by spatial analysis tool in ArcGIS environment (Table 3.3).

Table 3.3: Hotspot area classification for both wild and cultivated *Ensete ventricosum*.

Value	Classification
0.5-0.93	Primarily hotspot area
0.15-0.5	Secondary hotspot area
0-0.15	None

4. Results and Discussion

4.1. Characterizing of ensete

Results related to the spatial characterization of *Ensete ventricosum* based on agroecological zones, natural vegetation, soil type and land-use/land-cover are given in (Table 4.1). As per the total sample data collected during the fieldwork, results revealed that the tropic-cool/humid (132) and Dystric cambisol (48) are the most suitable agroecological zone and soil type for cultivated Ensete respectively. Besides, these plant species are currently categorized under dry vegetation Afro-mountain forest (148) and annual crop land (75). Unlike cultivated ensete, wild ensete is dominantly grown in tropics – cool sub-humid agroecological zones with soil types of Chromic Luvisols (2), dystric cambisols (15) and Orthic Acrisols (3). Wild ensete is characterized under different natural vegetation types such as, Combretum _Terminalia wood land and wooded grass land (14), Dry vegetation Afro-mountain forest and grass land complex (1), moisture evergreen Afro-mountain forest (4), transitional rain forest (3) and land-use/land-cover such as, dense forest (5), moderate forest (3) and spares forest (8). Besides, both cultivated and wild ensete is dominantly grown in southern part of Ethiopia and their distribution varies spatially.

Under the climatic condition such a temperature and precipitation, both wild and cultivated ensete were well grown in areas where the annual Precipitation ranges between 1100–2200 mm and mean annual temperature 10–21⁰C. In terms of topography, about 1036–3129 m altitude range is suitable for wild ensete and altitude range of 1344–3129 m for cultivated ensete. The characterization of these species in terms of climate, soil, topography, vegetation type, agroecology and land use land cover and the probabilistic distribution map of both wild and cultivated ensete with regard to their characterization are shown in Figure 4.7 and 4.8).

Table 4.1: Spatial characterizations of *Ensete ventricosum* based on agro ecology zones, natural vegetation, soil type and land-use / land-over.

Types of <i>Ensete Ventricosum</i>	Agro ecology zones	Natural vegetation	Soil types	Land-use/ land-cover
Cultivated ensete (192)*	<ul style="list-style-type: none"> • Tropic – cool / sub humid(59) • Tropic – cool / humid(132) 	<ul style="list-style-type: none"> • Dry vegetation Afro-mountain forest and grass land complex (148) • Moisture ever green Afro-mountain Forest (44) 	<ul style="list-style-type: none"> • Chromic Luvisols(35) • Chromic Vertisols(16) • Chromic Cambisols(9) • Eutric Netosols(12) • Dystric cambisols(48) • Orthic Luvisols(10) • Pellic Vertrisols(29) • Orthic Acrisols(33) 	<ul style="list-style-type: none"> • Dense forest(19) • Moderate forest(32) • Spares forest(68) • Annual crop land(75)
Wild ensete (20)*	<ul style="list-style-type: none"> • Tropic – warm / subhumid (3) • Tropic – cool / subhumid(14) • Tropic – cool / humid(3) 	<ul style="list-style-type: none"> • Combretum-Terminalia wood land and wooded grass land(14) • Dry vegetation Afro-mountain forest and grass land complex (1) • Moisture ever green Afro-mountain Forest (4) • Transitional rain forest (3) 	<ul style="list-style-type: none"> • Chromic Luvisols(2) • Dystric cambisols(15) • Orthic Acrisols(3) 	<ul style="list-style-type: none"> • Dense forest(5) • Moderate forest(3) • Spares forest(8)

* The total number of samples (ground control points) collected during the field work

4.1.1 Climate

The distribution of *Ensete ventricosum* is primarily constrained by climate conditions of the country. Bio10 (mean temperature of warmest quarter), bio 1(mean annual temperature) and bio 12(annual rain fall) are significant variables that determine cultivated ensete distribution where as bio7 (temperature annual range), bio1 (annual mean temperature) and bio12 (annual precipitation) are the most significant variables that affect the probabilistic distribution of wild ensete (Figure 4.1). Besides, the annual precipitation ranges between 1100–2200 mm and mean annual temperature between 10–21°C for both wild and cultivated ensete.

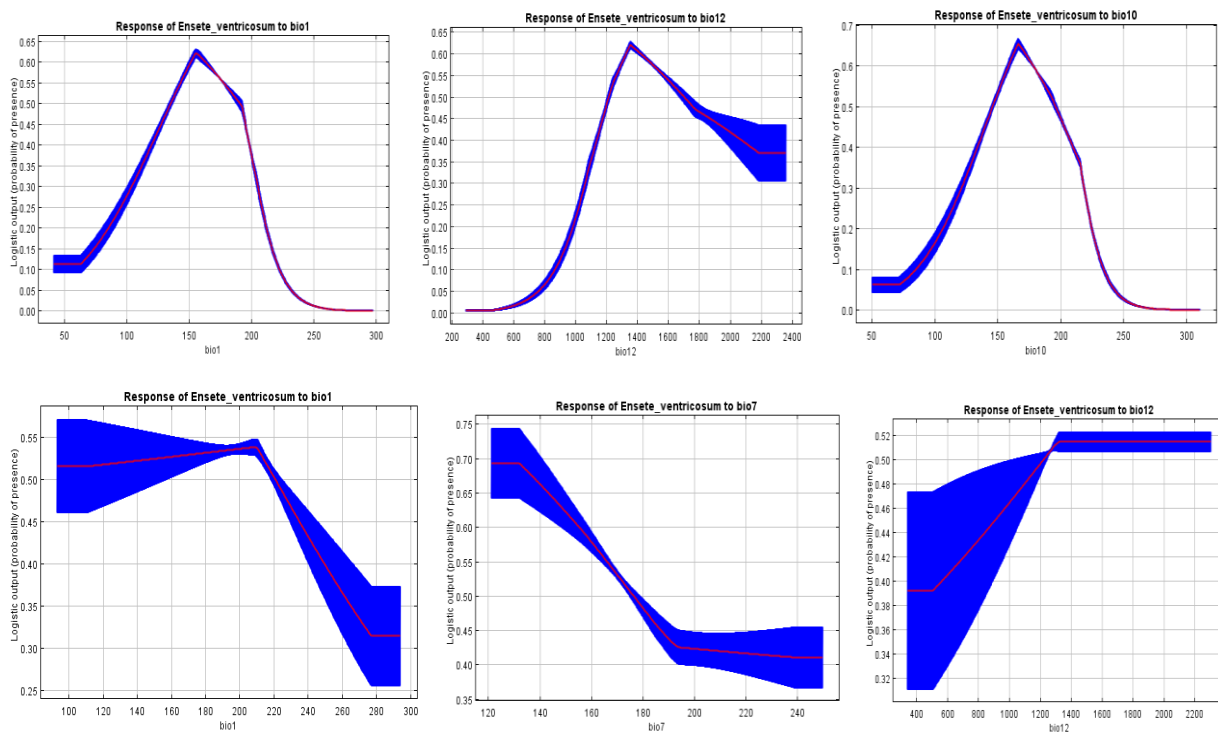


Figure 4.1: Response curve of for cultivated (top three) and wild ensete (bottom three) for climate variables.

4.1.2 Topography

Slope, aspect and elevation are the topographical variables that contribute to the model. Elevation is a significant factor that affects the probabilistic presence of cultivated and wild *Ensete ventricosum* (Figure 4.2). The response curve for elevation clearly reflects that both cultivated and wild ensete was highly distributed at an altitude of 1800 m. However, in general,

cultivated ensete is highly distributed at elevation range of 1344–3129 m and their probabilistic distribution is higher at the lowest slope whereas wild ensete well grow at altitude ranges from 1036 –3129m with higher slope as compared to the cultivated one.

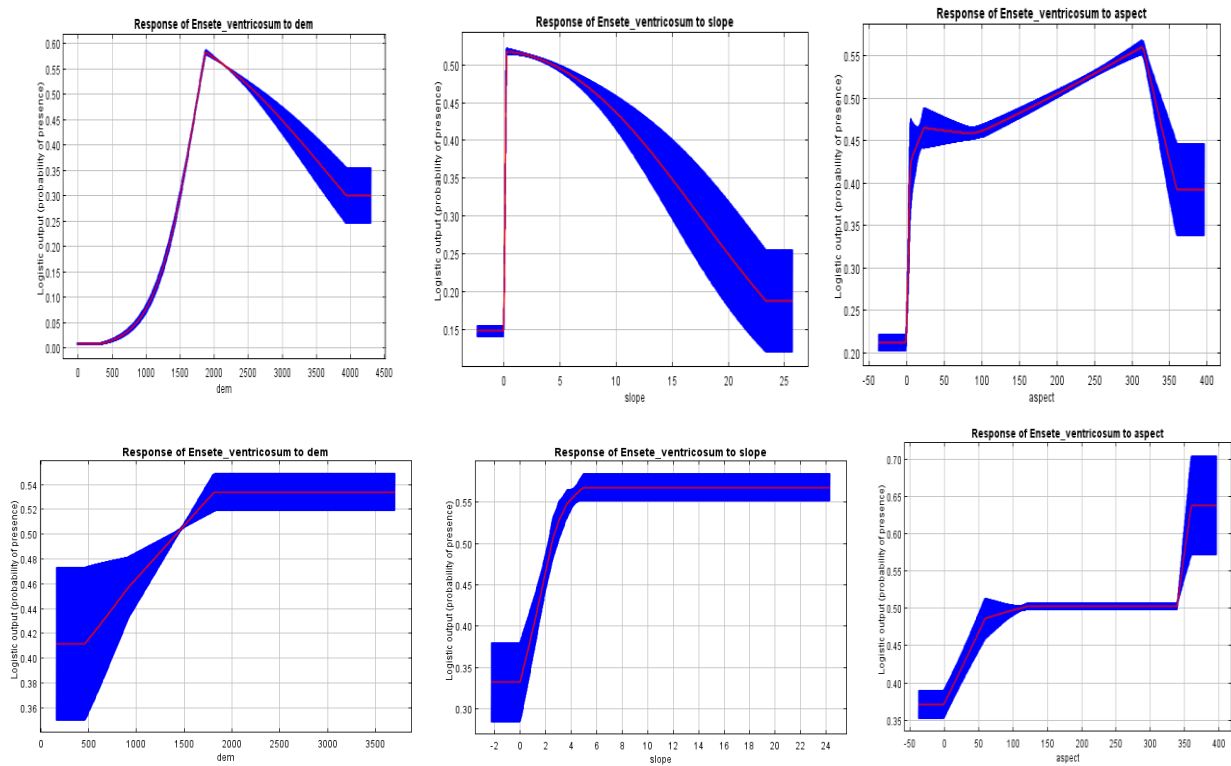
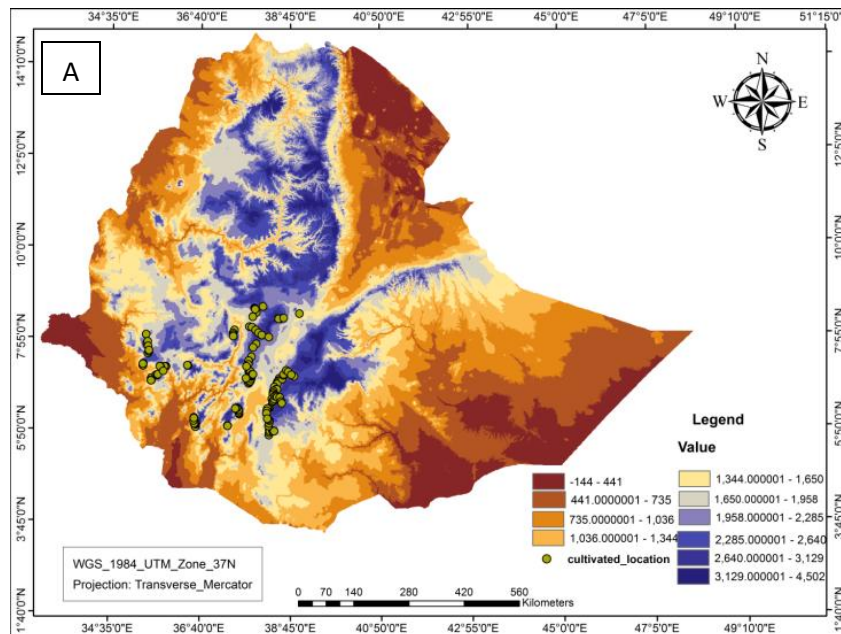


Figure 4.2: DEM, Slope and Aspect response curve for cultivated (top) and wild Ensete (bottom).



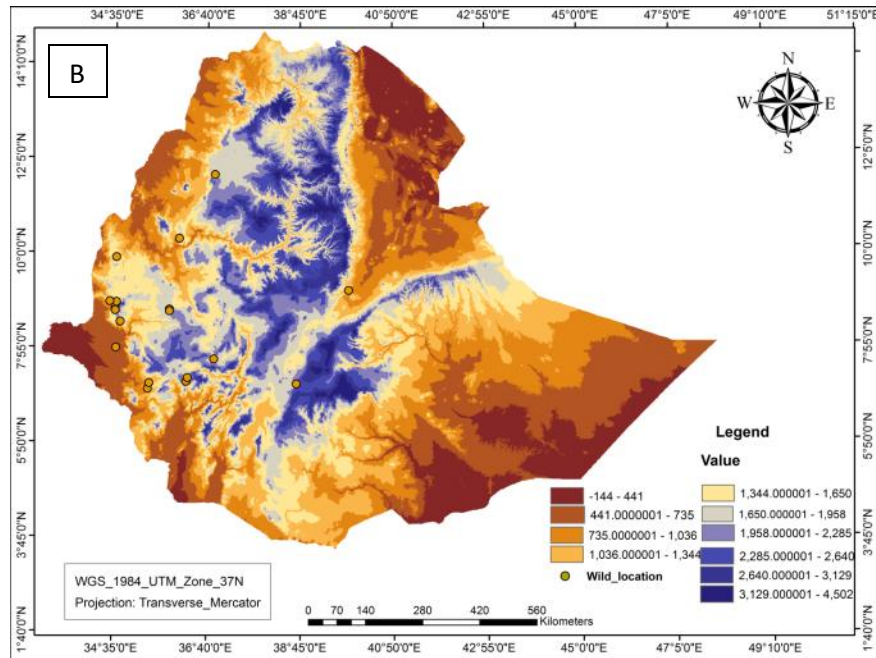


Figure 4.3: Characterized map of cultivated (A) and wild ensete (B) based on elevation.

4.1.3 Agroecological zones

The response curve of both wild and cultivated *Ensete ventricosum* clearly indicates that the probabilistic presence is higher at the tropic – cool / sub-humid agro-ecological zones. Tropic – cool / humid is also suitable for the probabilistic distribution for both wild and cultivated ensete next to subhumid agro-ecological zone (Figure: 4.4). As shown in the map below (Figure: 4.5), ensete is characterized under the agroecological zones found in the southern part of the country (tropical cool/ humid, sub-humid and warm/sub humid zones).

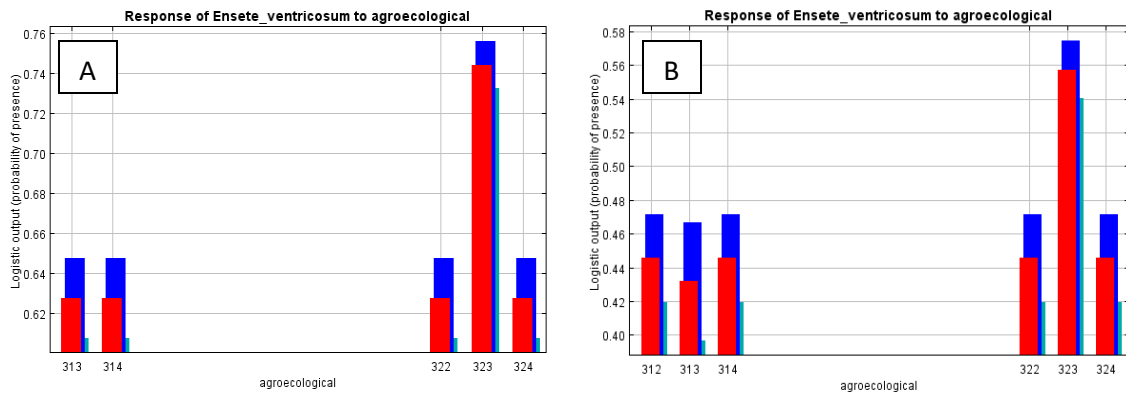


Figure 4.4: Agroecological zone response curve for cultivated (A) and wild (B) ensete.

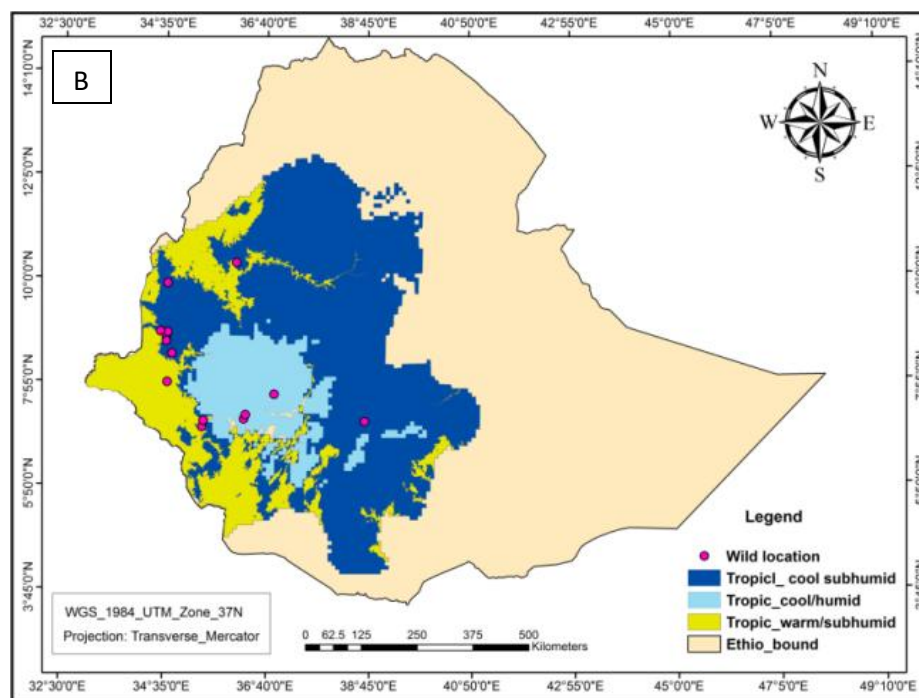
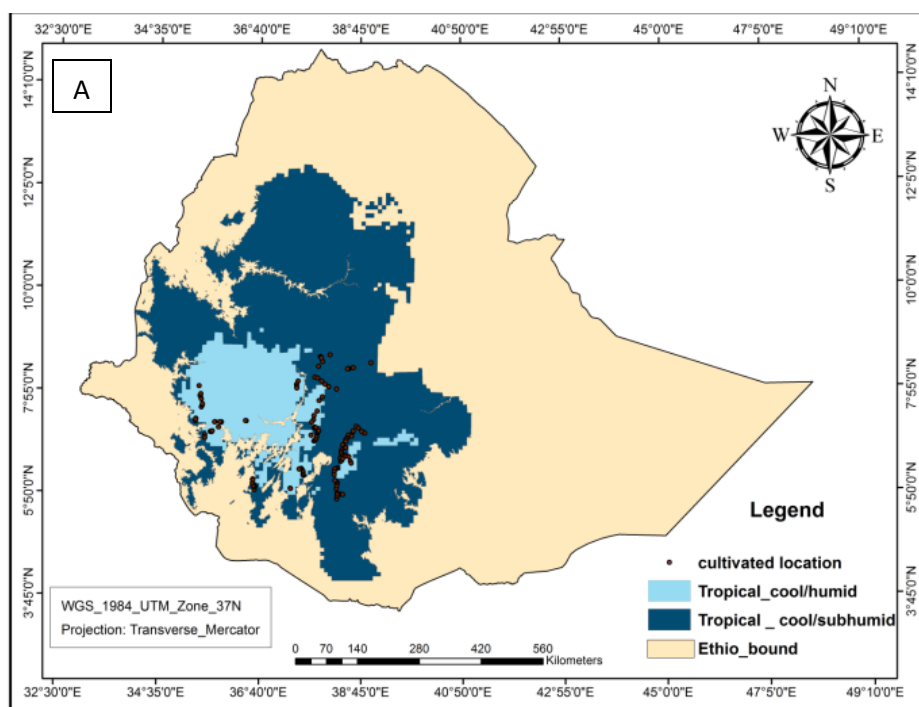


Figure 4.5: Characterized map of cultivated (A) and wild ensete (B) based on agroecological zone.

4.1.4 Vegetation type

Potential vegetation is one of the variables that contribute to MaxEnt model. According to the response curve (Figure 4.6), cultivated ensete were highly distributed in dry vegetation afro-mountain forest and moisture ever green Afro-mountain forest vegetation type where as Combretum_Terminalia wood land and Transitional rain forest was categorized under wild ensete distribution. Results revealed that, Across different natural vegetation types *Ensete ventricosum* is characterize under moisture evergreen Afro-mountain forest, dry vegetation afro-mountain forest, Combretum_Terminalia woodland, and transitional rain forest natural vegetation types (Figure 4.7)

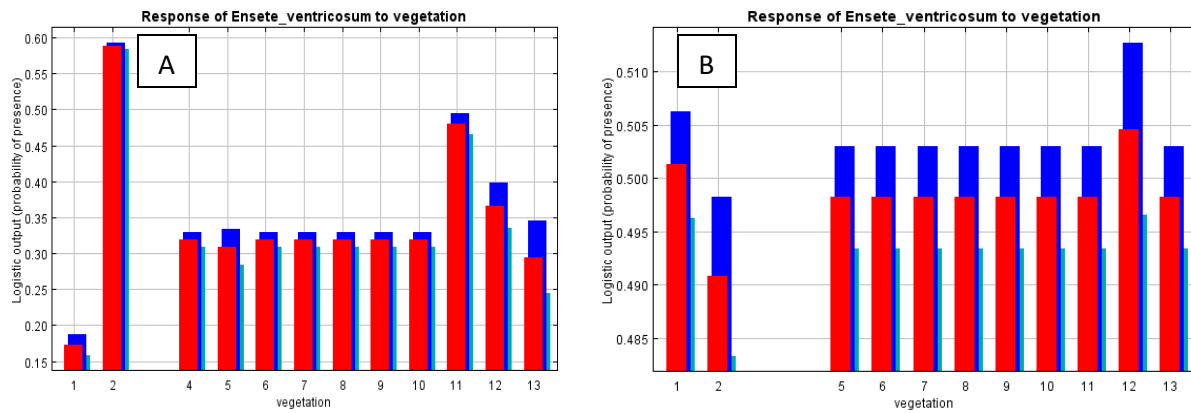
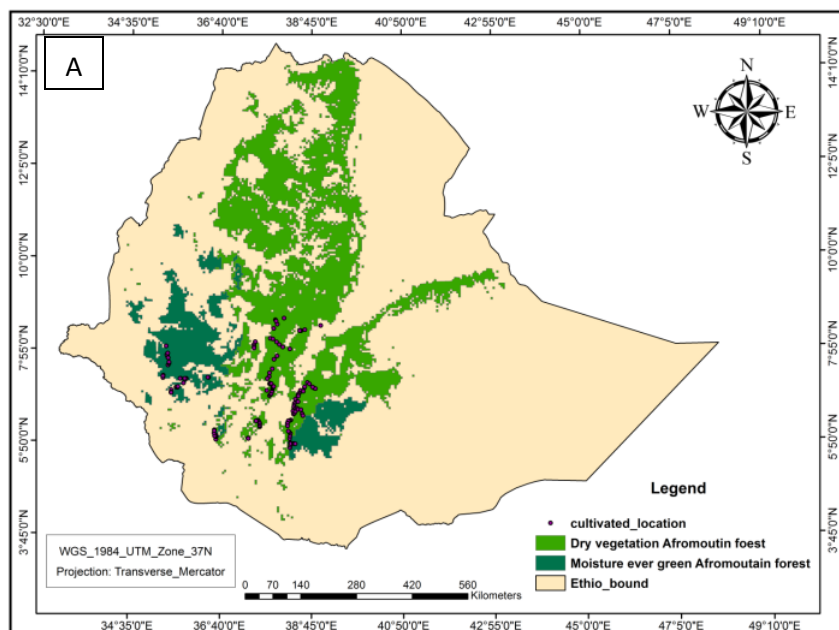


Figure 4.6: Potential Vegetation response curve for cultivated (A) and wild (B) Ensete.



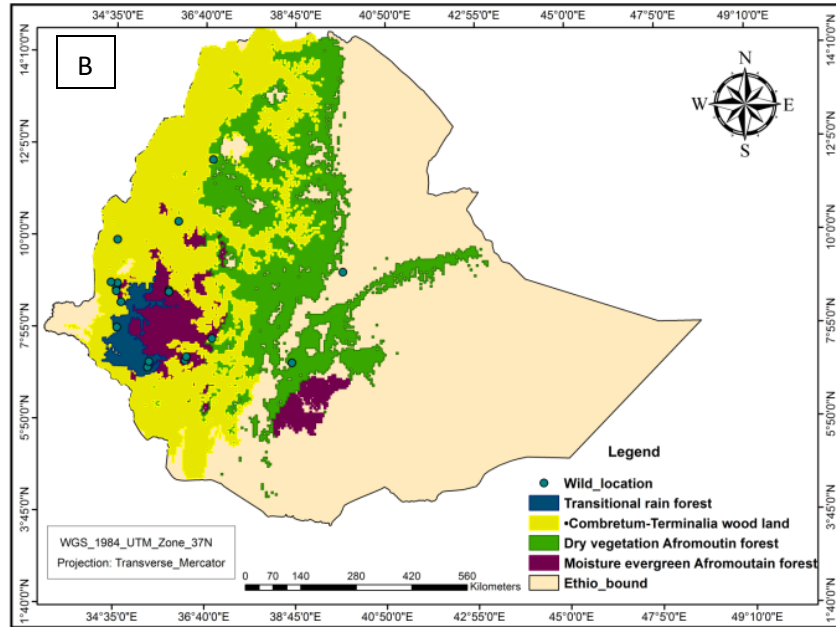


Figure 4.7: Characterized map of cultivated (A) and wild ensete (B) based on Natural vegetation types

4.1.5 Land-use/ land-cover

Annual crop land and spares forests are land-use/land-cover classes in which cultivated and wild ensete is highly distributed, respectively. As clearly indicated on the response curve (Figure 4.5), the probabilistic presence of ensete is also higher at dense forest and moderate forest. Based on the result, both cultivated and wild ensete is characterized under land-use/land-cover such as, dense forest, moderate forest, spares forest and annual crop land classes. As clearly shown in the maps, that LULC classes are not cover the eastern part of the country (Figure 4.9).

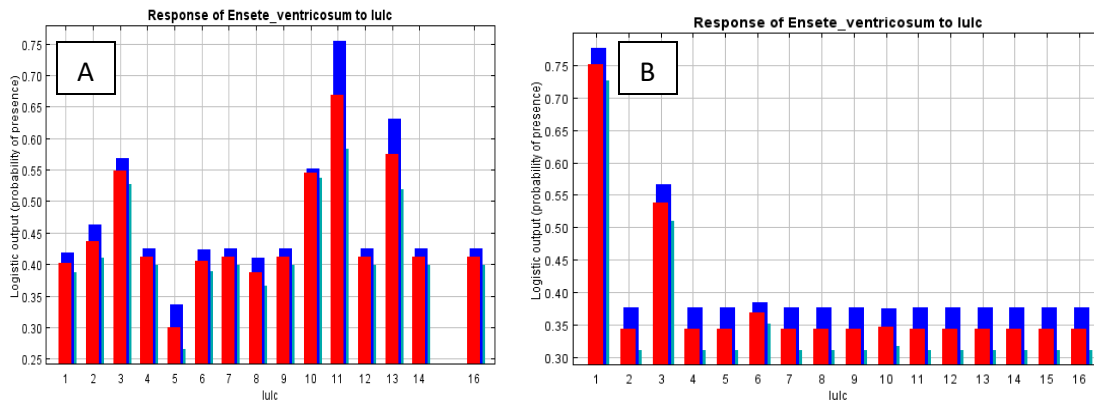


Figure 4.8: Land-use/land-cover response curve for cultivated (A) and wild (B) ensete.

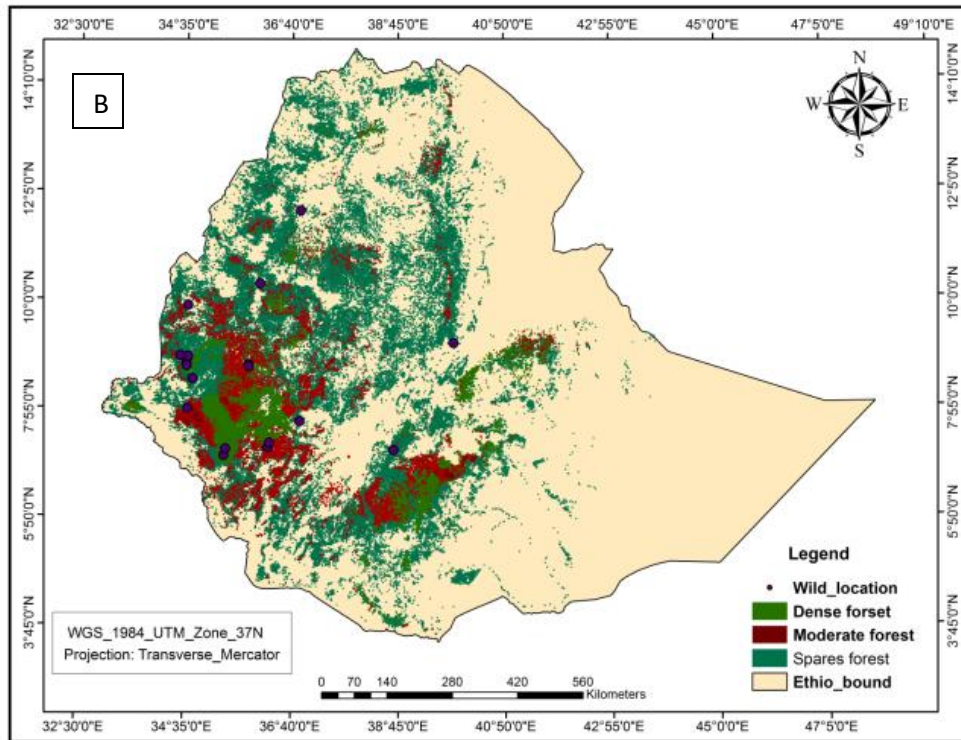
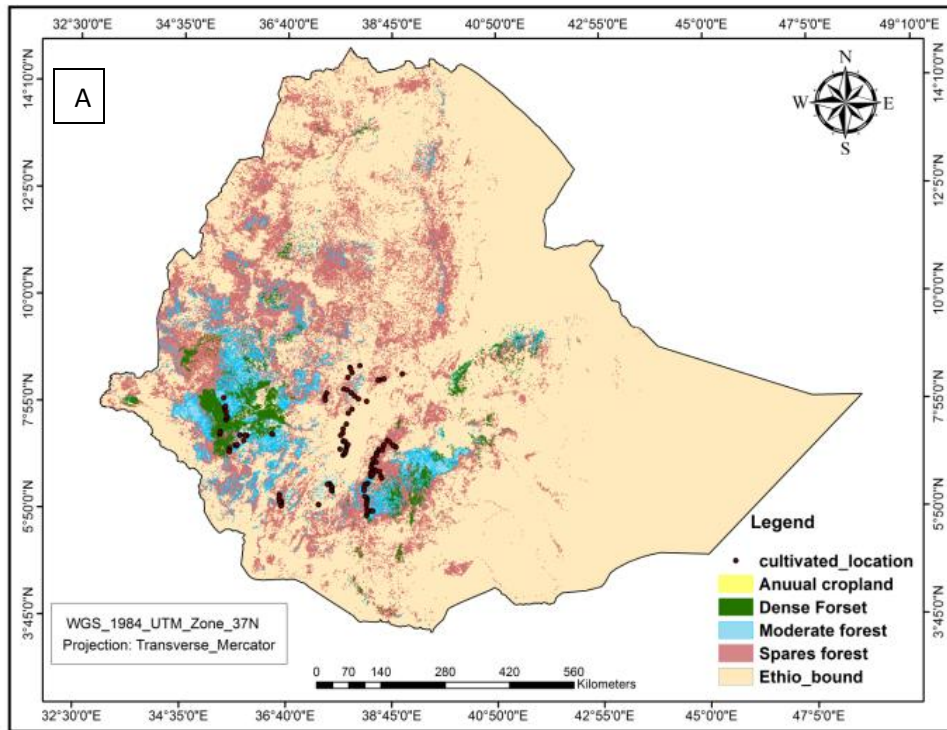


Figure 4.9: Characterized map of cultivated (A) and wild ensete (B) in LULC.

4.1.6 Soil type

Soil type is also having an impact for the probabilistic distribution of Ensete. In case of cultivated ensete, Chromic Luvisols, Chromic Vertisols, Chromic Cambisols, Eutric Netosols, Dystric Cambisols, Orthic Luvisols, Pellic Vertrisols and Orthic Acrisols are more suitable soils for the probability distribution of Ensete whereas Chromic Luvisols, Dystric cambisols and Orthic Acrisols are characterized under wild ensete also. Figure 4.11 shows the characterization map of cultivated and wild ensete under different soil types across the country.

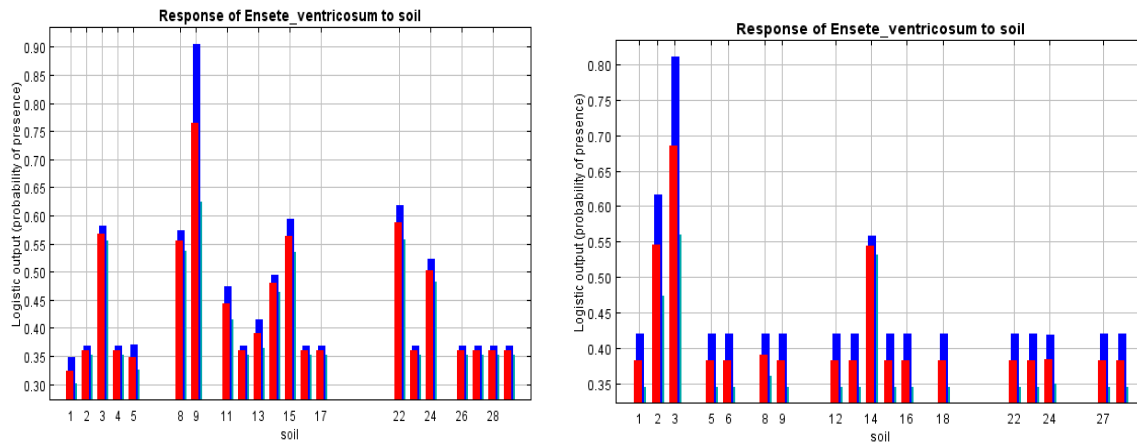
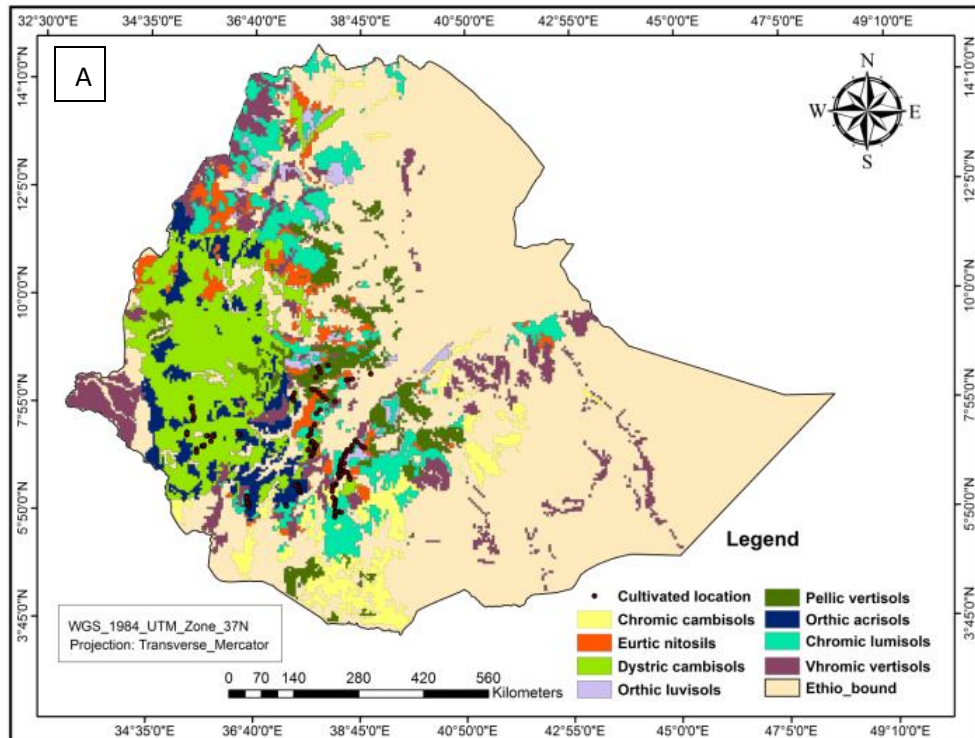


Figure 4.10: Soil type response curve for cultivated (right) and wild (left) Ensete.



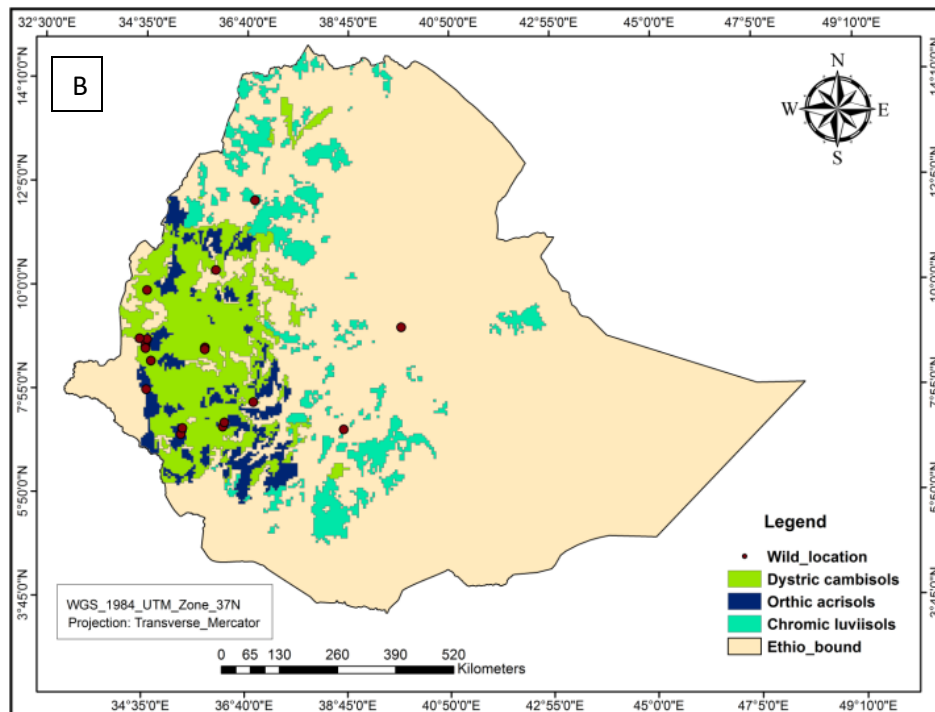


Figure 4.11: Characterized map of cultivated (A) and wild ensete (B) in soil type.

4.2. Selection of Environmental Variables

The result of pair-wise correlation of environmental variables is given in (Table 4.2). Results revealed that that some of the environmental variables are autocorrelated. For instance, bio5 and bio1, bio5 and bio6, bio14 and bio17, bio16 and bio19 had positively correlated whereas, DEM and bio1, slope and bio10, bio14 and LULC seems to have negative correlation. The description of environmental variables such as bio 1, bio12, DEM, is indicated in the Appendix 1.

Most of the environmental variables that determine the spatial distribution of ensete are not correlated. There is no dependency between these uncorrelated environmental variables. However, out of 26 environment variables, six variables namely bio2, bio3, bio4, bio15, bio17 and bio18 are highly correlated ($R > 0.8$) and thus discarded from analysis. Only 20 uncorrelated environmental variables were selected for the model.

Table 4.2: Matrices of Pearson’s correlation coefficients calculated for environmental variables.

	DEM	Slope	Aspect	bio1	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19	agroeco	LULC	soil	vegetati
DEM	1																									
Slope	0.444	1																								
Aspect	0.07	0.033	1																							
bio1	-0.729	-0.3	0.046	1																						
bio2	0.268	0.153	0.119	0.275	1																					
bio3	0.345	0.127	0.139	0.156	0.67	1																				
bio4	-0.174	0.025	0.044	0.375	0.06	-0.36	1																			
bio5	-0.611	-0.23	0.074	0.971	0.43	0.208	0.47	1																		
bio6	-0.818	-0.35	0.024	0.942	0.01	0.075	0.25	0.869	1																	
bio7	0.072	0.086	0.111	0.452	0.84	0.297	0.54	0.625	0.157	1																
bio8	-0.74	-0.31	0.024	0.977	0.21	0.097	0.4	0.933	0.916	0.417	1															
bio9	-0.728	-0.29	0.051	0.98	0.22	0.165	0.32	0.943	0.955	0.376	0.9381	1														
bio10	-0.705	-0.28	0.053	0.991	0.28	0.102	0.49	0.982	0.922	0.504	0.968	0.968	1													
bio11	-0.732	-0.32	0.044	0.987	0.29	0.223	0.23	0.947	0.947	0.397	0.9545	0.977	0.961	1												
bio12	0.643	0.266	0.133	-0.473	0.23	0.335	-0.2	-0.356	-0.48	0.05	-0.578	-0.4	-0.453	-0.45	1											
bio13	0.633	0.309	0.119	-0.425	0.4	0.291	-0.1	-0.264	-0.49	0.25	-0.533	-0.38	-0.39	-0.4	0.87	1										
bio14	0.492	0.258	0.073	-0.41	-0.04	0.284	-0.2	-0.384	-0.35	-0.21	-0.414	-0.35	-0.412	-0.4	0.58	0.259	1									
bio15	-0.154	-0.04	0.008	0.379	0.52	0.258	0.01	0.44	0.257	0.471	0.3507	0.321	0.366	0.41	-0.2411	0.151	-0.581	1								
bio16	0.614	0.278	0.125	-0.423	0.34	0.268	-0.1	-0.275	-0.48	0.202	-0.543	-0.37	-0.39	-0.4	0.9262	0.981	0.3173	0.039	1							
bio17	0.511	0.259	0.073	-0.422	-0.06	0.295	-0.2	-0.406	-0.37	-0.22	-0.418	-0.37	-0.426	-0.42	0.5695	0.215	0.9652	-0.672	0.28	1						
bio18	0.556	0.216	0.024	-0.414	0.22	0.366	-0.3	-0.39	-0.5	0.011	-0.381	-0.42	-0.446	-0.39	0.455	0.279	0.5157	-0.282	0.29	0.58	1					
bio19	0.289	0.113	0.12	-0.181	0.16	0.132	-0	-0.083	-0.16	0.094	-0.323	-0.09	-0.152	-0.16	0.7812	0.73	0.2489	-0.045	0.8	0.2	0.061	1				
Agroeco	0.303	0.14	0.168	0.325	0.69	0.767	0.17	0.434	0.158	0.617	0.2867	0.304	0.333	0.32	0.2793	0.285	0.1667	0.245	0.26	0.19	0.256	0.14	1			
LULC	-0.167	-0.06	-0.003	0.342	0.09	-0.06	0.46	0.358	0.255	0.313	0.3696	0.316	0.38	0.28	-0.2419	-0.19	-0.169	0.075	-0.2	-0.1	-0.18	-0.17	0.2163	1		
soil	-0.049	-0.14	0.019	0.082	0.04	0.206	-0.2	0.041	0.084	-0.05	0.0678	0.09	0.048	0.11	0.0491	-0.03	-0.019	0.111	-0	-0	0.059	0.06	0.0956	-0	1	
vegetati	-0.068	-0.17	-0.031	0.098	-0.01	0.161	-0.1	0.06	0.104	-0.04	0.1435	0.081	0.071	0.1	-0.0489	-0.18	0.1391	-0.086	-0.2	0.14	0.182	-0.16	0.1253	-0	0.11	1

4.3. Model Performance evaluation

Based on the model performance indicators, the model performs well. The average test AUC for the replicate runs was 0.842, and the standard deviation was 0.046 for the cultivated *Ensete ventricosum*. On the other hand, wild ensete have AUC 0.760 with standard deviation of 0.101. This value indicated that the constructed model had a better predictive value for cultivated ensete than the wild ensete. Higher AUC indicates better discrimination of suitable versus unsuitable areas for the species. AUC results show that the model is highly suitable for predicting the distribution of wild and Cultivated *Ensete ventricosum* (Figure 4.12).

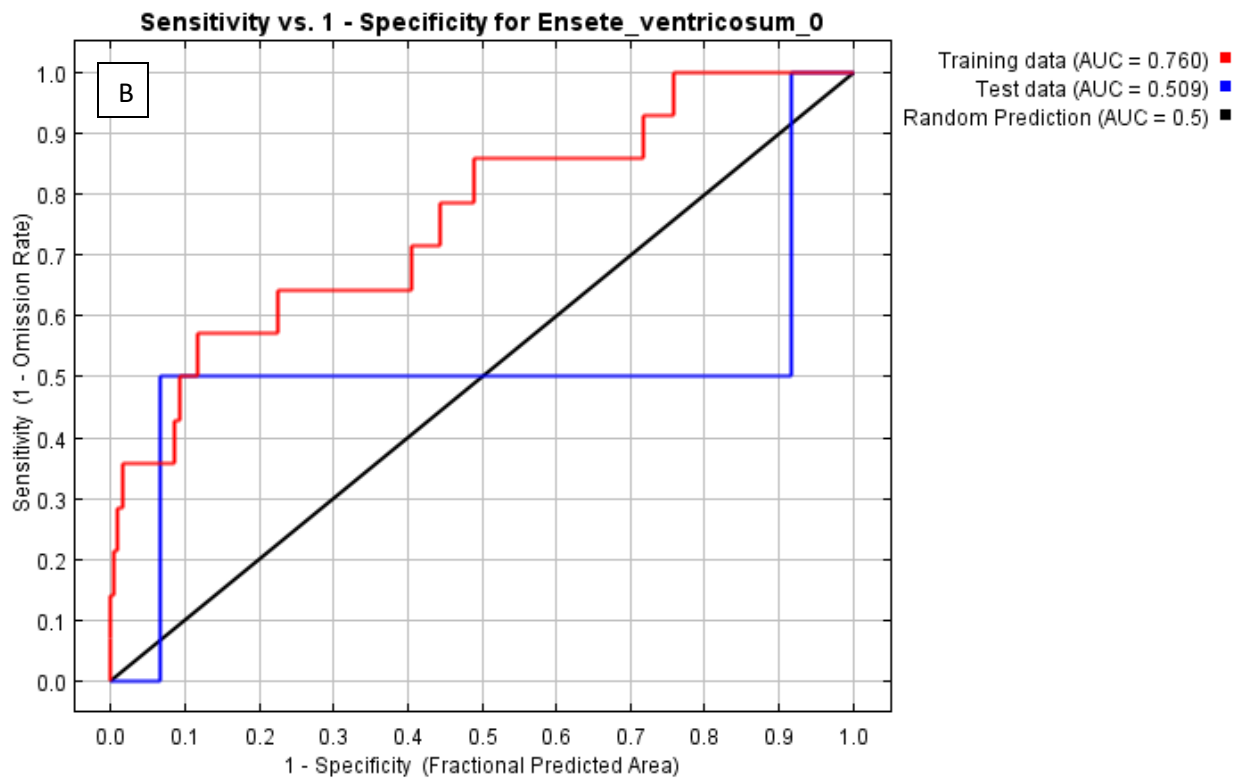
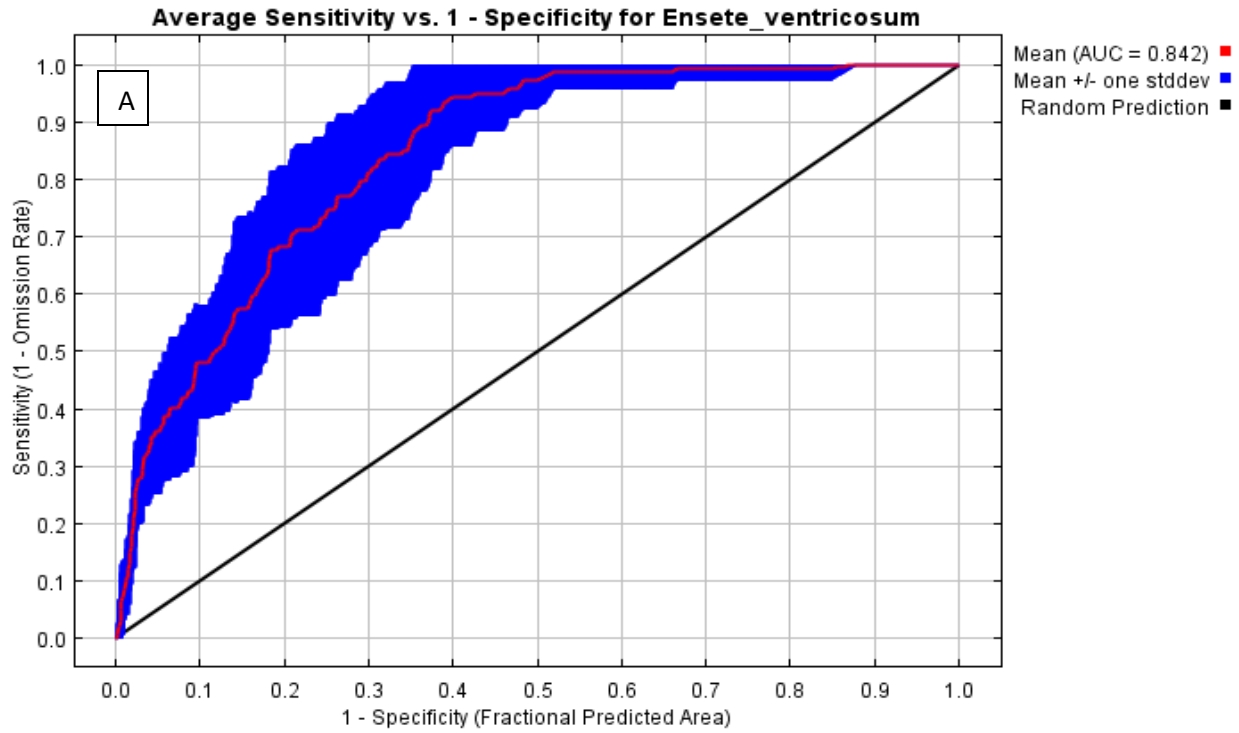


Figure 4.12: ROC or AUC for cultivated (A) and wild (B) ensete.

4.4. Ranking of environmental variables

The list of environmental variables and their ranks according to their contribution to the model is indicated in Tables 4.3 and 4.4. In case of, cultivated ensete, annual precipitation or bio12 (15.7%) is more important and highly contributes to the model next to mean temperature of wettest quarter or bio8 (19.4%). Besides, mean annual temperature or bio1 (0.1) is less contributed and has less permutation importance (Table 4.3). On the other hand, for wild ensete, land-use/land-cover have the most contribution to the model and bio10 (mean temperature of warmest quarter) had the least contribution.

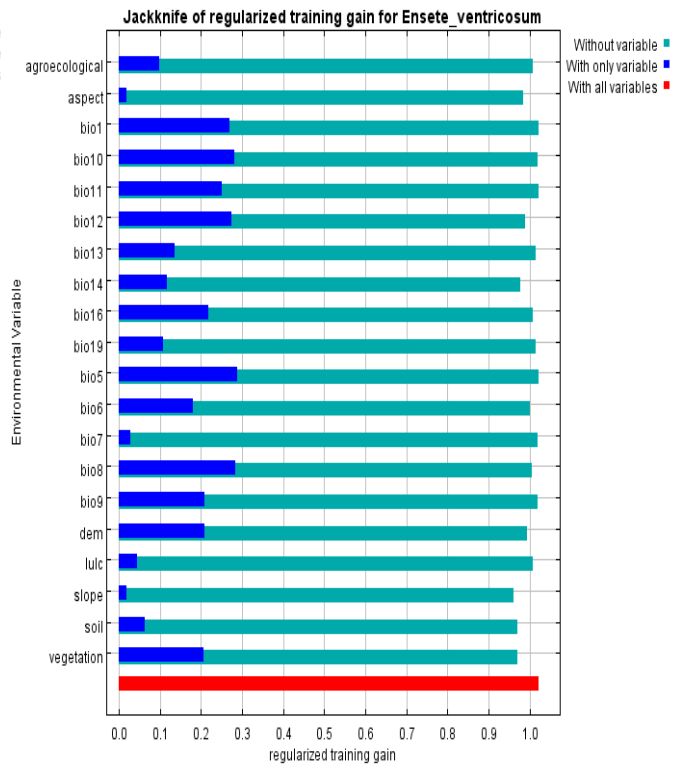
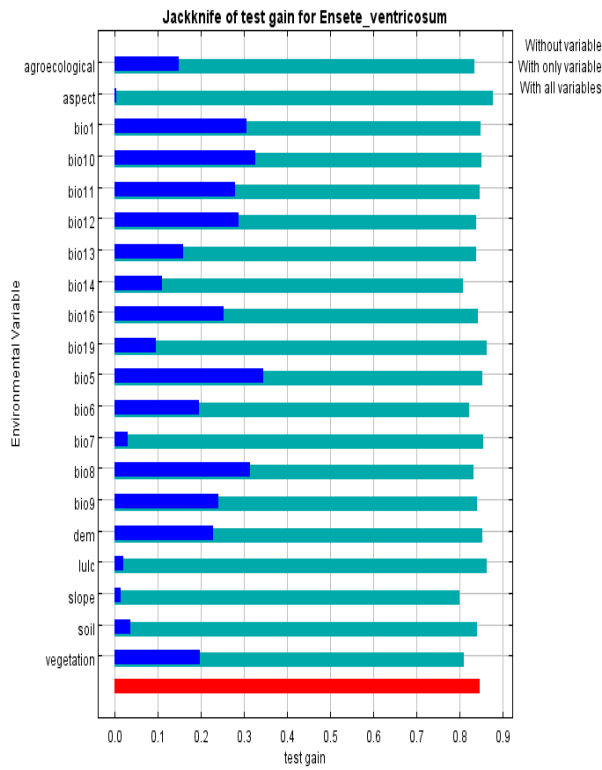
Table 4.3: Summary of environmental variables and their importance for cultivated ensete.

Variables	Percent contribution	Permutation importance
bio12	25.9	15.7
Vegetation	19.9	2.9
bio14	12.3	6.4
Bio5	9.2	0.2
Agro ecology	5.5	0.7
Soil	5	2.3
Bio6	4.3	2.3
Slope	3.1	2.6
bio16	2.5	15.6
Aspect	2.3	1.3
Dem	2.2	3.1
LULC	1.8	0.7
Bio7	1.7	0.4
Bio8	1.3	19.4
Bio19	1.2	1.1
Bio13	0.9	3.8
Bio10	0.5	1.5
Bio9	0.3	8.2
Bio11	0.1	1.6
Bio1	0	0.1

Table 4.4: Summary of environmental variables and their importance for wild ensete.

Variable	Percent contribution	Permutation importance
LULC	53.7	19.7
Soil	14.3	38.4
Slope	12.2	3.3
Agroecological	9.1	3.9
Bio14	4.3	9.4
aspect	2.4	0
bio19	1.2	7.1
vegetation	1.1	5.8
bio9	1	1.4
bio12	0.5	3.7
bio7	0.1	0.1
Bio10	0.1	2.1

Figure 4.10 and 4.11 shows jackknife test results for cultivated and wild Ensete, respectively. Blue bars indicate the gain achieved when including that predictor only. Green gray bars show how much the total gain is diminished without the given predictor. Red bar indicate the gain achieved when including all predictors. Accordingly, the Jackknife results show that the environmental variables with highest gain are mean temperature of warmest quarter (bio10), mean annual temperature (bio 1) and annual precipitation (bio 12), which are very important for predicting the distribution of cultivated ensete (Figure 4.10). On the other hand, slope, aspect and LULC are lowest gain environmental variables and less important for prediction as compared to the aforementioned variables.



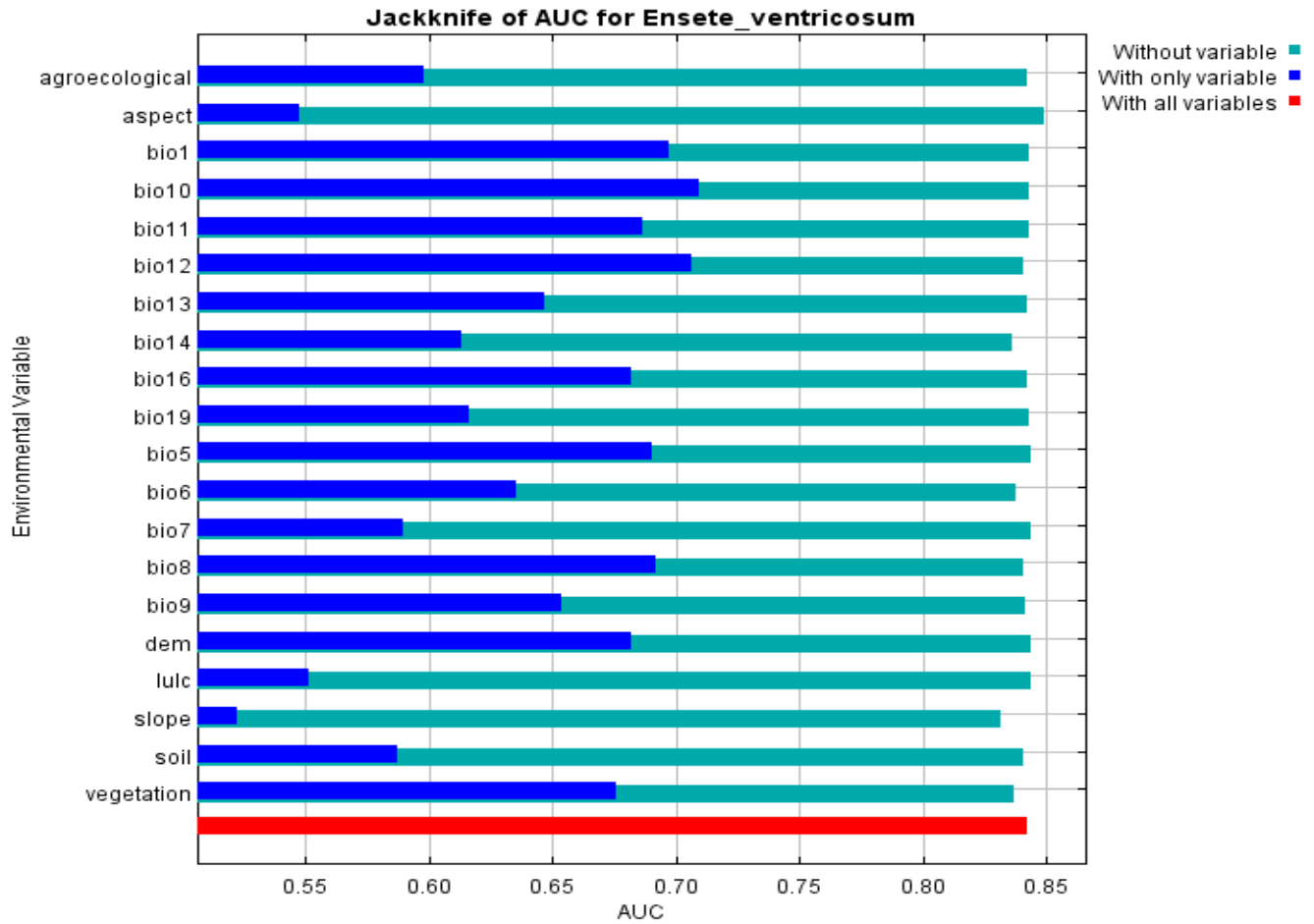


Figure 4.13: Jackknife results for cultivated *Ensete ventricosum*.

In case of wild Ensete, Jackknife results revealed that most bioclimatic variables were important predictor's. Under the continuous environmental variables, temperature annual range (bio7) and annual rain fall (bio12) are the most important variables for the distribution of wild ensete. Among the categorical variables, agro-ecology and land-use/land-cover also has higher contribution to MaxEnt modeling (Figure 4.11).

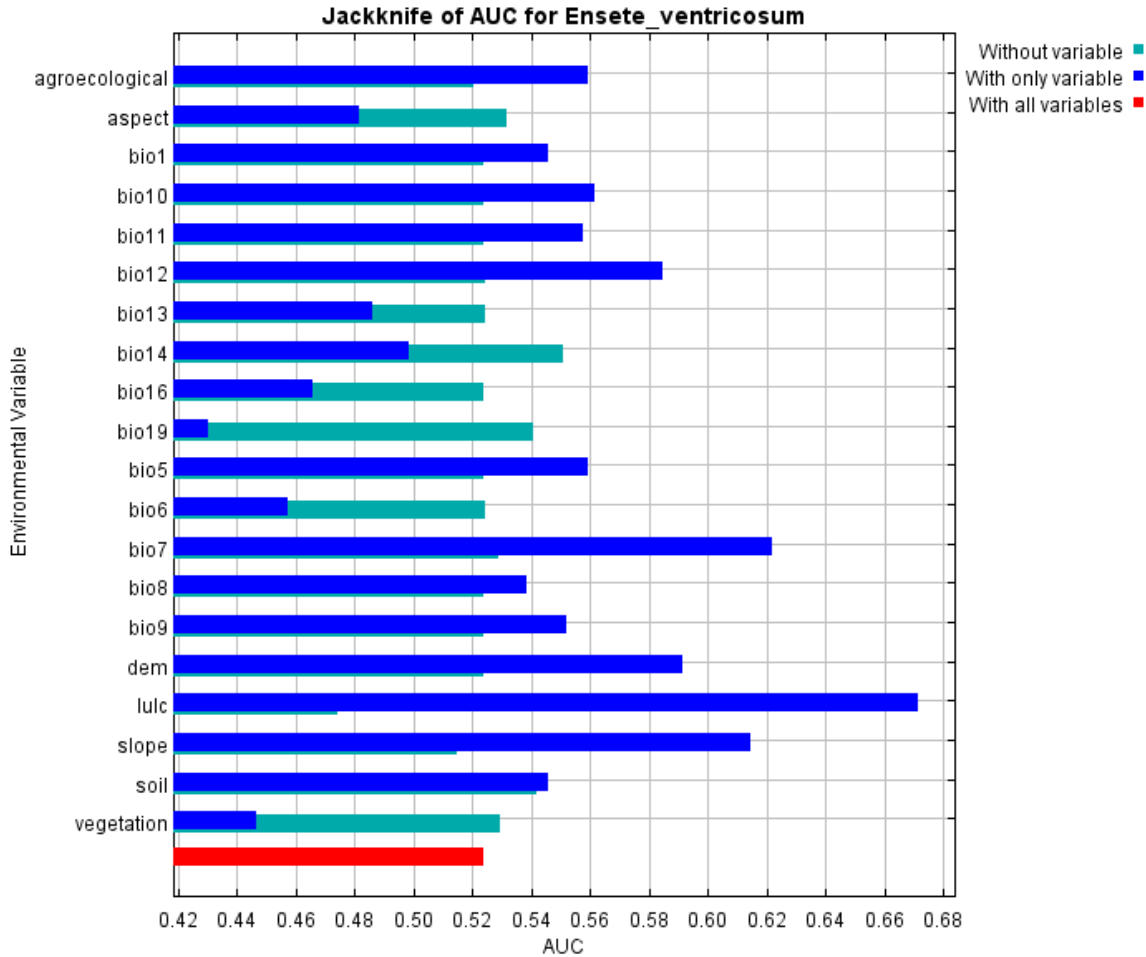


Figure 4.14: Jackknife of AUC for wild *Ensete ventricosum*.

4.5. Probabilistic distribution of *Ensete*

The distribution of both wild and cultivated *Ensete* of the model is predicted with a very good accuracy. However, no accurate model could be achieved. Taking this in to account, the probabilistic distribution of cultivated *Ensete* produced by MaxEnt model is depicted in Figure 4.15. The probabilistic distribution of cultivated *Ensete* is higher in the southern region, some part of Oromia regions, and also southern and eastern parts of Amhara region. In contrary, cultivated *Ensete* were not observed in Afar, Somalia, Deredewa, Tigray, Benshangul Gumuz and Gambela areas.

Figure 4.16 shows the result of wild *Ensete* probabilistic distribution across the study area. The probabilistic distribution map of wild *Ensete* clearly shows that wild *Ensete* is distributed across the above mentioned areas that cultivated *Ensete* is distributed. In addition it was observed around Tigray and Benshangul Gumuz.

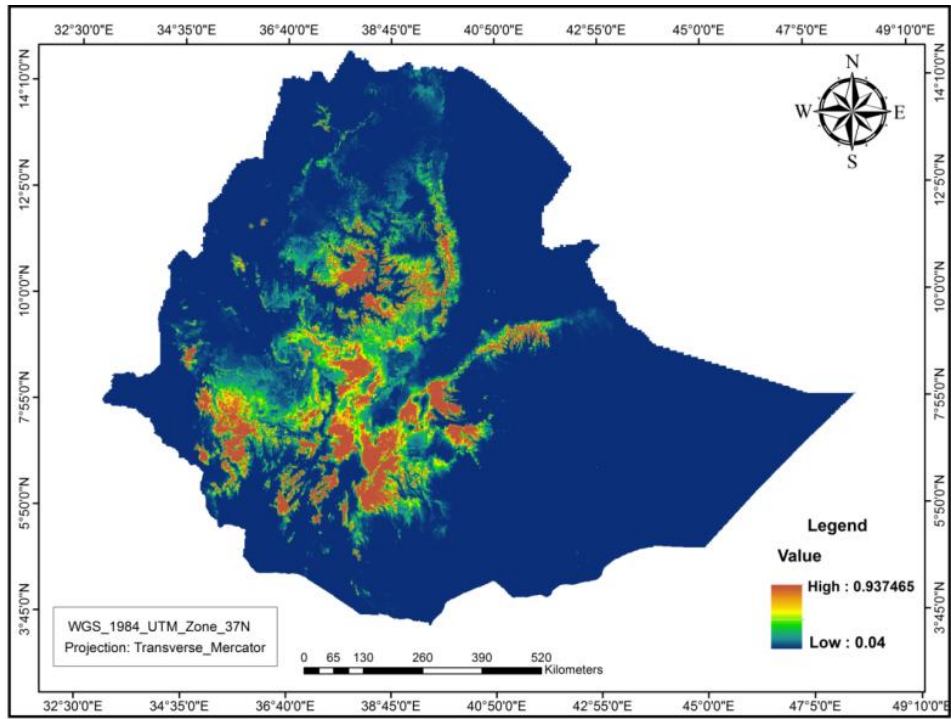


Figure 4.15: Probabilistic distribution of cultivated *Ensete ventricosum*.

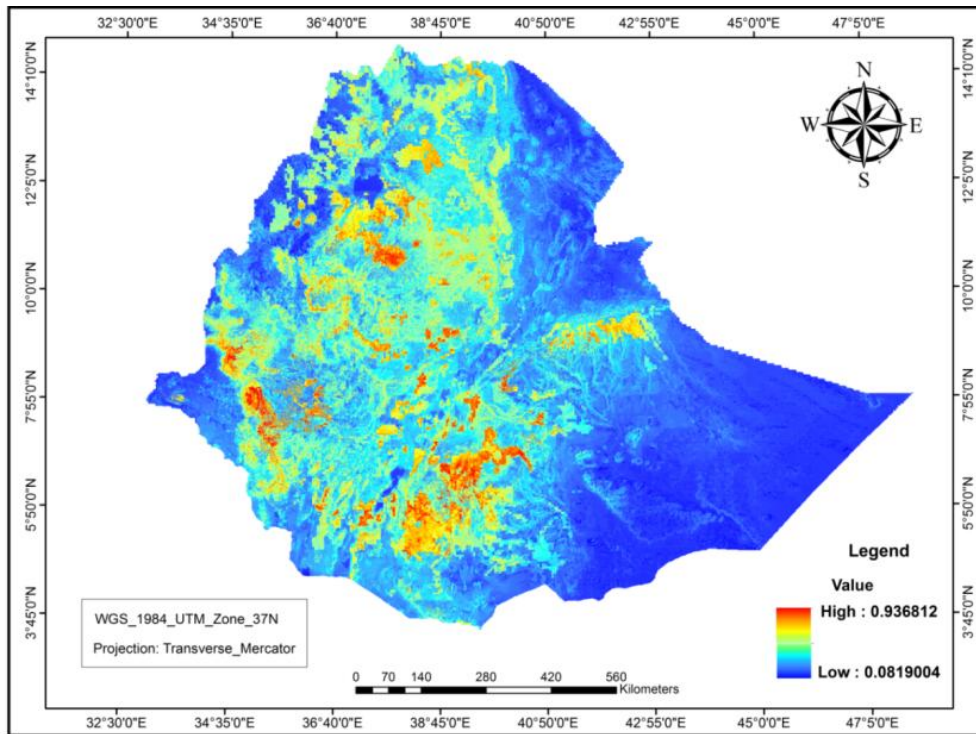


Figure 4.16: Probabilistic distribution of wild *Ensete ventricosum*.

4.6. Hotspot areas of *Ensete ventricosum*

Based on the result of MaxEnt distribution map, ensete hotspot areas are classified in to three (Table 3.3). Results revealed that about 17, 293.67 km² (1.55 %) of the area is primarily hotspot area of cultivated ensete whereas, 81,349.19 km² (7.29%) and 1,017,045.81km² (91.15%) is covered by secondary and none hotspot areas, respectively (Table 4.5). Accordingly, primarily hotspot areas of cultivated ensete is spatially distributed around Sidama, Gedeo, Keffa, Sheka, Ari, Southern Omo, Benche Maji, Arsi, some part of Bale and West Shewa region (Figure 4.17).

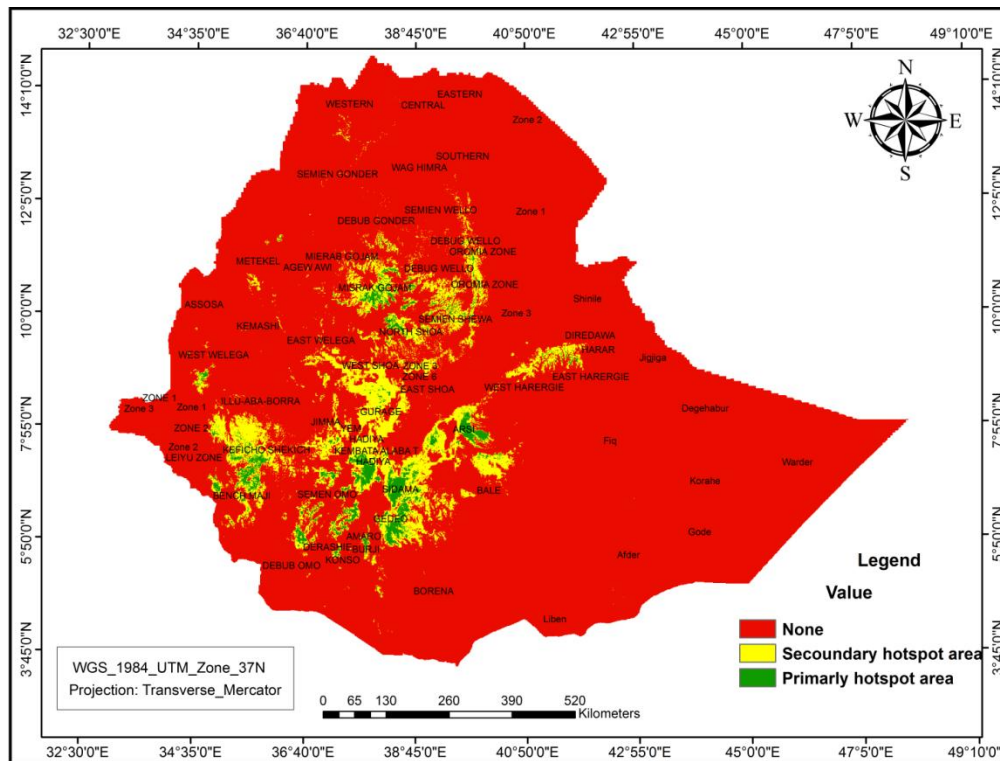


Figure 4.17: Hotspot areas of cultivated *Ensete ventricosum* in Ethiopia.

Table 4.5: Summary of the area coverage for each hotspot class.

Class	Cultivated ensete		Wild ensete	
	Area(km ²)	Area (%)	Area(km ²)	Area (%)
Primarily hotspot	17,293.67	1.55	40,402.09	3.62
Secondary hotspot	81,349.19	7.29	161,143.5	14.44
None	1,017,045.81	91.15	914,153.91	81.93

On the other hand, hotspot area of wild *Ensete ventricosum* is higher than the cultivate one. This is mainly due to the fact that wild ensete is not limited by cultural heritages and its growth is not inhibited by the local communities. Wild ensete grows everywhere when there is a favorable environmental condition. In contrary, the expansion and adoption of cultivated ensete highly depends on willingness of the local community to include cultivated ensete in their farming systems. Besides, the ground control points that can be used as a model input is also affected the distribution of both cultivated and wild ensete.

The probabilistic distribution map of wild ensete indicates that about 40,402.09 km² (3.62%) of the country is covered by primarily hotspot areas (Table 4.6). As it is clearly indicated in Figure 4.18, some part of the northern Ethiopia is also included in the primarily and secondary hotspot areas of wild ensete in contrary to cultivated ensete. Wild ensete is spatially highly distributed in the West Shewa, Welega, Eastern Tigray Southern Gonder, Western and Eastern Gojam, Wag himera, Sidama, Gedeo, Keffa, Sheka, Southern Omo, Benche Maji, Benishangul Gumuz, Arsi and also some part of Bale and West Shewa as a primary hotspot area.

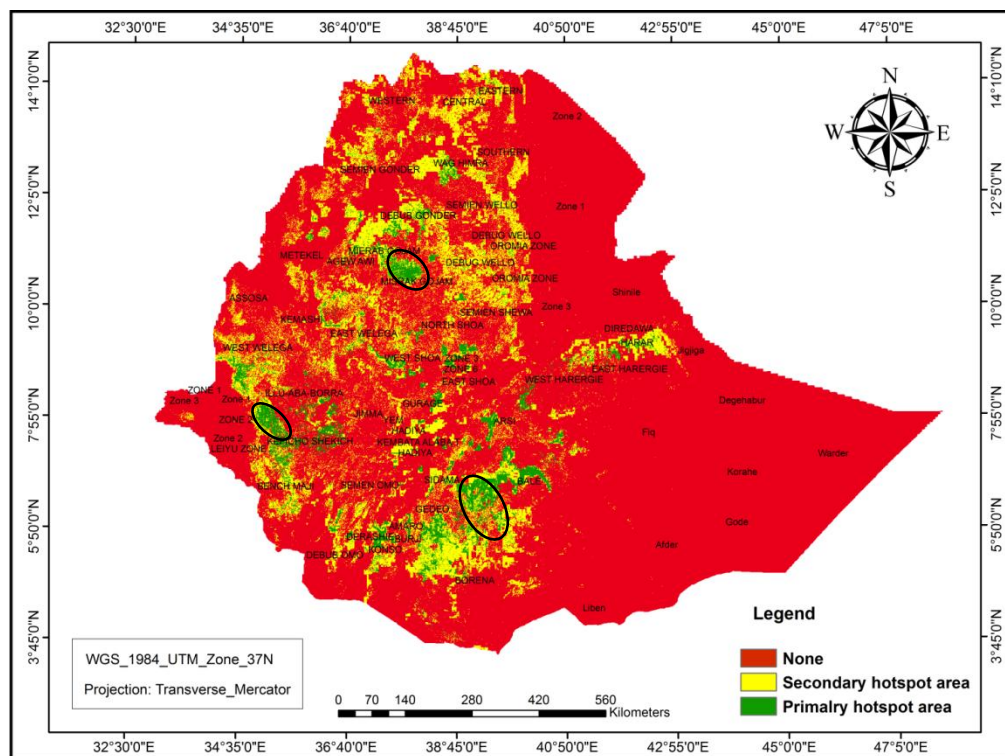


Figure 4.18: Hotspot areas of wild *Ensete ventricosum* in Ethiopia.

Table 4.6: List of primarily hotspot areas of wild and cultivated *Ensete ventricosum*.

Cultivated Ensete Hotspot areas	Wild Ensete Hotspot areas
Kefaa	Kefaa
Sheka	Sheka
Gedeo	Gedeo
Sidama	Sidama
Guragae	Guragae
Benche Maji	Benche Maji
Arsi	Arsi
Bale	Bale
Ari special zone	Welega
Southern Omo	Western and Eastern Gojam
West Shewa	West Shewa
-	Waghimera
-	Southern Gonder
-	Eastern Tigray (Adigrat)
-	Benishangul Gumuz

4.7. Discussion

As indicated in Figure 4.19, the distribution map of cultivated Ensete identified MaxEnt model and the existing distribution map developed by Brandt *et al.*, (1997). MaxEnt model results revealed that the majority of the probabilistic distributions were classified as hotspot area of the species. Accordingly, Sidama, Gedeo, Keffa, Sheka, Southern Omo, Ari, Benche Maji, Arsi, some part of Bale and West Shewa are categorized under hotspot areas for cultivated ensete. This result is consistent and comparable with the finding of the previous studies (Brandt *et al.*, 1997 and Shank, 1994).

The Primary hotspot areas for wild *Ensete ventricosum* are West Shewa, Welega, Southern Gonder, Western and Eastern Gojam, Wag himera, Sidama, Gedeo, Keffa, Sheka, Southern Omo, Benche Maji, Arsi, some part of Bale , West Shewa, and Eastern parts of Tigray Adegrat.

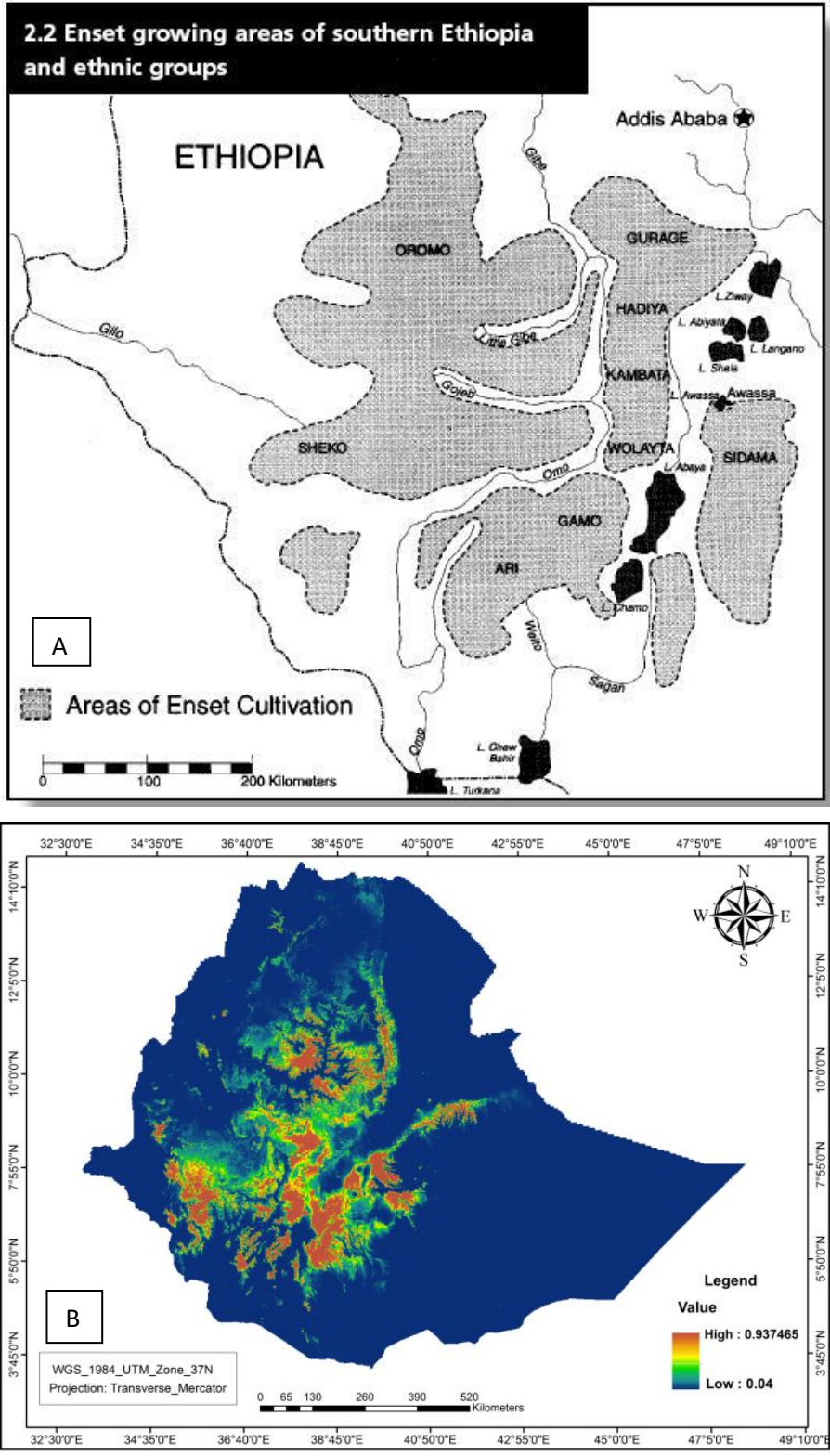


Figure 4.19: Comparison of existing map (A) and MaxEnt (B) Result of cultivated ensete.

Apart from the spatial distribution of cultivated ensete, results related to the characterization of cultivated ensete from MaxEnt model and survey result of the previous study are indicated in table 4.7. Accordingly, the optimal precipitation and temperature ranges suitable for both wild and cultivated ensete are 1100–2200 mm and 10–21°C, respectively. The result of this study is comparable with Brandt, *et al.*, (1997) despite some deviation for temperature and precipitation ranges. MaxEnt model results revealed that wild ensete is distributed at an altitude of 1036 – 3129 m while cultivated ensete is in the range of 1344–3129 m. In addition, present study work results indicated that wild and cultivated ensete are well grown not only in acidic and heavy clay soils, but also other soil types such as Chromic Luvisols, Dystric cambisols, Orthic Acrisols.

Table 4.7: Comparison of the characterization of cultivated and wild ensete identified by MaxEnt model and Brand *et al.*, (1997) survey results.

Characterization	MaxEnt model	MaxEnt Model	Survey Result (Brandt
	Wild ensete	Cultivated ensete	<i>et al.</i>, 1997)
Rainfall	1100–2200 mm	1100–2200 mm	1100–1500
Temperature	10–21 ⁰ C	10–21 ⁰ C	8–17 ⁰ C
Altitude	1036 –3129 m	1344–3129 m	1100–3100(cultivated), 1200–1600(wild)
Soil type	Chromic Luvisols, Dystric Cambisols, Orthic Acrisols	Chromic Luvisols, Dystric Cambisols,Orthic Acrisols.	Acidic and heavy clay soil

5. Conclusion and Recommendation

5.1. Conclusion

Both wild and cultivated ensete are well grown in areas where the annual Precipitation ranges between 1100–2200 mm and mean annual temperature 10–21 °C. And grow also in soil types of acidic and heavy clay. In terms of topography, about 1036–3129 m altitude range is suitable for wild ensete and 1344–3129 m for cultivated ensete. The probabilistic presence of both wild and cultivated *Ensete ventricosum* is higher at the tropic – cool / sub-humid agro-ecological zone. In other hand, dry vegetation Afro-mountain forest and grassland complex vegetation type are characterized under cultivated ensete, whereas Combretum_Terminalia wood land and wooded grassland are better for the wild ensete distribution.

MaxEnt modeling has proven to be very effective at determining habitat for a variety of species and localities. The probability distribution of both wild and cultivated ensete modeled by the MaxEnt program appears to be a reliable and stable model based on the diagnostic tests conducted within MaxEnt. The mean AUC for the 10 replicates was 0.84 and 0.76 with a standard deviation of 0.04 and 0.10 for cultivated and wild ensete distribution, respectively. The model prediction provided was more accurate for cultivated ensete than wild due to the reason that the background location of wild ensete is less than the cultivated one.

Generally, both Wild and cultivated ensete were distributed highly in highland of Ethiopia that receives high rainfall and low temperature. The probabilistic distribution of cultivated ensete is higher in southern region, some part of Oromia regions, and little areas of southern and eastern parts of Amhara region, whereas wild ensete is spatially highly distributed in Tigray and Benshangul Gumuz region in addition to the above mentioned areas. About 1.55% of the study areas were covered by primarily hotpot areas of cultivated and 3.6% is for wild ensete. All in all, Geospatial tools and MaxEnt modeling provides a tool for researchers, stakeholders and managers to understand the potential extent, characteristics and distribution of wild and cultivated *Ensete ventricosum* in Ethiopia.

5.2. Recommendation

Based on the findings and limitations noted in this study, the following recommendations were drawn:

Field Validation: Further field investigation should determine the probabilistic distribution of both wild and cultivated ensete is believed to be more accurate, which are not and collect evidence on variables that affect the predictions.

Experimentation: Further research was also recommended to undertaken to the analyses of the adaptation mechanisms for both wild and cultivated ensete in different agro ecology zones. That is, different varieties of ensete species should be tested whether the species is grown or not in the identified suitable /hot spot areas form this research.

Coarse resolution: The study was undergoing for the whole Ethiopia. Due to this, the data used to map the probabilistic distribution of wild and cultivated ensete were too coarse resolution. Using very high resolution data such as, IKONOSE, Quick Bird and Arial photograph as verification of the ensete distribution is imperative.

Small number of wild location: Location is one of the factors that contribute to the MaxEnt model. Because of a few numbers of Wild ensete locations (coordinates), the probabilistic distribution of wild *Ensete ventricosum* accuracy was reduced when compared to the cultivated one. Further studies should undergo by adding the localities for the wild ensete through the study area.

References

- Alemu, K., and Sandford, S. (1991). Enset in North Omo Region. FRP Technical Pamphlet, 1.
- Alemayehu Mengistu. (2006). Country Pasture/Forage Resource Profiles. Ethiopia View Article PubMed/NCBI Google Scholar.
- Brandt, S., Spring, A., Clifton, H., McCabe, J. T., Tabogie, E., Diro, M., and Tesfaye, S. (1997). The " tree against hunger": Enset-based agricultural systems in Ethiopia.
- Cheesman, E. E. (1947). Classification of the Bananas: The Genus *Musa* L. *Kew Bulletin*, 106-117.
- Chiche, Y. (1995). Assessment of Enset and root crops contribution to food supply in Ethiopia. FAO. Addis Ababa.
- Clark, J., Wang, Y., and August, P. V. (2014). Assessing current and projected suitable habitats for tree-of-heaven along the Appalachian Trail. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 369(1643), 20130192.
- Dowling, C. R. (2015).using MaxEnt modeling to predict habitat of mountain pine beetle in response of climate change (Doctoral dissertation university of Southern California).
- Elith, J., and Leathwick, J. R. (2009). Species distribution models: ecological explanation and prediction across space and time. *Annual review of ecology, evolution, and systematics*, 40, 677-697.
- FAO. (1984). Agroclimatic resources inventory for land-use planning, Ethiopia, v. 1: Main text and appendix 1; v. 2: Appendixes 2, 3 and 4.
- FAO. (1996). Guidelines: Agro-ecological zoning. Food and Agricultural Organisation, Soils Bulletin, Rome, Italy.
- Franklin, J. (2010). Mapping species distributions: spatial inference and prediction. Cambridge University Press.
- Friis, I., Demissew, S., and Breugel, P. V. (2010). Atlas of the potential vegetation of Ethiopia. Det Kongelige Danske Videnskabernes Selskab.

- Gebeyehu, A. (2003). Research and development in land and water resources. Integrated water and land management research and capacity building priorities for Ethiopia, 3.
- Genet Birmeta. (2004). Genetic variability and biotechnological studies for the conservation and improvement of *Ensete ventricosum* (Vol. 502).
- Getahun, Amare. (1977). Cropping systems in Africa: The Ethiopian case. In AAASA/AIC/Ford Foundation/Faculty of Agriculture, Proceedings of the Workshop on Cropping Systems in Africa (pp. 35-43).
- Getahun Amare. (1978). Agricultural systems in Ethiopia. *Agricultural Systems*, 3(4), 281-293.
- Choice H. (2010). "Agro-ecological Zones of sub-Saharan Africa." International Food Policy Research Institute, Washington, DC., and University of Minnesota, St. Paul, MN.
- Jimenez -Valverde, A., Lobo, J. M., and Hortal, J. (2008). Not as good as they seem: the importance of concepts in species distribution modelling. *Diversity and distributions*, 14(6), 885-890.
- Jones, P. G., Beebe, S. E., Tohme, J., and Galwey, N. W. (1997). The use of geographical information systems in biodiversity exploration and conservation. *Biodiversity & Conservation*, 6(7), 947-958.
- Kailihiwa, S. H. A. (2015). Using Maxent to Model the Distribution of Prehistoric Agricultural Features in a Portion of the Hōkūli 'a Subdivision in Kona, Hawai 'i (Doctoral dissertation, University of Southern California).
- Kumar, S., & Stohlgren, T. J. (2009). Maxent modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. *Journal of Ecology and the Natural Environment*, 1(4), 094-098.
- Mikias Haile. (2014). Cluster analysis for evaluation of genetic diversity in Enset (*Ensete ventricosum* (Welw.): Cheesman) clones at Areka Condition. *J Plant Sci*, 2(1), 55-69.
- Olango, T. M., Tesfaye, B., Catellani, M., & Pè, M. E. (2014). Indigenous knowledge, use and on-farm management of enset (*Ensete ventricosum* (Welw.) Cheesman) diversity in Wolaita, Southern Ethiopia. *Journal of ethnobiology and ethnomedicine*, 10(1), 41.

- Osman, Mahdi, and Petra Sauerborn. (2001). "Soil and water conservation in Ethiopia." *Journal of soils and sediments* 1, no. 2 117-123.
- Pallaris, K. (1998). *Modelling the Distribution of Cecropia species using GIS based techniques. Implications for Tropical Forest Conservation. Part of an Geography MSc. degree at King's College London.*
- Pankhurst, A. (1996). Social consequences of enset production. In *Enset-based Agriculture in Ethiopia. Proceedings of the International Workshop on Enset, Institute of Agricultural Research, Addis Ababa, Ethiopia.*
- Pearson, R. G. (2007). Species' distribution modeling for conservation educators and practitioners. *Synthesis. American Museum of Natural History*, 1, 1-50.
- Peveri, V. (2005). Enset, the Tree of the Poor: Nutrition and Identity in Hadiya Zone (South-central Ethiopia). In *ECAS Conference, Uppsala* (pp. 15-18).
- Phillips, S. J., Anderson, R. P., and Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological modelling*, 190(3), 231-259.
- Phillips, S. J., Dudík, M., Elith, J., Graham, C. H., Lehmann, A., Leathwick, J., and Ferrier, S. (2009). Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. *Ecological Applications*, 19(1), 181-197.
- Phillips, S. J., Dudík, M., and Schapire, R. E. (2004, July). A maximum entropy approach to species distribution modeling. In *Proceedings of the twenty-first international conference on Machine learning* (p. 83). ACM.
- Pollock, J. J. (2015). *A Maxent-based Model for Identifying Local-scale Tree Species Richness Patch Boundaries in the Lake Tahoe Basin of California and Nevada* (Doctoral dissertation, University of Southern California).
- Purseglove, J. W. (1972). *Tropical crops: monocotyledons, vols 1 and 2* (p. 334). Longman, London.
- Reddy, C. S. (2015). Applications of remote sensing in plant sciences: an overview. In *Plant Biology and Biotechnology* (pp. 713-727). Springer India.

- Reddy, M. T., Begum, H., Sunil, N., Pandravada, S. R., Sivaraj, N., and Kumar, S. (2015). Mapping the Climate Suitability Using MaxEnt Modeling Approach for Ceylon Spinach (*Basella alba* L.) Cultivation in India. *Journal of Agricultural Sciences*, 10(2).
- Sandford, J., and Kasa, H. (1994). The Effect of Gender on Resource Contribution, Decision Making and Influence; A Comparison Between Ensete, Teff and Maize. FRP Technical Pamphlet (Ethiopia).
- Shank, R. (1994). The Enset Culture. Technical Report on Enset or the False Banana. United Nations-Emergencies Unit for Ethiopia.
- Shiferaw, B., and Holden, S. (1999). Soil erosion and smallholders' conservation decisions in the highlands of Ethiopia. *World development*, 27(4), 739-752.
- Swets, J. A. (1988). Measuring the accuracy of diagnostic systems. *Science*, 240(4857), 1285.
- Tadessa Daba and Masayoshi, S.(2016). Enset (*Ensete Ventricosum*) Production in Ethiopia: Its Nutritional and Socio-Cultural Values. *Agriculture and Food Sciences Research*, 3(2), 66-74.
- Tedela, S., and Lemma, K. (1998). Environmental Management in Ethiopia: Have the National Conservation Plans Worked?. Organization for social science research in Eastern and Southern Africa (OSSREA).
- Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., and Steininger, M. (2003). Remote sensing for biodiversity science and conservation. *Trends in ecology & evolution*, 18(6), 306-314.
- VanGils, H., Conti, F., Ciaschetti, G., and Westinga, E. (2012). Fine resolution distribution modelling of endemics in Majella National Park, Central Italy. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, 146(sup1), 276-287.
- Westphal, E., Stevels, J. M. C., & Stevels, J. M. C. (1975). *Agricultural systems in Ethiopia* (Vol. 826). Wageningen: Centre for Agricultural Publishing and Documentation.
- Zerihun Doda. (2006). An Ethnographic overview of Enset production peoples of Ethiopia.

<https://lta.cr.usgs.gov/SRTM2>. USGS. 2007. SRTM30 Elevation Data. Accessed on January 2017

<http://www.worldclim.org/> WorldClim climatic data. Accessed on January 2017

Appendices

Appendix A: list of tables

Table A.1: List of Bioclimatic variables

BIO1 = Annual Mean Temperature
 BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
 BIO3 = Isothermality (BIO2/BIO7) (* 100)
 BIO4 = Temperature Seasonality (standard deviation *100)
 BIO5 = Max Temperature of Warmest Month
 BIO6 = Min Temperature of Coldest Month
 BIO7 = Temperature Annual Range (BIO5-BIO6)
 BIO8 = Mean Temperature of Wettest Quarter
 BIO9 = Mean Temperature of Driest Quarter
 BIO10 = Mean Temperature of Warmest Quarter
 BIO11 = Mean Temperature of Coldest Quarter
 BIO12 = Annual Precipitation
 BIO13 = Precipitation of Wettest Month
 BIO14 = Precipitation of Driest Month
 BIO15 = Precipitation Seasonality (Coefficient of Variation)
 BIO16 = Precipitation of Wettest Quarter
 BIO17 = Precipitation of Driest Quarter
 BIO18 = Precipitation of Warmest Quarter
 BIO19 = Precipitation of Coldest Quarter

Table A.2: List of environmental variables used for MaxEnt modelling.

Variables	Title	Source
bio1	annual mean temperature	WorldClim
bio2	mean diurnal range (mean of monthly (max temp2min temp))	WorldClim
bio3	isothermality (bio2/bio7) (_100) % TOPS	WorldClim
bio4	temperature seasonality (standard deviation_100)	WorldClim
bio5	max temperature of warmest month	WorldClim
bio6	min temperature of coldest month	WorldClim
Bio7	temperature annual range (bio5–bio6)	WorldClim
Bio8	mean temperature of wettest quarter	WorldClim
Bio9	mean temperature of driest quarter	WorldClim
Bio10	mean temperature of warmest quarter	WorldClim
Bio11	mean temperature of coldest quarter	WorldClim
Bio12	annual precipitation	WorldClim
Bio13	precipitation of wettest month	WorldClim
Bio14	precipitation of driest month	WorldClim
Bio15	precipitation seasonality (coefficient of variation)	WorldClim
Bio16	precipitation of wettest quarter	WorldClim
Bio17	precipitation of driest quarter	WorldClim
Bio18	precipitation of warmest quarter	WorldClim
Bio19	precipitation of coldest quarter	WorldClim
DEM	Elevation	Gtopo 30
Slope	Slope	DEM

Aspect	Aspect	DEM
Agroecology	Agroecological zones	(Harvest choice, 2010)
Vegetation	Natural vegetation	(Ib Friis, Sebsebe Demissew and Paulo van Breugel. 2010)
Soil	Soil type	FAO
LULC	Land use land cover	EMA

Table A. 3: List of Species name, woreda, zone and location of GCP considered for cultivated Ensete.

Specie name	Grid reference		Altitude	Region	Zone	Worda	Kebele
	x	Y					
Ensete V.	8.64392	38.1212	2354 m	Oromia	West shewa	Weliso	Tulo Bolo
Ensete V.	8.50518	37.96752	1978 m	Oromia	West shewa	Weliso	Gurabaka
Ensete V.	8.48033	38.95888	1940 m	Oromia	West shewa	Weliso	Gurabaka
Ensete V.	8.41078	37.8852	1873 m	Oromia	West shewa	Guro	Adame Wedesa
Ensete V.	8.40996	37.88517	1871 m	Oromia	West shewa	Guro	Adame Wedesa
Ensete V.	8.60737	37.92367	2113 m	Oromia	West shewa	Wenche	
Ensete V.	8.59712	37.93188	2112 m	Oromia	West shewa	Wenche	
Ensete V.	8.57892	37.94218	2080 m	Oromia	West shewa	Wenche	
Ensete V.	8.57892	37.94194	2079 m	Oromia	West shewa	Wenche	
Ensete V.	8.1047	37.46659	1930 m	Oromia	West shewa	Sokoro	
Ensete V.	8.10497	37.46666	1926 m	Oromia	West shewa	Sokoro	
Ensete V.	8.03917	37.43588	1924 m	Oromia	Jima	Natremenchu	
Ensete V.	8.03885	37.43522	1925 m	Oromia	Jima	Natremenchu	
Ensete V.	7.99762	37.43799	1904 m	Oromia	Jima	Saja	
Ensete V.	7.96436	37.43973	1924 m	Southern	Yem s. zone	Yem special zone	
Ensete V.	7.2903	36.40477	2493 m	Southern	Kefa	Ade	Boka
Ensete V.	7.28957	36.40601	2493 m	Southern	Kefa	Ade	Boka
Ensete V.	7.29409	36.38977	2459 m	Southern	Kefa	Ade	Boka
Ensete V.	7.29453	36.38955	2455 m	Southern	Kefa	Ade	Boka
Ensete V.	7.26461	35.89896	2006 m	Southern	Kefa	Chenna	Shishoende
Ensete V.	7.25895	35.8942	1997 m	Southern	Kefa	Chenna	Shishoende
Ensete V.	7.26616	35.86605	1930 m	Southern	Kefa	Chenna	Shishoende
Ensete V.	7.26794	35.77007	1944 m	Southern	Kefa	Beta	Beta
Ensete V.	7.26519	35.75762	1961 m	Southern	Kefa	Beta	Dacha
Ensete V.	7.2822	35.3685	1585 m	Southren	Sheka	Yeki	Eremeche
Ensete V.	7.33551	35.37492	2028 m	Southren	Sheka	Yeki	Gumare
Ensete V.	7.32051	35.36862	1886 m	Southren	Sheka	Yeki	Gumare
Ensete V.	8	35.43607	1906 m	Southren	Sheka	Andarecha	Togere
Ensete V.	7.56759	35.4838	2330 m	Southren	Sheka	Andarecha	Geteba

Ensete V.	7.60585	35.504	2467 m	Southren	Sheka	Masha	
Ensete V.	7.77549	35.4664	2172 m	Southren	Sheka	Masha	Welo
Ensete V.	7.80238	35.4566	2136 m	Southren	Sheka	Masha	Keja
Ensete V.	7.8025	35.45634	2133 m	Southren	Sheka	Masha	Keja
Ensete V.	7.83598	35.47295	1778 m	Southren	Sheka	Masha	Keja
Ensete V.	7.73038	35.48277	2242 m	Southren	Sheka	Masha	Gomaye Mender
Ensete V.	7.73015	35.48331	2245 m	Southren	Sheka	Masha	Ateso
Ensete V.	7.63331	35.50542	2353 m	Southren	Sheka	Masha	Gina
Ensete V.	7.63389	35.5052	2356 m	Southren	Sheka	Masha	Gina
Ensete V.	7.00488	35.56083	1456 m	Southren	Benhe Maje	Semen Benche	Edeget
Ensete V.	7.00506	35.55987	1453 m	Southren	Benhe Maje	Semen Benche	Edeget
Ensete V.	6.95416	35.55596	1331 m	Southren	Benhe Maje	Debub Benche	Omota
Ensete V.	6.95254	35.55779	1342 m	Southren	Benhe Maje	Debub Benche	Omota
Ensete V.	6.94347	35.55568	1354 m	Southren	Benhe Maje	Debub Benche	Shesheka
Ensete V.	6.94447	35.5614	1359 m	Southren	Benhe Maje	Debub Benche	Shesheka
Ensete V.	6.94474	35.55578	1357 m	Southren	Benhe Maje	Debub Benche	Shesheka
Ensete V.	6.9442	35.55764	1368 m	Southren	Benhe Maje	Debub Benche	Shesheka
Ensete V.	7.06835	35.66899	1839 m	Southren	Benhe Maje	Semen Benche	Endade
Ensete V.	7.06871	35.66859	1836 m	Southren	Benhe Maje	Semen Benche	Endade
Ensete V.	7.2822	35.3685	1585 m	Southren	Sheka	Yeki	Eremeche
Ensete V.	7.33551	35.37492	2028 m	Southren	Sheka	Yeki	Gumare
Ensete V.	7.32051	35.36862	1886 m	Southren	Sheka	Yeki	Gumare
Ensete V.	8	35.43607	1906 m	Southren	Sheka	Andarecha	Togere
Ensete V.	7.56759	35.4838	2330 m	Southren	Sheka	Andarecha	Geteba
Ensete V.	7.60585	35.504	2467 m	Southren	Sheka	Masha	
Ensete V.	7.77549	35.4664	2172 m	Southren	Sheka	Masha	Welo
Ensete V.	7.80238	35.4566	2136 m	Southren	Sheka	Masha	Keja
Ensete V.	7.8025	35.45634	2133 m	Southren	Sheka	Masha	Keja
Ensete V.	7.83598	35.47295	1778 m	Southren	Sheka	Masha	Keja
Ensete V.	7.73038	35.48277	2242 m	Southren	Sheka	Masha	Gomaye Mender
Ensete V.	7.73015	35.48331	2245 m	Southren	Sheka	Masha	Ateso
Ensete V.	7.63331	35.50542	2353 m	Southren	Sheka	Masha	Gina
Ensete V.	7.63389	35.5052	2356 m	Southren	Sheka	Masha	Gina
Ensete V.	7.00488	35.56083	1456 m	Southren	Benhe Maje	Semen Benche	Edeget
Ensete V.	7.00506	35.55987	1453 m	Southren	Benhe Maje	Semen Benche	Edeget
Ensete V.	6.95416	35.55596	1331 m	Southren	Benhe Maje	Debub Benche	Omota
Ensete V.	6.95254	35.55779	1342 m	Southren	Benhe Maje	Debub Benche	Omota
Ensete V.	6.94347	35.55568	1354 m	Southren	Benhe Maje	Debub Benche	Shesheka
Ensete V.	6.94447	35.5614	1359 m	Southren	Benhe Maje	Debub Benche	Shesheka
Ensete V.	6.94474	35.55578	1357 m	Southren	Benhe Maje	Debub Benche	Shesheka
Ensete V.	6.9442	35.55764	1368 m	Southren	Benhe Maje	Debub Benche	Shesheka

Ensete V.	7.06835	35.66899	1839 m	Southren	Benhe Maje	Semen Benche	Endade
Ensete V.	7.06871	35.66859	1836 m	Southren	Benhe Maje	Semen Benche	Endade
Ensete V.	7.06122	35.69827	2013 m	Southern	Benche Maje	Semen Benche	Genja
Ensete V.	7.06991	35.70419	2059 m	Southern	Benche Maje	Semen Benche	Genja
Ensete V.	7.08072	35.71109	2111 m	Southern	Benche Maje	Semen Benche	Genja
Ensete V.	7.08122	35.71081	2113 m	Southern	Benche Maje	Semen Benche	Genja
Ensete V.	7.16139	35.83751	2164 m	Southern	Kefa	Chena	Wacha
Ensete V.	8.18323	37.80859	1907 m	Southern	Guragae(7th bet)	Cheha	Deneb
Ensete V.	8.17084	37.86698	1939 m	Southern	Guragae(7th bet)	Cheha	Endeber
Ensete V.	8.1057	37.95169	2140 m	Southern	Guragae(7th bet)	Cheha	Geshewar
Ensete V.	8.04407	38.01695	2634 m	Southern	Guragae(7th bet)	Cheha	Moche
Ensete V.	7.99004	38.09318	2918 m	Southern	Guragae(7th bet)	harekete	Budana denber
Ensete V.	7.99021	38.09335	2920 m	Southern	Guragae(7th bet)	harekete	Budana denber
Ensete V.	7.78711	37.96497	2901 m	Southern	Silte	Gira	Belalo
Ensete V.	7.70799	37.89608	2609 m	Southern	Silte	Gira	Demala
Ensete V.	7.49382	37.85736	2212 m	Southern	Hadiya	Lemo	Shecha
Ensete V.	7.15271	37.79806	1909 m	Southern	Hadiya	Seki	Andena koto
Ensete V.	7.16792	37.80355	1925 m	Southern	Hadiya	Seki	Andena koto
Ensete V.	7.1495	37.82278	1988 m	Southern	Hadiya	Seki	Grebo
Ensete V.	7.15402	37.83514	1980 m	Southern	Hadiya	Seki	Danema
Ensete V.	7.40083	37.79437	2326 m	Southern	Kenebata Tenbaro	Dougena	Mursa Weramo
Ensete V.	7.40128	37.7939	2330 m	Southern	Kenebata Tenbaro	Dougena	Mursa Weramo
Ensete V.	7.31722	37.78458	2703 m	Southern	Kenebata Tenbaro	Dougena	Lemisotecho
Ensete V.	7.31705	37.78511	2707 m	Southern	Kenebata Tenbaro	Dougena	Lemisotecho
Ensete V.	7.27192	37.74465	2373 m	Southern	Kenebata Tenbaro	Kacha Bera	Becheka
Ensete V.	7.27198	37.74502	2373 m	Southern	Kenebata Tenbaro	Kacha Bera	Becheka
Ensete V.	6.88194	37.79261	2216 m	Southern	Welita Sodo	Soda zureya	kokatemare chere
Ensete V.	6.90851	37.81823	2211 m	Southern	Welita Sodo	Soda zureya	Shasha
Ensete V.	6.90821	37.81764	2119 m	Southern	Welita Sodo	Soda zureya	weshae
Ensete V.	6.93103	37.83587	2121 m	Southern	Welita Sodo	Damote Gale	Fakae
Ensete V.	6.93149	37.8361	2119 m	Southern	Welita Sodo	Damote Gale	Fakae
Ensete V.	6.98558	37.8507	1974 m	Southern	Welita Sodo	Damote Bulata	Walibela Golo
Ensete V.	7.03985	37.86295	1948 m	Southern	Welita Sodo	Damote Pulasa	Adeshaneto
Ensete V.	7.05788	37.86819	1938 m	Southern	Welita Sodo	Damote Pulasa	Hilinakoreke
Ensete V.	7.07254	37.87098	1924 m	Southern	Welita Sodo	Damote Pulasa	Tonetomeneta
Ensete V.	7.07254	37.87067	1924 m	Southern	Welita Sodo	Damote Pulasa	Tonetomeneta
Ensete V.	7.09119	37.87106	1932 m	Southern	Welita Sodo	Damote Pulasa	Gotu
Ensete V.	7.09126	37.89167	1931 m	Southern	Welita Sodo	Damote Pulasa	Gotu
Ensete V.	7.00135	37.73374	1862 m	Southern	Welita Sodo	Bolso Sore	Dona
Ensete V.	5.91039	37.3163	2087 m	Southern	Gamogofa	Bonkae	Gerese
Ensete V.	5.91054	37.31611	2089 m	Southern	Gamogofa	Bonkae	Gerese

Ensete V.	5.9146	37.30851	2242 m	Southeren	Gamogofa	Bonkae	Gerese
Ensete V.	5.90798	37.31345	2139 m	Southeren	Gamogofa	Bonkae	Gerese
Ensete V.	5.88753	36.57859	1636 m	Southeren	south Omo	South Are	Pela
Ensete V.	5.94579	36.58471	1794 m	Southeren	south Omo	South Are	Doredora
Ensete V.	5.96017	36.58718	1720 m	Southeren	south Omo	South Are	Doredora
Ensete V.	5.97013	36.58297	1712 m	Southeren	south Omo	South Are	Sedo
Ensete V.	5.97908	36.58197	1673 m	Southeren	south Omo	South Are	Sedo
Ensete V.	5.98178	36.57411	1665 m	Southeren	south Omo	South Are	Besera
Ensete V.	5.96442	36.55112	1667 m	Southeren	south Omo	South Are	shesher
Ensete V.	6.02848	36.53644	1590 m	Southeren	south Omo	South Are	Ayenalem
Ensete V.	6.10328	36.54415	1520 m	Southeren	south Omo	South Are	Tenbel
Ensete V.	6.08495	36.54415	1692 m	Southeren	south Omo	South Are	Tenbel
Ensete V.	6.17857	37.57718	2253 m	Southern	Gamogofa	Chencha	Amara bodo
Ensete V.	6.1872	37.57355	2356 m	Southern	Gamogofa	Chencha	Amara bodo
Ensete V.	6.20424	37.57061	2457 m	Southern	Gamogofa	Chencha	Hayezo
Ensete V.	6.24468	37.57639	2625 m	Southern	Gamogofa	Chencha	2
Ensete V.	6.27954	37.56572	2829 m	Southern	Gamogofa	Chencha	Deda
Ensete V.	6.32163	37.53619	2673 m	Southern	Gamogofa	Deta	Sesha
Ensete V.	6.31646	37.52803	2583 m	Southern	Gamogofa	Deta	Sesha
Ensete V.	6.31276	37.49711	2495 m	Southern	Gamogofa	Deta	Delebasa
Ensete V.	6.30869	37.49016	2496 m	Southern	Gamogofa	Deta	Delebasa
Ensete V.	6.30874	37.4902	2496 m	Southern	Gamogofa	Deta	Delebasa
Ensete V.	6.30849	37.49015	2497 m	Southern	Gamogofa	Deta	Delebasa
Ensete V.	7.00088	38.49987	1726 m	Southern	Sidama	Tula(northern sidama)	Bametogabe
Ensete V.	6.94286	38.47316	1897 m	Southern	Sidama	Tula(northern sidama)	Bametogabe
Ensete V.	6.91931	38.45206	1906 m	Southern	Sidama	Laco	Murachoeutala
Ensete V.	6.87929	38.43975	1854 m	Southern	Sidama	Laco	Murachoeutala
Ensete V.	6.87291	38.45013	1888 m	Southern	Sidama	Shebedeno	Moracho
Ensete V.	6.87278	38.44947	1890 m	Southern	Sidama	Shebedeno	Moracho
Ensete V.	6.87301	38.44931	1890 m	Southern	Sidama	Shebedeno	Leku
Ensete V.	6.80269	38.38288	1766 m	Southern	Sidama	Dalae	North Mesenkala
Ensete V.	6.74923	38.42904	1759 m	Southern	Sidama	Dalae	Yirga Alem
Ensete V.	6.74867	38.43361	1771 m	Southern	Sidama	Dalae	Yirga Alem
Ensete V.	6.74615	38.44427	1790 m	Southern	Sidama	Dalae	Yirga Alem
Ensete V.	6.74606	38.44431	1790 m	Southern	Sidama	Dalae	Yirga Alem
Ensete V.	6.70789	38.36116	1786 m	Southern	Sidama	Dalae	Magera
Ensete V.	6.66314	38.35316	1798 m	Southern	Sidama	Chuko	Denegora
Ensete V.	6.6288	38.3526	1817 m	Southern	Sidama	Chuko	korekae
Ensete V.	6.53262	38.32989	1745 m	Southern	Sidama	Chuko	Teso
Ensete V.	6.33101	38.28051	1627 m	Southern	Gedo	Wenago	Tumata cherecha

Ensete V.	6.31574	38.25266	1768 m	Southern	Gedeo	Wenago	Tumata cherecha
Ensete V.	6.30931	38.22187	1873 m	Southern	Gedeo	Wenago	Tumata cherecha
Ensete V.	6.25603	38.20873	1861 m	Southern	Gedeo	Yirgachefe	Cheliba
Ensete V.	6.1956	38.20695	1840 m	Southern	Gedeo	Yirgachefe	Cheliba
Ensete V.	5.69939	38.25927	1879 m	Oromia	GujeLeta	Bolehora	Murei turekuma
Ensete V.	5.75249	38.26825	2208 m	Oromia	GujeLeta	Bolehora	Toma Mete
Ensete V.	5.81378	38.26883	2354 m	Oromia	GujeLeta	Bolehora	Toma Mete
Ensete V.	5.79317	38.28035	2317 m	Oromia	GujeLeta	Bolehora	Eralebetu
Ensete V.	5.79473	38.34432	2419 m	Oromia	GujeLeta	Karecha	Lemireba
Ensete V.	5.79223	38.35669	2409 m	Oromia	GujeLeta	Karecha	Lemireba
Ensete V.	5.79027	38.38196	2299 m	Oromia	GujeLeta	Karecha	Lemi kercha
Ensete V.	5.7897	38.38234	2302 m	Oromia	GujeLeta	Karecha	Lemi kercha
Ensete V.	5.90687	38.25269	2269 m	Southern	Gedeo	Gedeb	Bereda
Ensete V.	5.96607	38.26091	2420 m	Southern	Gedeo	Gedeb	Haremufa
Ensete V.	6.02862	38.27159	2465 m	Southern	Gedeo	Gedeb	Choreso mazoreya
Ensete V.	6.05637	38.24634	2521 m	Southern	Gedeo	Gedeb	Geshe
Ensete V.	6.07416	38.22375	2325 m	Southern	Gedeo	Kochere	kisha
Ensete V.	6.46491	38.34275	1846 m	Southern	Sidama	Dara	Gelewacho
Ensete V.	6.48621	38.36309	1829 m	Southern	Sidama	Dara	Setamo
Ensete V.	6.52363	38.38301	1868 m	Southern	Sidama	Aletachuko	Lelahonja
Ensete V.	6.59625	38.39053	1917 m	Southern	Sidama	Aletawendo	Omecho
Ensete V.	6.59625	38.42866	1927 m	Southern	Sidama	Aletawendo	Buletuma
Ensete V.	6.57089	38.44833	2279 m	Southern	Sidama	Aletawendo	Buletuma
Ensete V.	6.56459	38.50774	2566 m	Southern	Sidama	Hula(Hagerselam)	Loya
Ensete V.	6.47159	38.53819	2736 m	Southern	Sidama	Hula(Hagerselam)	odola
Ensete V.	6.42968	38.55478	2724 m	Southern	Sidama	Bore	Egete
Ensete V.	6.98359	38.5648	1714 m	Southern	Sidama	Wendo Genet	Aroma
Ensete V.	7.06903	38.59038	1688 m	Oromia	GujeLeta	Wendo Genet	Shesha
Ensete V.	7.07132	38.58987	1689 m	Oromia	GujeLeta	Wendo Genet	Shesha
Ensete V.	7.08697	38.59459	1700 m	Oromia	GujeLeta	Wendo Genet	Shesha
Ensete V.	7.18205	38.6577	2124 m	Oromia	Aresi	Shashemen	Huresa
Ensete V.	7.15039	38.70159	2352 m	Oromia	Aresi	Shashemen	Huresa
Ensete V.	7.06077	38.80148	2629 m	Oromia	Aresi	Kofele	Toma betacha
Ensete V.	7.04299	38.83582	2628 m	Oromia	Aresi	Kofele	Toma betacha
Ensete V.	7.07899	38.77328	2641 m	Oromia	Aresi	Kofele	Geremama
Ensete V.	7.94309	38.25439	2386 m	Oromia	Silte	silte	Arateber
Ensete V.	8.36091	38.51041	2447 m	Southern	Guragae(sodo)	Buki	Fatu
Ensete V.	8.36458	38.49739	2505 m	Southern	Guragae(sodo)	Buki	Fatu
Ensete V.	8.36059	38.48032	2633 m	Southern	Guragae(sodo)	Buki	Fatu
Ensete	8.3826	38.59808	2169 m	Southern	Guragae(sodo)	Sodo	Suten zureya

Table A.4: List of Species name, region and location of GCP considered for wild Ensete.

no	region	x	y
1	Benishangul Gumuz National Regional State	74612.02013	3168629.59371
2	Benishangul Gumuz National Regional State	177372.00000	1143269.00000
3	Benishangul Gumuz National Regional State	21169.78687	876912.29531
4	Benishangul Gumuz National Regional State	98705.12755	776083.53191
5	Benishangul Gumuz National Regional State	192698.55980	792975.58315
6	Benishangul Gumuz National Regional State	23478.41161	1098278.62834
7	Oromia	19814.59936	972547.73713
8	Oromia	20138.78214	981414.28477
9	Oromia	23311.30456	988657.99026
10	Oromia	6685.22796	990649.52151
11	Oromia(Jimma)	260989.82233	848051.11026
12	Oromia(Weliga)	591551.48714	1015227.36087
13	Southren (Kefaa)	196310.53604	802305.92078
14	Southren (Sheka)	102234.80248	790041.74105
15	Southren (sidama)	463192.01194	786659.25871
16	Oromia(Weliga)	31810.66395	940537.06641
17	Oromia(Weliga)	32088.17609	940681.83837
18	Oromia(Weliga)	19914.46860	968481.01803
19	bahirdar	265008.6209	1299035.557
20	Oromia	152730.7595	969859.3046
21	Oromia	152683.8555	965796.1013

Appendix B: List of pictures



Plate B.1: The Boundary of Masha (Sheka zone) and Oromia where distribution of Ensete is stop. (A), Ensete around kofele where the distribution of Ensete is becoming decrease because of the climate and altitude condition of the area. (B)



Plate A.2: Homestead cultivation of Ensete (A) and packing of Ensete products by local people around Gedeo zone. (B)