Journal of Agriculture and Environmental Sciences
June 2024, Volume 13, pp. 1-15
ISSN: 2372-5060 (Print), 2372-5079 (Online)

Published by The Brooklyn Research and Publishing Institute
DOI: 10.15640/ijhs.v13a1
URL: https://doi.org/10.15640/ijhs.v13a1

Climate and Soil Suitability for Maize, Dry bean and Sweet potato production under irrigated Smallholder Agricultural Enterprises in Vhembe District Municipality of Limpopo Province, South Africa

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Abstract

Purpose of the study was to investigate climate and soil suitability for production of maize, dry bean, and sweet potato. The study employed mixed-methods approach in which both quantitative and qualitative data was used. In winter temperatures were generally lower, whereas in summer temperatures were a minimum >17.4 °C and maximum of about 31 °C were generally suitable for production of the three selected crops. Madimbo Corridor received less rainfall (201–400 mm) than the minimum required by each of the three crops and was generally not suitable for rainfed production. Rainfall at the Upper Mutale Valley (401–600 mm and 601–800 mm) sufficed for suitable for production of these crops. Soil at Madimbo Corridor were less suitable for production of three crops whereas in Upper Mutale Valley soil were suitable. It was recommended that climatic and soil suitability be assessed to decide on crops to be produced in any area

Keywords: Climate, Soil, Suitability, Upper Mutale Valley, Madimbo corridor.

1. Introduction

Vhembe District Municipality in South Africa is blessed with a diverse climate and soils that suit production of a wide range of field crop commodities. The climate and soil types influenced the agro-ecological conditions and associated range of potentials and constraints for cropping (FAO, 1996). The potentials and constraints of an agro-ecological zone for production of a specific crop is influenced by the extent to which the climate and soils of that zone match the requirements of the crop (Nyahunda and Tirivangasi, 2020). An agro-ecological zone offering the climate and soils required by a crop presents potential and is regarded suitable for production of the crop; one offering climate and soils not required by the crop presents a constraint and is regarded unsuitable.

Rankoana, (2016) suggested that irrigated smallholder agricultural enterprises led by women and youth (ISHAE-WY) in Limpopo province and indeed in Vhembe District has been dominated by women, and these would mean that gender differences are likely to influence the capacity of ISHAE-WY to adapt to climate change as well as their choices of climate change adaptation strategies. These also revealed that probably men are able to make appropriate farming decisions that reflect improved adaptive capacity to challenges such as climate change and variability. Statement by Mpandeli and Maponya, (2013) revealed that the study area encountered one of the worst droughts during the 1991/92 summer rainfall season, and that affected production of ISHAE-WY in negative ways.

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As affirmed by Nyahunda and Tirivangasi, (2019), ISHAE-WY in the study area experienced water scarcity and wilting of desirable crops, due to unfavourable climatic conditions, characterized by low rainfall and high temperatures.

The climate and soil suitability could probably also be described based on crop suitability modelling defined as the congruence between the crop requirements and the geo-climatic conditions necessary for such crops (FAO, 1976). It is vital to select crop commodities for cultivation based on suitability in a particular production area, so that maximum benefit could be achieved while maintaining the ecological sustainability. The extent of crop suitability to geo-climatic condition of an area influences the production performance of the crop in that area (He, *et al.,* 2011). The purpose of the study was to assess the climate and soil suitability for production of maize (*Zea mays L.)*, dry bean *(Phaseolus vulgaris*) and sweet potato (*Ipomoea batatas L*) under smallholder agricultural enterprises in Vhembe District Municipality of Limpopo province, South Africa.

The rationale for conducting the suitability assessment was to determine the potential and limitations of climate and soils for production of the selected crops in the study area (Pan and Pan, 2012) and to avoid environmental stresses (FAO, 2007a; Elsheikh, *et al.,* 2013).

2. METHODOLOGY

2.1. Research approach

The study followed a mixed-methods approach that combines the quantitative and qualitative approaches in one study (Tashakkori and Teddlie, 1998). The quantitative approach was defined as an enquiry into a problem based on testing a theory made up of variables, measured with numbers and analyzed using statistical procedures, to determine whether the predictive generalizations of the theory hold true (Creswell, 2003; Leedy and Ormrod, 2010). The qualitative research approach was defined as an enquiry process of comprehending a problem or phenomenon based on building a complex holistic picture formed with words, reporting detailed views of informants, and conducted in a natural setting (Lincoln and Guba, 1985; Cresswell, 2003; Smyth and Dumanski, 1983). The mixed approach as used in this study included (1) review of literature that presented mainly qualitative information from scientific journals, books and reports and (2) presentation of mainly quantitative climate and soil information (Hurmerinta-Peltomaki and Nummela, 2006; Leedy and Ormrod, 2010).

2.2. The study site in context

The study was conducted in the Madimbo Corridor under Musina Local Municipality and the Upper Mutale Valley under Thulamela Local Municipality. Musina Local Municipality is in the north while the Thulamela Local Municipality is in the north-eastern part of Vhembe District Municipality of the Limpopo province of South Africa (Figure 1). The Vhembe District Municipality is strategically located close to international borders with Botswana in the north-west, Zimbabwe in the north and Mozambique in the north-east. Within South Africa, the district municipality borders Mopani District Municipality in the south-east, Capricorn District Municipality in the south, and Waterberg District Municipality in the west. The other municipalities in Vhembe District Municipality are Makhado Local Municipality south of Musina and Collins Chabane Local Municipality south of Thulamela Local Municipality.

2.3. Data collection

The data required for the research included that of climatic and soil conditions in the study area. Also important were the requirements of the three selected field crops (maize, dry bean, and sweet potato) for the climate and soil types. Suitability assessment of the climate and soils for production of the selected crops would match the crop requirements of the two factors against the condition offered by the study sites regarding the factors.

2.4. Climate and soil data for the study sites

The climate and soil data were quantitative in nature and described through maps sourced from the GIS Directorate of the LDARD.

(a) Climate

Maps for climatic factors of temperature and rainfall were generated from data collected over 20 years in numerous weather stations located in the province. Temperature maps were for minimum and maximum summer and winter temperatures. Within each map, the temperatures were split into categories from lower to higher temperatures, with the different temperature values shown in various sites within the study area. The rainfall map, on the other hand, presented annual rainfall values in the same map without splitting it according to seasons. The study was conducted in a summer rainfall area with minimum rainfall received in winter; hence, it was deemed unnecessary to split the seasons. Also, the rainfall was split into categories (e.g., 0–200 mm, 201–400 mm per annum etc.) with different values presented for various sites within the study area.

(b) Soil types

Up to 73 soil forms were reported for the South African classification, and those could be placed into 14 groups. Soils in the study area were presented in a map sourced from the GIS Directorate, and the enlisted soils were calcareous, eutrophic, mesotrophic, and non-calcareous soils, with some transitional soil types, such as dystrophic to mesotrophic and mesotrophic to eutrophic also included.

2.5. Crop requirements

The information regarding requirements of the three selected crops for climate and soil types was mostly also quantitative in nature, with some qualitative information included, mostly in the form of descriptions and explanations. All the information was sourced from relevant reports and literature. With regards to climate, the minimum and maximum temperature requirement and ideal rainfall range for each of the three selected field crops was presented. As for soil requirements, recommended soils were presented based on texture (with a focus on average clay percentage), effective soil depth, and pH.

2.6. Data processing for suitability assessment

According to Carl, (1996), data processing incorporates the gathering and manipulation of the data to generate meaningful and descriptive information. The processing of data entailed comparing the climate and soil information observed for the study area with that reportedly required by the selected field crops. The purpose of the comparison was to determine if there was a congruence or fit between the climate and soil condition observed in the study area and that required by the selected crops. If there was a match, it would suggest that the study area is suitable for production of the crop regarding that factor.

Lack of congruence, on the other hand, would require further consideration and not automatically imply lack of suitability. For instance, if a crop requires a minimum rainfall of 400–500 mm per annum and a rainfall of 700 mm per annum was observed in a site in the study area, the crop will likely produce more with the relatively higher rainfall than the minimum required, and the site would be regarded as more suitable. While the collected data was mostly quantitative, the processing and suitability assessment was mostly qualitative; hence, the study employed mixed methods.

3. RESULTS AND DISCUSSION

As alluded to earlier, the results and their discussion focused on climate and soil factors prevailing in the study area and the growth requirements of the selected crops for those factors.

3.1. Climatic conditions and suitability for selected crops

3.1.1. Climatic conditions

Climate is the primary variable for assessing suitability of crops in an area (Chapman, *et al.,* 2020). As stated by Shahi, (2011), climatic conditions are based on what people observe in their local environment. Agriculture is deeply interconnected with climate as an important driver of agricultural production (Selvaraju, *et al.,* 2011). Agricultural production depends on climatic conditions, such as temperature and rainfall (Mpandeli and Maponya, 2013). Climate is a primary determinant of agricultural productivity, and any significant change in climate tends to influence crop productivity (Jayne *et al.,* 2003). The trends on climate change in Southern Africa project an increase of temperatures, occurrence of droughts, and an increase in the intensity and frequency of extreme weather events (Nhamo, *et al.,* 2020).

The impact of climatic conditions such as rainfall on agriculture can no longer be ignored as agricultural production is largely dependent on the amount of water available (Shrestha, *et al.,* 2014). Adverse climatic conditions resulted in declines in crop yield, and that increased the global occurrence of food insecurity (Bhatt, *et al.,* 2014). Such negative impacts were more significant in arid and semi-arid areas, and those included the study areas of Madimbo Corridor under Musina local Municipality and Upper Mutale Valley under Thulamela Local Municipality. As stated by Nana, *et al.,* (2014), crops such as maize, sweet potato and dry bean require a conducive climate for production.

(a)Temperature

The effect of increasing temperature is argued to have a pronounced negative impact on field crop yields, particularly in semi-arid and arid regions. Smallholder farmers are vulnerable to the impacts of increased temperature (Vermeulen, *et al.,* 2012) often associated with drought (Ziervogel, *et al.,* 2014). Increased temperatures are among the recent pervasive stressors with which rural communities must cope with (Maponya and Mpandeli, 2013). However, Lynam and Brown, (2011) believed that perceptions of increased temperature were shaped by observations of changing weather patterns. The increase in temperatures has a detrimental effect on agricultural sector performance and economic development (Faramarzi, *et al.,* 2013). As affirmed by (Nhamo, *et al.,* 2018), the projected increases in warming conditions across most parts of the region would worsen the challenges associated with water insecurity (mainly due to reduced rainfall), adversely affecting both rainfed and irrigated agriculture production, as well as negatively impacting energy generation.

The temperature increases are expected to be higher in the arid regions of the African continent compared to the rate of global average increases (Almazroui, *et al.,* 2020). Furthermore, there is a remarkable ecological variability because of increased temperature and associated drought, which resulted from increased evapotranspiration (Intergovernmental Panel on Climate Change (IPCC), 2013), and these threaten the livelihoods of rural communities (Lasage, *et al.,* 2015), including the ISHAE-WY in the area under study. Also, temperature extremes may result in frosts and heat waves, and these may cause damage to crop plants.

(i) Summer temperatures in the study area

The summer temperatures in Madimbo Corridor and Upper Mutale Valley tend to influence the selection of crops to be planted in those areas during the summer season. Based on the findings of the study, such temperatures may be diverse (Figure 2 and Figure 3).

The minimum temperature in summer at Madimbo Corridor was >17.4 ^{o}C with the maximum of >31 ^{o}C. At Upper Mutale Valley, minimum temperature in summer was also >17.4 ^{o}C with temperatures of 15.3–17.4 ^{o}C in some surrounding areas (Figure 5.2). The maximum summer temperatures at Upper Mutale Valley were observed to be 29.3–31 ^{o}C (close to that of Madimbo Corridor) with temperatures of 27 –29.2 ^{o}C and those >31 ^{o}C recorded in some surrounding areas (Figure 3).

(ii) Winter temperatures

As was the case for summer, the winter temperatures in the area under study had a strong influence on the types of crops selected for planting during the season. The occurrence of certain minimum and maximum winter temperatures (Figure 4 and Figure 5) tended to influence the dates by which certain crops should be planted.

The minimum temperature in winter at Madimbo Corridor was like that of the Upper Mutale Valley at >10 ^{o}C with lower temperatures (7.5–10 ^{o}C) recorded for some parts around the valley. Similarly, maximum winter temperatures were >24 ^{o}C for both sites with lower temperatures (21.9–24 ^{o}C) recorded in some parts around the Upper Mutale Valley. Within each of the study sites, temperatures could vary across specific localities influenced by aspects such as terrain. North-facing slopes optimize the repose angle with the sun, which increases sunlight and temperature (Inger, *et al.,* 2015). Also, altitude is a critical variable for growth and yield potential of crops (Smith and Donahue, 1991; Terashima, *et al.,* 1995; Sakata and Yokoi, 2002). Gale, (2004) implies that although altitude is often overlooked in assessment of crop production potential, it contributes immensely to good health and plant growth.

(b) Rainfall

Rainfall (trend and quantity) influences the state of water resources at any given locality (Omokanye, *et al.,* 2018). There is a strong relationship between precipitation and the prevalent agro-ecological setting (Kala, *et al.,* 2012). According to He, *et al.,* (2013), rainfall is a primary factor in rain-fed agriculture. Daccache, *et al.,* (2012) inferred that the distribution and quantity of precipitation influenced crop yields, especially in semi-arid regions. Elwell (1994) established a linear relationship between crop yields and precipitation.

According to Mosase and Ahiablame, (2018), the Limpopo River Basin, of which the study area forms a small part, received monthly rainfall more than 100 mm for some rainy months. Proper selection of crops to be produced in Madimbo Corridor (Musina Local Municipality) and Upper Mutale Valley (Thulamela Local Municipality) necessitated information on rainfall received in the study area (Figure 6). Madimbo Corridor received rainfall of 201–400 mm per annum, whereas the Upper Mutale Valley received higher rainfalls varying between 401–600 mm and 601–800 mm per annum, although some localities around the valley received 201–400 mm of rainfall per annum (Figure 5.6). In accordance with its low rainfall, Madimbo Corridor was characterized by a severe lack of water resources. This lack was exacerbated by higher rates of evapotranspiration associated with relatively higher temperatures (Derya, *et al.,* 2009). Production of most crops would, therefore, be difficult in the Madimbo Corridor—except under irrigation. In semi-arid tropics, unreliable rainfall combined with high evaporative demand result in a high risk of water deficit at any stage of crop growth (Muchow and Bellamy, 1991). As alluded to previously, in addition to seasonal rainfall variability, higher growing season temperatures can have dramatic impacts on agricultural productivity (Battisti and Naylor, 2009).

Research findings have illustrated the occurrence of climate change and variability quite broadly. Spatial considerations have comprehensively demonstrated climate variability. For instance, temperatures were reportedly higher in arid and semi-arid regions of the African continent (which includes the study area) compared to those of other continents (Almazroui, *et al.,* 2020). Also, temporally, climate has been reported to be changing. Lynam and Brown, (2011) indicated to increases in temperature over time that tend to serve as a stressor with detrimental effects on agricultural production. According to Nhamo, *et al.,* (2018), the general trend indicates increasing rainfall variability with incidences of floods and droughts. Accordingly, some variability was observed even between the two study sites. Stresses brought about by climate change were, in fact, reported to have adverse effects on broader agricultural sector performance and economic development (Faramarzi, *et al.,* 2013). As affirmed by Nhamo, *et al.,* (2018), projected increases in warming conditions across most parts of the region would worsen the challenges associated with water insecurity (mainly due to reduced rainfall), adversely affecting both rainfed and irrigated agricultural production.

3.1.2. Climate suitability for selected field crops

With the climatic condition of the study area assessed, determination of the suitability of the area for production of the selected crops based on climate necessitates knowledge of the climatic requirements of the designated crops. Such determination entails comparison of their climatic requirements with the climatic condition in the study area (Table 1).

(a) Temperature suitability

Temperature is one of the major environmental factors affecting the growth, development and yields of crops, especially the rate of development (Luo, 2016). According to de Plessis, (2003,) maize is a summer crop and requires a frost-free period of 120 to 140 days to prevent damage. Maize crop production requires a minimum of 21 °C and a maximum of 32 °C for optimal growth. In comparison with the temperature in the area, the minimum temperature in summer at Madimbo Corridor was >17.4 °C with a maximum temperature of >31 °C. At Upper Mutale Valley, minimum temperature in summer was also >17.4 °C (the same as Madimbo Corridor) with temperatures of 15.3–17.4 °C recorded in some localities around the valley.

The maximum summer temperature in the Upper Mutale Valley was 29.3–31°C, with some localities around the valley having recorded temperatures of 27–29.2 and 31 °C (Figure 2, Figure 3). The minimum winter temperatures were >10 °C at both Madimbo Corridor and Upper Mutale Valley, while the maximum temperatures were >24 °C for both sites. Based on temperature conditions, maize may reasonably be considered for production in the study area during the summer season, and this affirms the statement by de Plessis, (2003). The minimum summer temperatures of the study sites were slightly lower than the requirement for optimum growth of the maize plant. Accordingly, production of the maize crop should involve manipulation of planting dates—to avoid the colder spells—and choice of cultivars that are more adaptable to the temperatures in these areas.

Higher temperatures can cause severe yield reductions; their effects on silk-tasseling are difficult to identify because of the short duration of that phase (Porter and Semenov, 2005). The frequency of extreme temperatures may reduce yield, but a direct relation is not quantifiable because temperature and water availability act together in a nonlinear manner to crop response (Bonfante, *et al.,* 2015). The dry bean is a crop which thrives in a warm climate. With a temperature requirement of 18 °C to 24 °C, the crop can successfully be produced in both study sites, provided the colder winter temperatures are avoided. Temperatures during the flowering stage that were too high led to abscission of flowers and a low pod set, resulting in yield loss. Day temperatures below 20 °C delayed maturity and caused empty mature pods to develop. The sweet potatoes adapted well in the warm climate. The crop is sensitive to cold and should not be planted until the danger of frost is over. Best growth temperatures are 21–30 °C, and the crop can, therefore, be successfully produced in the area(s) under study. Sweet potatoes require four months of frost-free growing season (120 days). Due to high temperatures sometimes experienced in the production area, smallholder agricultural entrepreneurs should plant in early or late summer to avoid extreme temperatures. This can also increase a chance of earning high profit due to producing off-season when the crop is not produced in other areas.

(b) Rainfall suitability

Field crops are native to specific areas in geological time (Raihana, *et al.,* 2015) and are known to be suitable in marginal areas characterized by severe dry spells and flash floods (Massawe, *et al.,* 2016). South Africa is considered a dry country with more of its area experiencing below average annual rainfall. Low-lying coastal areas receive moist air from the east and south of the Limpopo Basin, giving rise to a better rainfall distribution and longer growing season (Tadross, *et al.,* 2005). In these areas, rainwater harvesting can play a significant role in reducing production risk in smallholder cropping systems (Bouma, *et al.,* 2016). The high variability in the length of the growing season further confirms the need for adopting production risk mitigating measures, such as growing drought tolerant crops, staggered planting and soil water management.

The amount of water required to produce one kilogram of the three selected crops was estimated at 1.5 m^3, 1.0 m^3 and 2.5 m^3 respectively (Bouman, 2009). It was, therefore, anticipated that areas with limited water availability due to climate change impacts would experience significant losses of crop yields, and that would compromise food security in the long term (Olabanji, *et al.,* 2021).

Maize requires a minimum of 350–450 mm of rainfall per annum to produce optimum yield. In comparison with the rainfall in the study area, the available average rainfall was 201–400 mm in Madimbo Corridor and between 401–600 mm and 601–800 mm in the Upper Mutale Valley. Based on the rainfall condition, the Madimbo Corridor was too dry for dryland maize production, while the Upper Mutale Valley tended to be suitable. At maturity, maize requires enough water to maximize grain filling. Evapotranspiration was estimated at 365.3 mm at the Upper Mutale Valley and 456.4 mm at Madimbo Corridor. As indicated by DAFF, (2010), dry beans cultivated under rain-fed conditions required a minimum of 400–500 mm rainfall during the growing season; however, an annual total of 600–650 mm was considered ideal. The rainfall condition at Madimbo Corridor was too low for rainfed production of this crop, while that at the Upper Mutale Valley was adequate. Low relative humidity led to flower abscission and low pod set, which is aggravated by low soil moisture. Also, rainfall at the Madimbo Corridor was too low for dryland production of sweet potato, while that at the Upper Mutale Valley seemed adequate.

3.2. Soil conditions and suitability

3.2.1. Soil conditions

The important role of soils in crop production includes the source of support (anchor) to the plant and the supply of nutrients, water, and oxygen. The extent to which the soil can play these roles in the production of crops tends to be influenced by its properties. The soil properties could be categorized as physical, chemical and biological. Physical properties include texture, structure, bulk density and porosity; chemical properties include pH, cation exchange capacity (CEC), base saturation, sodium adsorption ratio (SAR), salinity, and the concentration of specific plant nutrients (e.g. nitrogen, phosphorus, potassium, etc.), while biological properties include content of organic matter, active total carbon, and occurrence of earthworms, nematodes, fungi and bacteria. The various properties are influenced by soil types occurring in the study area (Figure 7).

As mentioned, soil type determines the capacity of the soil to store water and nutrients, and the level of aeration, drainage, and ease of working on the field. In Madimbo Corridor, the soil types were predominantly calcareous and eutrophic, whereas in Upper Mutale Valley the soil type was solely eutrophic (Figure 7). Calcareous soils as observed in Madimbo Corridor have higher contents of calcium carbonates (lime). The soils tend to be in flocculated condition (granulated), have high porosity and are, accordingly, more permeable to water and air; these could be favourable attributes for field crop production. The soils tend to have high pH and are sometimes referred to as alkaline soil. Calcareous soils are formed in arid areas; hence, their occurrence in the low rainfall Madimbo Corridor. Madimbo Corridor had fine-grained sandstone with calcareous concretions (Johnson, *et al.,* 2006). Within the Corridor, the Gumbu Group was characterized predominantly by marbles and calc-silicate rocks with minor greywacke—and for most of the site, the geology was covered by quaternary sediments in which mainly sandy soils have formed (van 't Zelfde, 2019). With regards to the Upper Mutale Valley, soils were described as deep and well drained, with small portions of moderately drained soils in some places (Nethononda and Odhiambo, 2011).

Eutrophic soils were observed in both the Madimbo Corridor and the Upper Mutale Valley and were described as soils with high nutrient loading, resulting in increased availability of the nutrients to plants. The word 'eutrophic' is a Greek word that means 'well fed' (Weaver and Summers, 2001); hence, the eutrophic soils were regarded to be rich with nutrients such as nitrogen and phosphorus. Also, eutrophication can be defined as 'the nutrient enrichment of waters which results in the stimulation of an array of symptomatic changes, among which increased production of algae and macrophytes, deterioration of water quality and other symptomatic changes are found to be undesirable and interfere with water uses' (OECD, 1982). The adverse effects of eutrophication of water bodies necessitate proper management of agricultural soils to reduce the flow of nutrients to the water bodies.

3.2.2. Soil suitability

Land suitability assesses the appropriateness of land for production of crops (Ziadat, 2007). Precisely, land suitability evaluates land capability as well as other factors such as land quality (Malczewski, 2006). Suitability of the soils for production of crops, including those selected for this study, was influenced by soil properties, whether physical or chemical (Table 2). The soil required for optimal maize production should texturally have ≥10 percent clay, effective depth of at least 60 cm and a pH of between 5.8 and 7.0.

The soil condition at Madimbo Corridor was observed to possess a lesser clay proportion (≥5 and ≤10) and higher pH (≥7.0 and ≤8.94) than the crop requirements. Production of the crop in this area tends to require some corrective measures to the soil to allow for optimum yields. To the contrary, the soils at the Upper Mutale Valley were observed to be suitable for maize production considering all the properties— clay percentage (≥16 and ≤32), effective depth (≥120 cm), and pH (≥5.7 and ≤7.2). Although large-scale maize production takes place in soils with a clay content of greater than 10% (sandy soils) or more than 30% (clay and clay-loam soils), the texture classes between 10% and 30% have air and moisture regimes that are optimal for healthy maize production (DAFF, 2003).

Dry bean was reported to require a soil with a clay percentage of between 15 and 35, effective depth of at least 40 cm, and a pH between 5.5 and 7.5. Soils at Madimbo Corridor would be less favourable for dry bean production, especially when clay percentage and pH were considered, while those at the Upper Mutale Valley were suitable in all respects. Sandy loam, sandy clay loam or clay loam soils with a clay content of between 15% and 35% are suitable (DAFF, 2010). As stated in DAFF, (2010), beans grow well in soils with a depth of at least 90 cm, which have no deficiencies and are well drained. As for sweet potato, the soil pH seemed to be a challenge affecting suitability for optimum production of this crop, especially at Madimbo Corridor. Heavy clay soil should be avoided as they can retard root development (DAFF, 2011).

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

(a) Climate suitability

The results for climate suitability for maize, dry bean, and sweet potato production in Madimbo Corridor and Upper Mutale Valley varied for the two assessed climatic factors—temperature and rainfall. The temperature conditions, especially summer temperatures that were minimum >17.4 °C and maximum of about 31°C (both sites) were generally suitable for production of the three selected crops. Proper management of agronomic practices such as planting dates and cultivar selection would be necessary for critical growth stages of the crops not to coincide with unfavourable temperature conditions.

With regards to moisture, Madimbo Corridor received less rainfall (201–400 mm per annum) than the minimum required by each of the three crops—maize (350–450 mm), dry bean (400–500 mm) and sweet potato (360–400 mm per annum) and would generally not be suitable for rainfed production. Contrary to the situation at Madimbo Corridor, the rainfall at the Upper Mutale Valley (401–600 mm and 601–800 mm per annum) sufficed for production of all the three crops under study.

(b) Soil suitability

Results for soil suitability varied for the two study sites. Soils at Madimbo Corridor possessed a rather less clay proportion (≥ 5 and ≤ 10) and higher pH (≥ 7.0 and ≤ 8.94) than the clay proportion of ≥10% and pH of ≥ 5.8 and ≤ 7.0 respectively as required for maize. To the contrary, the soils at the Upper Mutale Valley were observed to be suitable for maize production considering all the properties—clay percentage (≥16 and ≤32), effective depth (≥120 cm), and pH (≥5.7 and ≤7.2). Also, soils at Madimbo Corridor were less suitable for production of dry bean with a requirement of 15%–35% clay content and pH of 5.5–7.5 while those at the Upper Mutale Valley were suitable. Similar results were also reflected for sweet potato.

4.2. Recommendations

Based on the results of the study, it is recommended that:

(a) Decisions on selected crops produced in the ISHAE-WY should consider climatic and soil suitability of such areas.

(b) Where justifiable, crops may be selected for production in the ISHAE-WY, where a factor of climate or soil may not be suitable, and measures should be in place for minimizing the adverse effect of the less suitable factor on crop production. Such measures may include provision of resources for correcting the less suitable climate and soil factors or use of pertinent agronomic practices for minimizing adverse effects of such factors.

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List of figures and tables

6.1. Figures

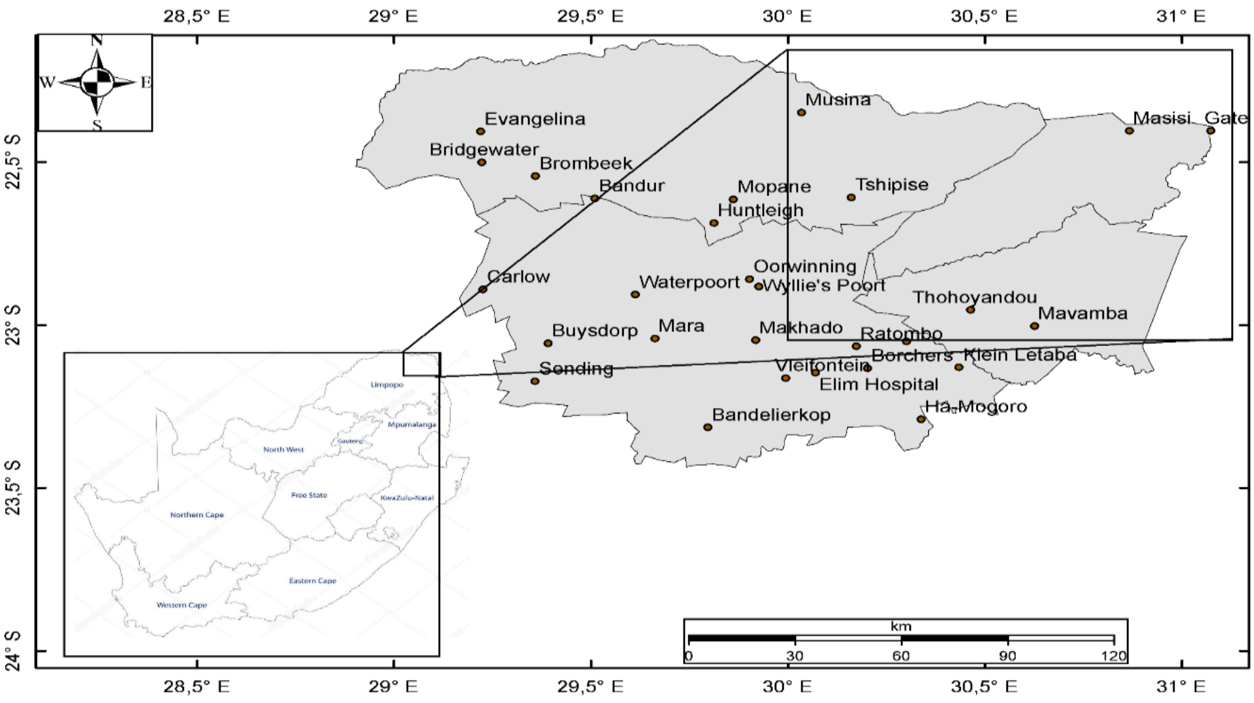

Figure 1 : Location of Madimbo Corridor and Upper Mutale Valley

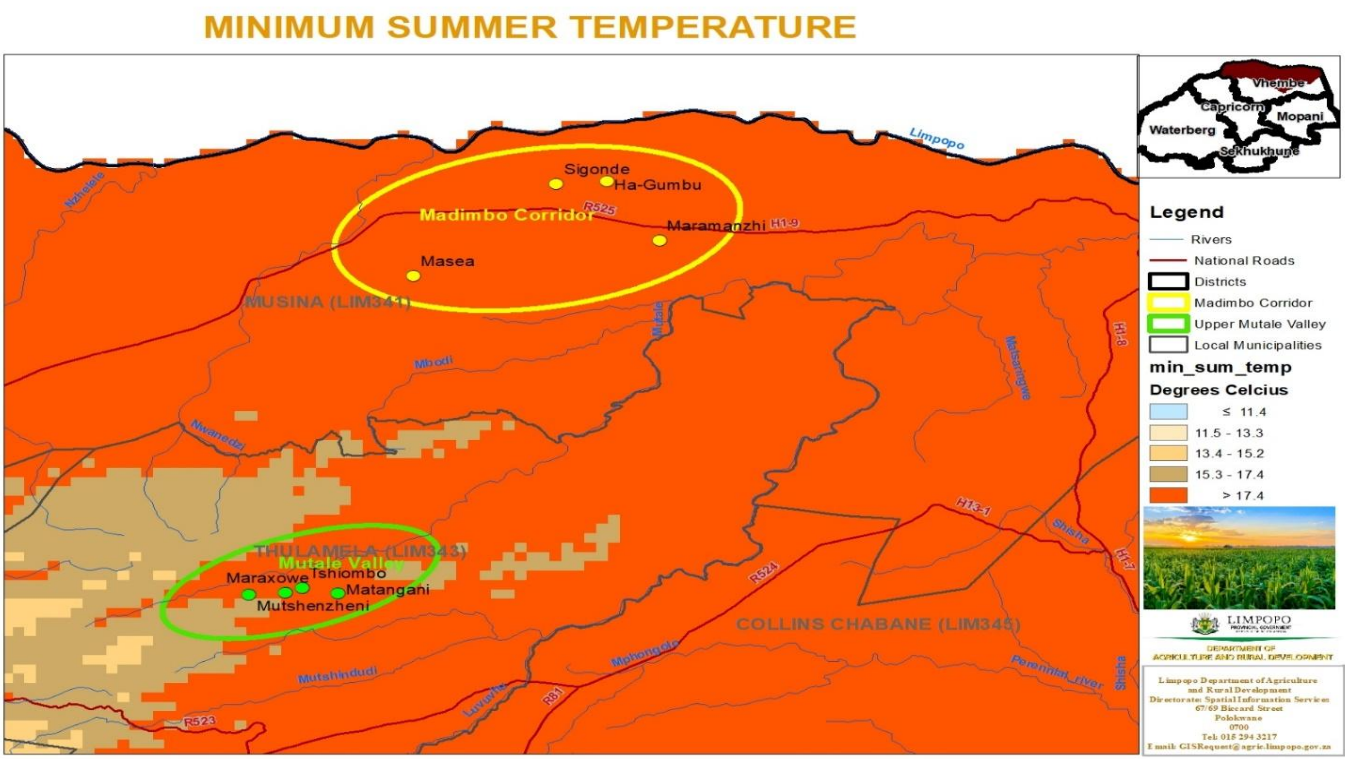

Figure 2. Minimum summer temperature at Madimbo Corridor and Upper Mutale Valley in Thulamela

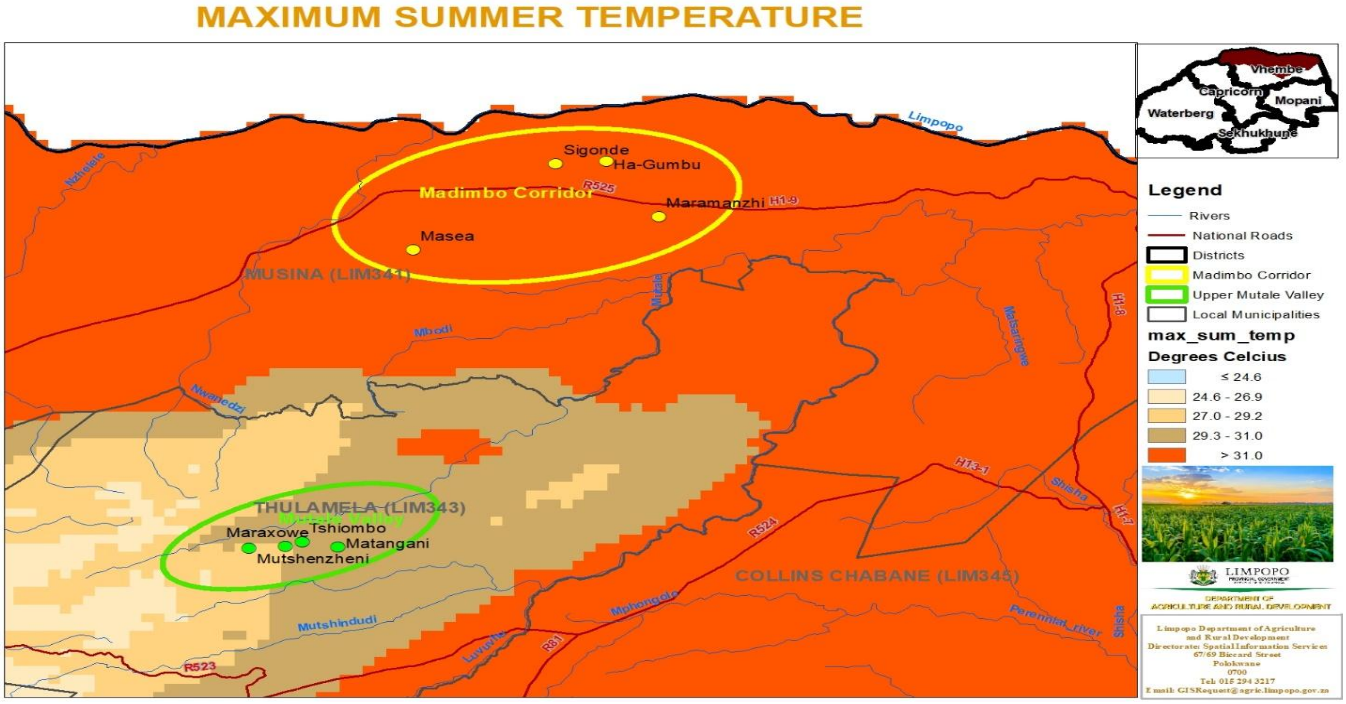

Figure 3: Maximum summer temperature at Madimbo Corridor and Upper Mutale

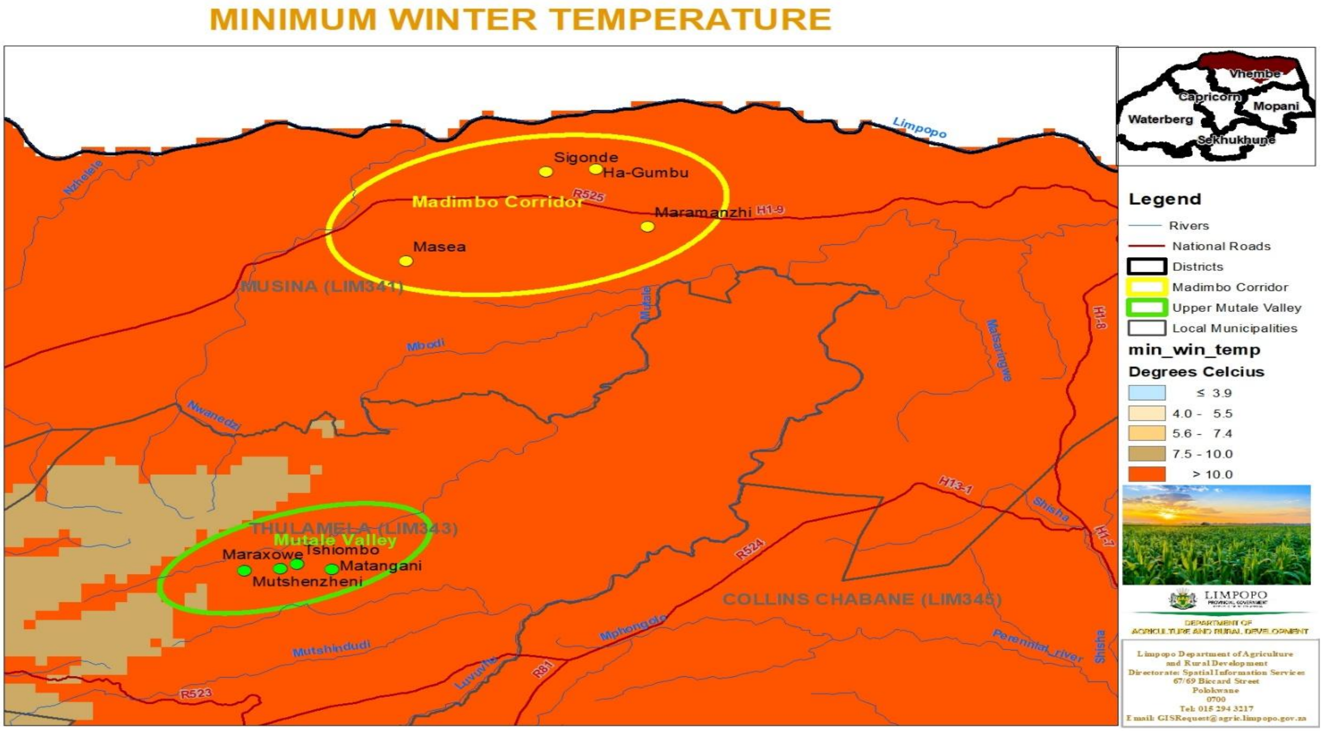

Figure 4: Minimum winter temperature at Madimbo Corridor and Upper Mutale Valley

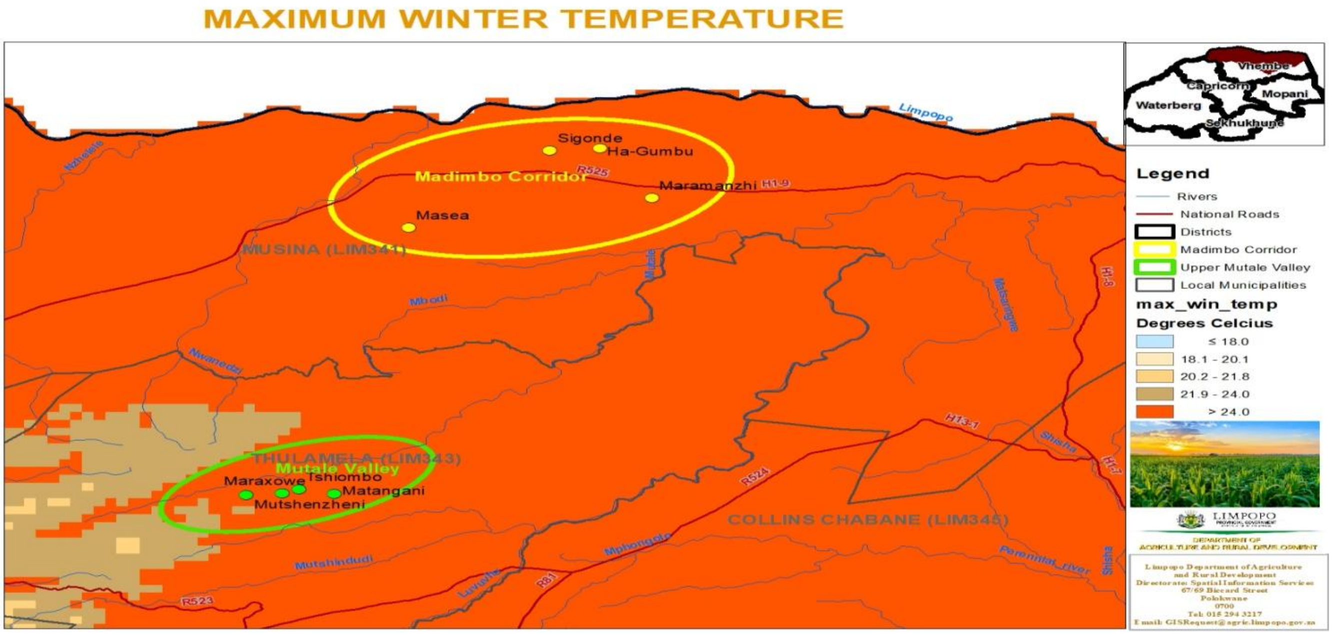

Figure 5. Maximum winter temperature at Madimbo Corridor and Upper Mutale Valley

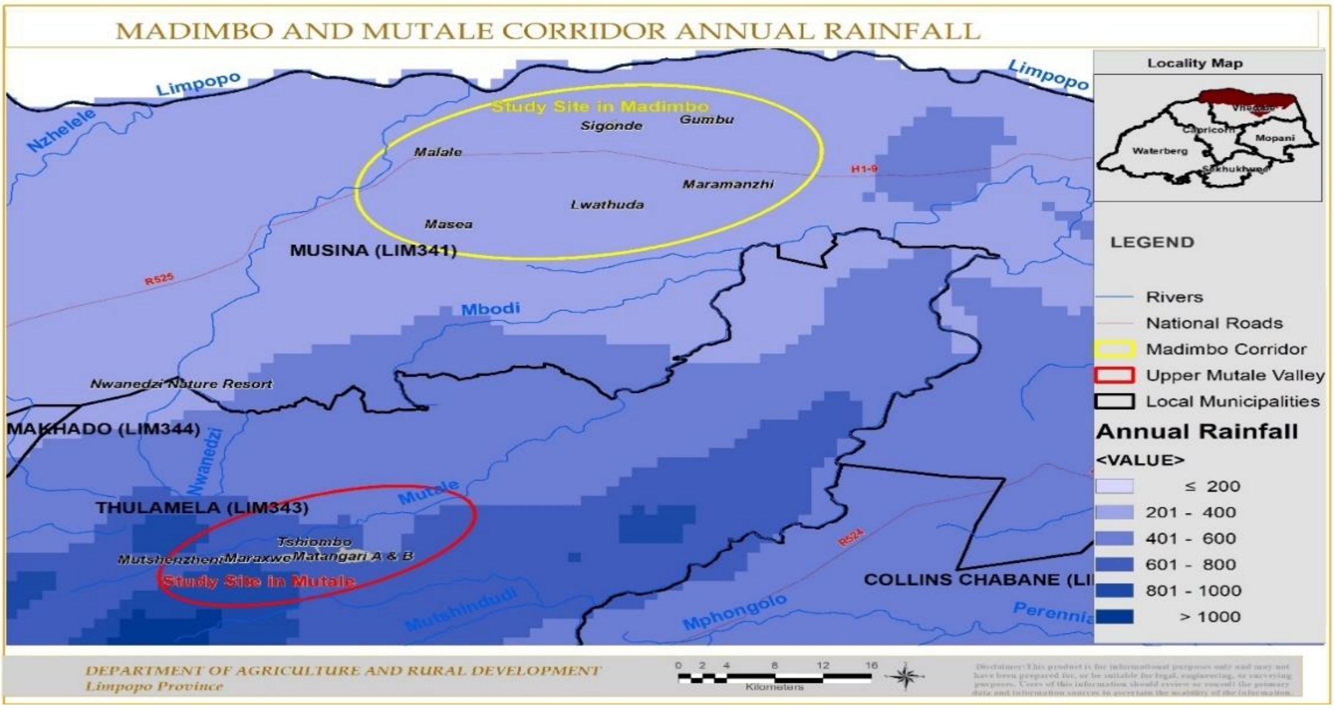

Figure 6: Annual rainfall distribution at Madimbo Corridor and Upper Mutale Valley

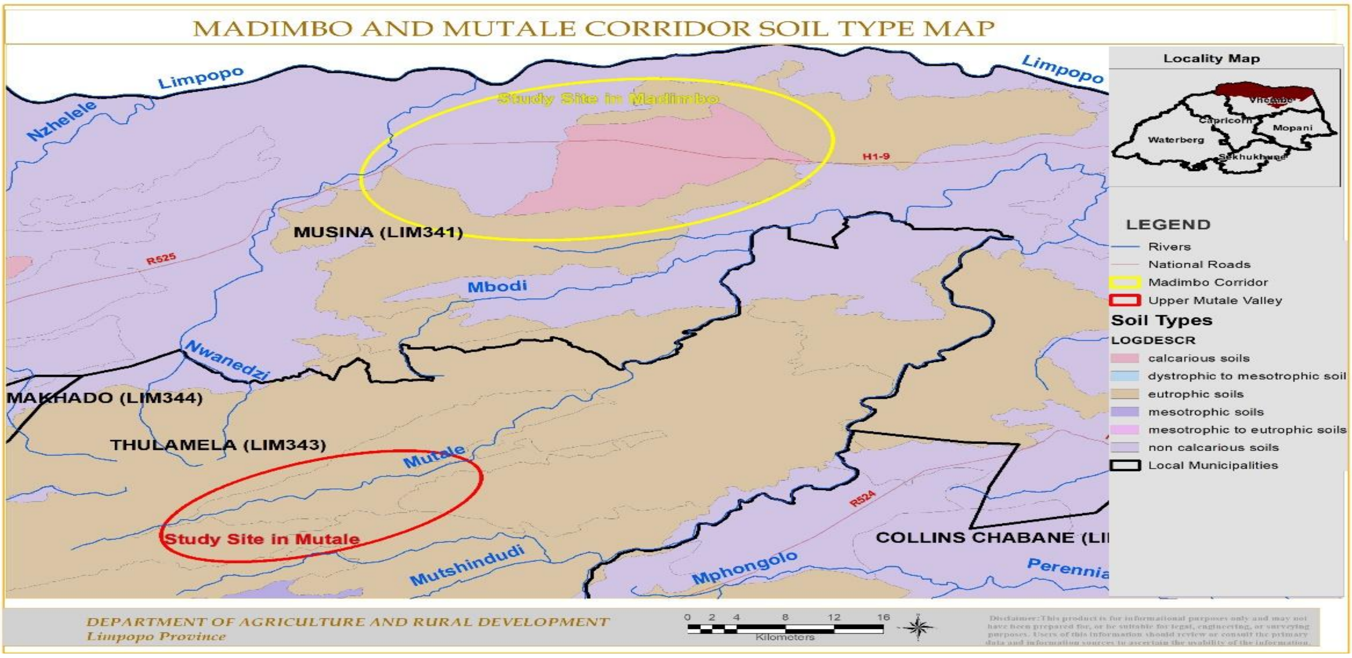

Figure 7: Soil types at Madimbo Corridor and Upper Mutale Valley

Tables

Table 1. Climatic suitability of Madimbo Corridor and Upper Mutale Valley in Vhembe District Municipality of Limpopo province for production of maize *(Zea mays L)*, dry bean *(Phaseolus vulgaris)*, and sweet potato *(Ipomoea batatas L)*

Period	Climatic factor	Production area climatic condition		Selected crops required climatic condition		
		Madimbo Corridor	Upper Mutale Valley	Maize	Dry bean	Sweet potato
Summer	Min temperature (°C)	>17.4	>17.4	21–32	18–24	21–30
			(15.3–17.4)			
	Max temperature (°C)	>31.0	29.3–31			
			(27–29.2; >31)			
Winter	Min temperature (°C)	>10.0	>10.0			
			(7.5–10)			
	Max temperature (°C)	>24.0	>24.0			
			(21.9–24)			
Annual	Rainfall (mm/annum)	201–400	401–600	350–450	400–500	360–400
		(401–600)	601–800			
			(201–400)			

Table 2 Soil suitability for production of maize *(Zea mays L)*, dry bean *(Phaseolus vulgaris)*, and sweet potato *(Ipomoea batatas)* at Madimbo Corridor and Upper Mutale Valley in Vhembe District of Limpopo province, South Africa

Suitable soil data required and available for selected field crops						
		Soil data required by selected crops			**Soil condition at production area**	
Variables	**Category**	**Maize**	**Dry bean**	**Sweet potato**	**Soil condition at Madimbo Corridor**	**Soil condition at Upper Mutale Valley**
Soil physical status	Average clay %	≥10	≥15 and ≤35	≤25	≥5 and ≤10	≥16 and ≤32
	Effective soil depth	≥60 and <90 cm	≥40 cm	≥60 cm	≥30 and <150 cm	≥120 cm
Soil chemical status	pH	≥5.8 and ≤7.0	≥5.5 and ≤7.5	≥4.5 and ≤ 7.5	≥7.0 and ≤8.94	≥5.7 and ≤7.2