Current Research Journal of Biological Sciences 3(4): 273-281, 2011
ISSN: 2041-0778

Received: October 26, 2010 Accepted: November 18, 2010 Published: July 15, 2011

Investigation of the Reasons for the Unique Growth and Development of *Agave* Species (*Agave sisalana* and *Agave americana*) Crop Plants at the Southern, Central, North Western and Eastern Parts of Tigray, Ethiopia

Kinfemichael Geressu Asfaw
Biology Department, College of Natural and Computational Sciences (CNCS),
Mekelle University (MU), P.O. Box: 3112, Ethiopia

Abstract: Composite topsoil samples from 16 study sites were taken and then their physical as well as chemical attributes were determined at the National Soil Testing Center (NSTC). Moreover, plant attributes such as Leaf Length (LL), Leaf Biomass (LB), Fiber Length (FL) and Tensile Strength (TS) were measured. Data analysis was carried out using JMP5 (version 5.0) and SPSS (version 12.0) statistical softwares. The one way analysis of variance (ANOVA) for Leaf Length (LL), Leaf Biomass (LB), and Tensile Strength (TS) showed statistical significance with respect to the study sites ($p<0.0001$). Furthermore, one way ANOVA for tensile strength (TS), Leaf Biomass (LB) and Leaf Length (LL) with respect to blocks found statistically significant at $p<0.0001$, $p<0.001$ and $p<0.05$ respectively. Nevertheless, one way ANOVA for Fiber Length (FL) appeared statistically insignificant ($p>0.05$) with respect of blocks. On the other hand, the one way ANOVA for both soil chemical and physical attributes with respect to blocks found statistically insignificant ($p>0.05$). The rainfall, sunshine, and temperature situations as well as the soil chemical and physical attributes being inline with the requirements of Agave species could be reasons for the unique growth and development of *A. americana* and *A. sisalana* crop plants in the study area.

Key words: Fiber length, leaf biomass, plant attributes, soil attributes, tensile strength

INTRODUCTION

The genus Agave possesses over 300 species where all of them are native to tropical and subtropical North and South America (Gibbon and Pain, 1985). Even if agaves are tropical by origin, there are very few commercial plantations outside the Tropics (Wienk and Schendellaan, 1979). Century plant (*Agave americana*) and sisal (*Agave sisalana*) are among such agaves. They grow from sea level to mountains over 8000 feet above sea level. Agaves have been used for food, drink, soap, clothing, rope and other fibers, needles and thread, paper, glue, medicines, red coloring matter, and as ornamental and hedge plants (Moore, 2008).

Century plant (*A. americana* L.) requires a minimum temperature of 10ºC, full sun exposure and it is extremely heat tolerant. Moreover, it tolerates poor and shallow soil, and drought but it awfully needs an excellent drainage (Faucon, 2005). Furthermore, it needs natural rainfall but it would be better if supplement water is provided once per a month during summer time (Arizona Board of Regents, 2006). The cultivated varieties include the 'marginata' which has yellow strips along the margin of each leaf and 'americana' with entirely green leaves. This crop plant has different uses, for example, it is used to produce the drink called pulque which finally may give mescal upon distillation. Fibers especially pita could be obtained from leaves which are suitable for making rope, matting and coarse cloth. Moreover, pitas are used for embroidery of leather using piteado technique (Wikipedia, 2008).

Sisal (*Agave sisalana*) is a perennial succulent crop with good growing conditions forms an inflorescence after 6-9 years after producing 200-500 leaves and then it dies. Leaves are arranged spirally around the thick stem and their average length is about 120 cm. Sisal has a shallow root system but it extends up to 3.5 m from the stem (UNIDO, 2006). It is essentially a plant of the tropics and subtropics and production benefits from temperature of 25ºC and plenty of sunshine. It survives and produces a marketable product in infertile arid regions which in many cases would be unproductive. Sisal generally prefers a medium or light soil with a pH between 5.5 and 7.5. Where rainfall levels are good, nitrogen can be supplied by growing leguminous cash crops in-between rows. It has a sizeable demand for calcium as a nutrient and also susceptible to Boron deficiency (Bachthaler, 2006). Its leaf tissue yields hard flexible fibers which have different uses (Bachthaler, 2006; UNIDO, 2006). Long fibers (greater than 90 cm long) are used for ropes and binder twine. Approximately, 25% of fibers are shorter (flume tow and tow fiber) and these are used for padding, mat and stair carpet, paper, and building panels. A total of about 300 leaves may be harvested during the economic life of each plant which gives a total of 500-600 tonnes of fibers/ha (Bachthaler, 2006). Sisal accounts for 2/3 of the world production of hard fibers and about ¾ of its consumption is agricultural twine (UNIDO, 2006). It occupies the 6^{th} place among fiber plants; representing 2% of the world's production of plant fibers (plant fibers provide 65% of the world's fibers). After fiber extraction, 95-96% of the leaves' weight still remains and this is used as fertilizer or the dried pulp as a fuel for methane production (Bachthaler, 2006). According to the Mycological Society of America (2004), sisal wastes supplemented with 5% chicken manure had a second best mushroom harvest. In Ethiopia also, in the year 1981/1982 about 2,100 tonnes of sisal waste was used as cattle feed (Alemayehu Mengistu, 2006).

In Ethiopia, the production of both *A. americana* and *A. sisalana* is quite minimal. Nevertheless, most part of the country is semi-arid (Gebre and Georgis, 1988) and it accounts for about 71% of the entire 1.115 million Km^2 land area and about 46% of the arable lands (Reda and Deressa, 1997). Most of the areas being dryland implies that there is a fertile ground and tremendous potential to produce *A. americana* and *A. sisalana* on small-scale basis (by farmers) and on large scale basis. Since the crop is quite labor intensive, it could offer a great deal of job opportunity for the large rural population (Bachthaler, 2006).

Unlike other parts of the country, in Tigray, the crop has flourished and attractive growth. Irrespective of such unique performance and potential, there is hardly any study in examining the reasons for being so. Nevertheless, there must be a profound study so as to examine the main reasons that enabled the crop to achieve such peculiar performance. So that it could be possible to recommend the cultivation of this important crop on both small and large scale basis. Thus the aim of this research was to find out the underlying reasons for the unique growth and development of Agave sp. (*A. americana* and *A. sisalana)* and the status of plant parameters in Tigray, Ethiopia.

MATERIALS AND METHODS

The study site: Tigray is one of the regional states of Ethiopia, where it is located in the northern part of the country (Fig. 1) between 12º15′ to 14º50′ N latitude and 36º27′ to 39º59′ E longitude (Haregeweny *et al*., 2006). The region has an approximate area of 80,000 km^2 where it is bounded by Sudan in the west, by Eritrea in the north, by Amhara regional state in the south, and by Afar regional state in the East (Hagos *et al*., 2002).

The region possesses several agroclimatic zones which mainly emanate from temperature, rainfall and altitude. About 50% of the entire agro-ecological zone is upper kolla dry (22.7%) and weyna dega dry (26.2%). However, the wurch dry area has the smallest coverage in the region and it is found only around Tsibet Mountain in Enda Mekoni Wereda, Southern Tigray (TRFEDB, 1995). In general, rainfall in the region is unpredictable (erratic) and it is common to see both water logging and drought in the same cropping season (Esser *et al*., 2002). The amount of rainfall varies with altitude and also it decreases from south to north but increases from east to west. The average rainfall in the south western highland is about 1000 mm whereas it is about 200 mm in the north east lowlands.

In the region, the temperature varies greatly with altitude but the average temperature is 18ºC. During November, December and January in the highlands of the region the temperature may drop to 5ºC. On the other hand, it may elevate from 28 to 40ºC in the lowlands, Western Tigray around Humera during summer season (Hagos *et al*., 2002). On the other hand, in the region there are about thirteen soil types such as Cambisols, Rendzinas, Lithosols, Acrisols, Fluvisols, Luvisols, Regosols, Nitosols, Arenosols, Vertisols, Xerosols, Solonchacks and Andosols (Hunting Technical Services, 1975 cited in Hagos *et al*. (2002).

Soil samples: This study was conducted from September 2006 to February 2008 at the southern, central, north western and eastern parts of Tigray, Ethiopia in Mekelle University, Biology Department Laboratory and at the National Soil Testing Center (NSTC), Addis Ababa. Composite topsoil samples were taken at a radius of 4 meters from *Agave* sp. (*A. americana* and *A. sisalana)* plant using a spade. Then the samples were mixed thoroughly in a plastic bucket, inserted into soil sample bags and finally the bags were labeled twice (i.e., both internally and externally). Moreover, ring samples (100 mL) were taken for the determination of soil physical attributes. Then the soil samples were analyzed at the National Soil Testing Center (NSTC), Addis Ababa, Ethiopia. The soil chemical attributes measured include pH water (1:2.5, w/v); organic carbon (Walkley-Black); total nitrogen (Kjeldahl); available phosphorous (Olsen); exchangeable cations (Na^+, K^+, Ca^{++} and Mg^{++}), cation exchange capacity or CEC (1M NH4 OAc at pH 7); Calcium Carbonate ($CaCO_3$), Boron content and Electrical Conductivity (EC). On other hand, the soil physical attributes measured were soil texture, Permanent Wilting Point (PWP), Field Capacity (FC) and Bulk Density (BD).

Plant samples: *Agave* sp. (*A. americana* and *A. sisalana)* crop plants were sampled from the Southern, Central,

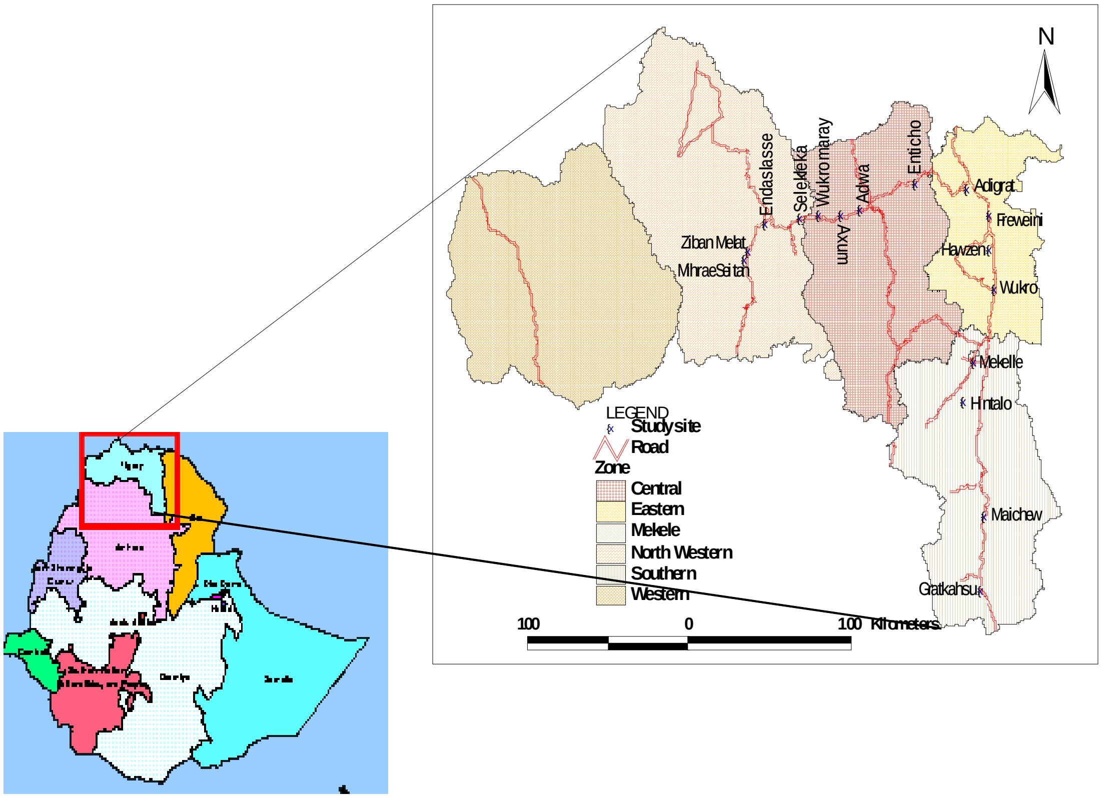

Fig. 1: *Agave* sp. (*Agave americana* and *Agave sisalana*) study sites in Southern, Eastern, Central and North Western Zones of Tigray

Eastern and North Western parts of Tigray, Ethiopia. From each site, four different Agave species crop plants were sampled. Then from each plant, six ripen leaves were sampled and their lengths were measured (in centimeter). Out of the six leaves measured, three were cut using a cutter, labeled and the biomass possessed by each leaf was measured in terms of leaf fresh weight (in grams).Then the leaves were transported to Mekelle University (MU) and were decorticated manually. Then the length of the longest possible fibers and Fiber Tensile Strength (TS) were determined at G-Seven Trading & Industry P.L.C., Meher Fiber Products Factory, Addis Ababa.

Statistical analysis: Data analysis was carried out by JMP5 (Version 5.0) statistical software where one way analysis of variance (ANOVA) and correlation analysis were carried out.

RESULTS AND DISCUSSION

Soil attributes: One way analysis of variance (ANOVA) for all soil chemical attributes (TN, O.C., Na^+, K^+, Ca^{++}, Mg^{++}, CEC, Av. P, AV.B, BSP, SAR, ESP, EC and pH) and physical attributes (soil texture, FC, PWP, BD and AWC) with respect to blocks found statistically insignificant ($p>0.05$).

Soil chemical attributes: *Agave* sp. in general and sisal in particular need soil total nitrogen (TN) content of more than 0.15% and C/N ratio of around 10 (Kimaro *et at*., 1994). In the present study, Adigrat, Gratkasu, Adwa, Hawzen, Wukromaray and Enticho had total nitrogen content of 0.308, 0.174, 0.169, 0.157, 0.155 and 0.152%, respectively which is well above the optimum amount of soil total nitrogen required by sisal. However, the remaining study sites had total nitrogen content from 0.028-0.136% (Fig. 2). Even if most of the study sites had total nitrogen content below the optimum value, it would not be a problem for the growth and development of *A. sisalana* and *A. americana*. This is because it has already been reported that nitrogen can be supplied by growing some legume cash crops in between rows of sisal provided that the rainfall level is good (Bachthaler, 2006). Likewise Gratkasu, Mekelle, Maichew, Axum, Enticho, Wukro, Adigrat and Endabaguna study sites had C/N value above 10 which is well beyond the optimum standard for sisal cultivation. Moreover, the rest study sites had C/N ratio closer to the optimum standard value, 7-9.

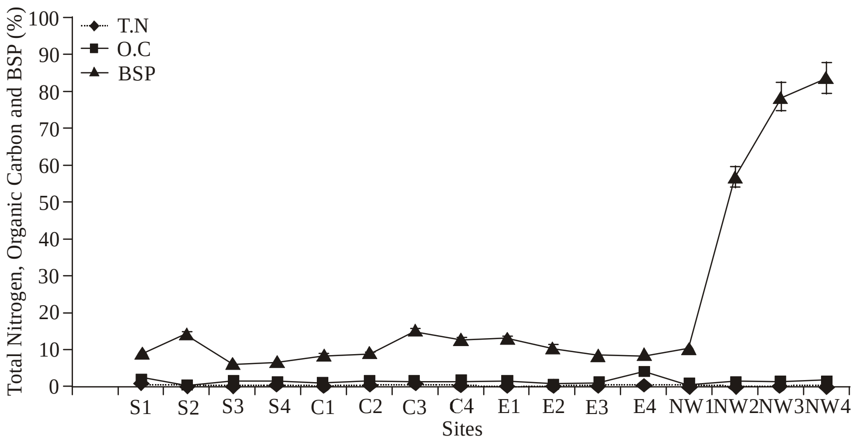

Fig. 2: Total Nitrogen (TN), Organic carbon (OC) and Base saturation Percentage (BSP) of soil samples from different study sites. (Key: S_1= Gratkahsu, S_2= Hintalo, S_3= Mekelle, S_4= Maichew, C_1= Axum, C_2= Enticho, C_3= Adwa, C_4= Wukromaray, E_1= Hawzen, E_2= Freweini, E_3= Wukro, E_4= Adigrat, NW_1= Selekleka, NW_2= Zibanmelat, NW_3= Endaselasse and NW_4= Mihrae Seitan)

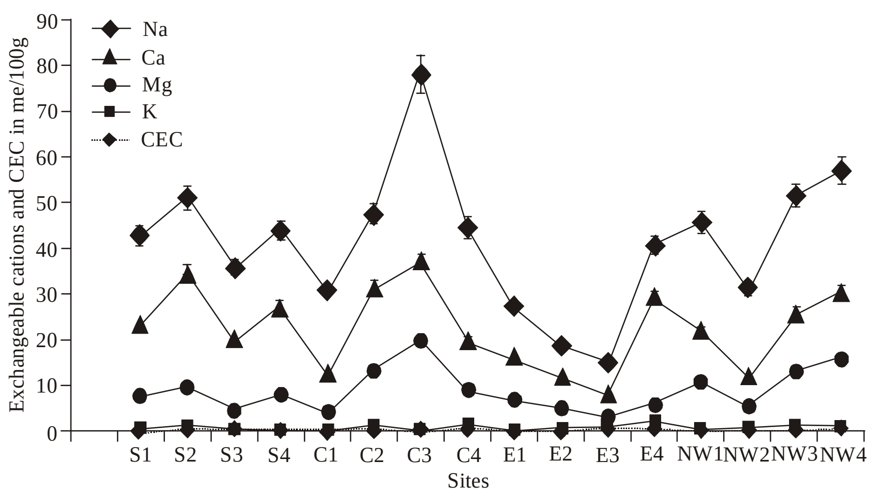

Fig. 3: Exchangeable sodiun (Na^+), exchangeable potassium (K^+), Exchangeable Sodiun (Ca^{+2}), Exchangeable Potassium (Mg^{+2}) and Cation Exchange Capacity (CEC) values of soil samples from different study sites. (Key: S_1= Gratkahsu, S_2= Hintalo, S_3= Mekelle, S_4= Maichew, C_1= Axum, C_2= Enticho, C_3= Adwa, C_4= Wukromaray, E_1= Hawzen, E_2= Freweini, E_3= Wukro, E_4= Adigrat, NW_1= Selekleka, NW_2= Zibanmelat, NW_3= Endaselasse and NW_4= Mihrae Seitan)

On the other hand, soil samples from Gratkasu, Enticho, Adigrat and Miraeseitan contained low (OC, 1996) soil organic carbon content, 1.696-3.711%. But the remaining study sites had very low*soil organic carbon content, 0.2 to 1.237% (Fig. 2). Even if most of the study sites had low soil organic carbon content; since *A. sisalana* and *A. americana* could survive in infertile arid regions (Bachthaler, 2006), the very low soil organic carbon content would not be a problem for their cultivation in most of the study sites. In line with this, Kimaro *et al*. (1994) has pointed out that even if organic carbon is important for sisal cultivation as nitrogen and magnesium are, it's content being low does not seem to be a problem, especially for surface soils.

For sustained sisal cultivation, soil fertility is a liming factor. It could be showed using its simple index, Base Saturation Percentage (BSP) (Kimaro *et al*., 1994). In the present study, soil samples from Endaselasse and Miraeseitan had BSP of 78 and 84%, respectively. This implies that these two study sites are equipped with highly* fertile soil. On the other hand, study sites like Enticho, Adwa, Hawzen, Freweini, Selekleka and Zibanmelat had moderately*fertile soil with the BSP value of 23 to 29%. The remaining study sites had soil with low*fertility level, having 13 to 19% BSP (Fig. 2). Notwithstanding, none of the study sites had infertile soils. Thus all study sites are suitable for *A. sisalana* and *A. americana* cultivation with respect to soil fertility.

Sisal has high demand for exchangeable cations such as calcium, magnesium and potassium (Hartemink and Bridges, 1995). More specifically, sisal needs exchangeable potassium (K^+) and exchangeable calcium (Ca^{2+}) of more than 0.3 me/100 g dry soil with a pH (H_2O) between 6 and 7 in topsoil (Kimaro *et al*., 1994). In the present study, soil samples from all the study sites except Maichew, Adwa, Hawzen and Selekleka had exchangeable potassium above 0.3 me/100 g dry soil. Moreover, the exchangeable Ca^{+2} content of all the study sites was well above 7 me/100 g dry soil. Especially, study sites such as Gratkasu, Hintalo, Maichew, Axum, Enticho, Adigrat, Selekleka, Endaselasse and Endabaguna had exchangeable Ca^{+2} above 20 me/100 g dry soil (Fig. 3). On the other hand, in all the study sites, the amount of exchangeable magnesium was 2.90-19.74 me/100 g dry soil which is sufficient enough for *A. sisalana* and *A. americana* growth and development.

The exchangeable Ca^{+2} and Mg^{+2} contents being sufficient enough for sisal and century plant growth and development indicates the presence of optimum soil Cation Exchange Capacity (CEC). In this study, soils of all the study sites had CEC value of 15.2 me/100 g dry soil and above. Particularly, Gratkasu, Hintalo, Maichew, Enticho, Adwa, Wukromaray, Agigrat, Selekleka, Endaselasse and Miraeseitan study sites had very high CEC value, 40.6 to 78.2 me/100 g dry soil (Fig. 3). The CEC value being the highest in the above study sites indicates the absence of very strong acid soil reaction that might have an adverse effect on the growth and development of sisal (Hartemink and Bridges, 1995). This is because when CEC is high the soil will retain and release nutrients including trace elements optimally (Wang *et al*., 2003) and the resulting optimum amount of exchangeable Ca^{++} and Mg^{++} buffer the soil pH nearly to neutral (Hossain *et al*., 2003).

Boron is one of the essential micronutrients for plants. Some plants are more susceptible to boron deficiency and toxicity than others (Ross *et al*., 2006). Sisal is one of such crop plants susceptible to boron deficiency (Bachthaler, 2006). In this study, Hintalo, Wukromaray and Endaselasse study sites had boron content of 0.44, 0.46 and 0.434 ppm, respectively which is rated as the possibly deficient level (Soil Boron deficiency level rating is based on Booker Tropical Soil Manual, 1996). On the other hand, Gratkasu, Mekelle, Maichew, Axum, Enticho, Freweini, Adwa, Adigrat and Mihraeseitan study sites had soil boron content of 0.578-1.170 ppm which is rated as the borderline for boron deficiency. However, soil samples from Wukro, Selekleka and Zibanmelat contained boron content of 1.682, 1.572 and 1.872 ppm, respectively which is rated as satisfactory (OC, 1996) for most crops (Fig. 4). There was no boron deficiency all over the study sites. This might be due to the high pH and CEC values, reasonable amount of organic carbon, fine-textured and less freely drained soil. In line with this, Shorrocks (1997) reported that boron deficiency is more frequent on course-textured and freely drained soils, soils with low pH and low organic carbon content than on fine-textured and less freely drained soils.

In study sites such as Hintalo, Maichew, Adwa, Hawzen and Endaselasse, the soil available phosphorous content was trace. However, in all the rest study sites it varied from 0.07 to 2.98 ppm where it is rated as low phosphorous content for plant growth (Fig. 4). The low as well as trace phosphorus contents in all the study sites might be attributed to the soil high pH value. This is because except Axum (pH 5.5), all the study sites had pH value above 5.5. According to Hartemink and Bridges (1995) when the soil pH is over 5.5, there will be no exchangeable aluminum and consequently the capacity for phosphorus fixation will be quite minimal in the soil. Even if the available phosphorus is low in most of the study sites, it would not be a problem for sisal cultivation as it often occurs at low concentration in soil solution as compared to other major nutrients (Alam, 1994).

Sisal needs a pH between 5.5 and 7.5 (Bachthaler, 2006). Since it is a calcicole plant, it will be affected seriously by acidic soil, and pH below 5.0 limits its growth (Rijkebusch and Osborne, 1965 cited in Hartemink *et al*., 1996). In the present study, soil of all the study sites had pH H_2O (1:2.5) and EC values between 5.5 and 8.00 and 0.064 to 1.035 dS/m, respectively. This indicates the presence of optimal background soil chemical matrices (Wang *et al*., 2003). Moreover, Hintalo, Mekelle, Maichew, Enticho, Wukro, Adigrat and Endabaguna study sites had pH H_2O (1:2.5) value of 7.6, 8.0, 7.5, 7.3, 7.3, 7.5 and 7.3, respectively. Thus these study sites are quite suitable for sisal cultivation. Because it had already been reported that a pH above 7 may lead to favorable soil physical conditions as the clay complex will be dominated by exchangeable calcium (Hartemink and Bridges, 1995).

Furthermore, the Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR) of soil samples from all the study sites lied between 0.201-0.97% and 1.8-8.6%, respectively. But soil sample from Mekelle had 20.1% Sodium Adsorption Ratio (SAR). Generally the pH, EC, ESP and SAR values of the entire study sites assured the absence of threats for soil salinity as well as alkalinity. Thus the study sites had normal and conducive soil chemical situations for Agave species (*A. americana* and *A. sisalana*) growth and development.

Soil physical attributes: Clay, clay loam and silt topsoils may have bulk density (BD) within the range 1 to 1.6 g/cm^3 depending on their condition. On the other hand, bulk density of sand and sandy loam soil displays

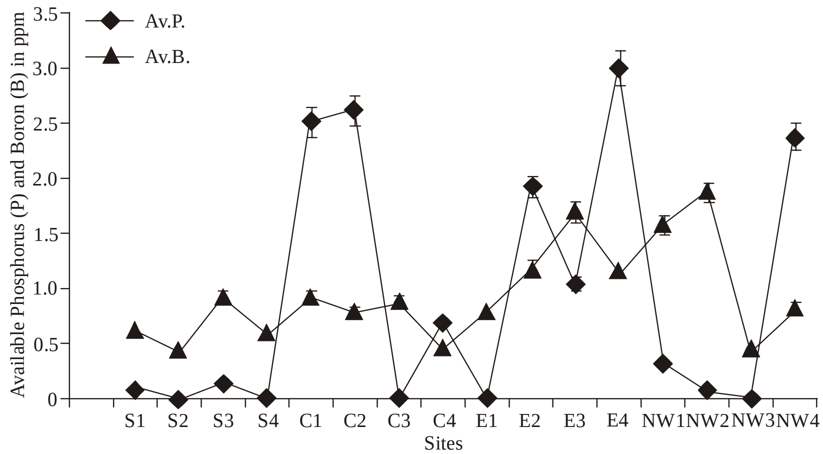

Fig. 4: Available Phosphorus (P) and available Boron (B) content (ppm) of soil samples collected from different study sites. (S_1= Gratkahsu, S_2= Hintalo, S_3= Mekelle, S_4= Maichew, C_1= Axum, C_2= Enticho, C_3= Adwa, C_4= Wukromaray, E_1= Hawzen, E_2= Freweini, E_3= Wukro, E_4= Adigrat, NW_1= Selekleka, NW_2= Zibanmelat, NW_3= Endaselasse and NW_4= Mihrae Seitan)

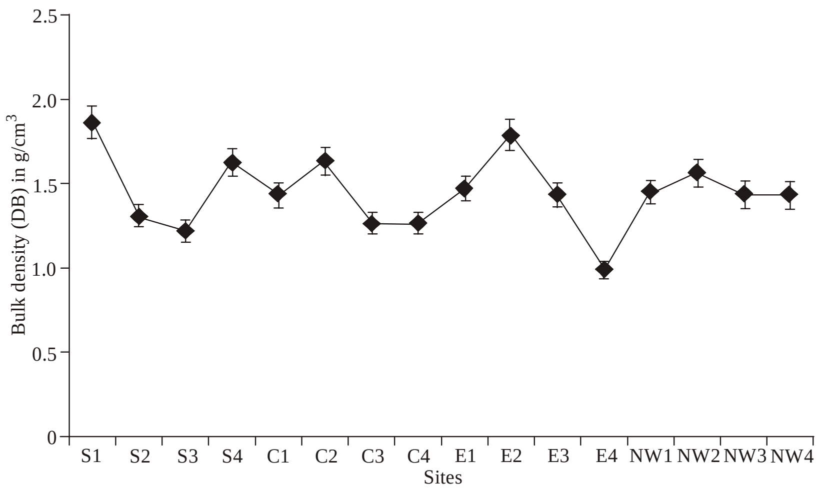

Fig. 5: Bulk Density (BD) of soil samples collected from different study sites. (S_1= Gratkahsu, S_2= Hintalo, S_3= Mekelle, S_4= Maichew, C_1= Axum, C_2= Enticho, C_3= Adwa, C_4= Wukromaray, E_1= Hawzen, E_2= Freweini, E_3= Wukro, E_4= Adigrat, NW_1= Selekleka, NW_2= Zibanmelat, NW_3= Endaselasse and NW_4= Mihrae Seitan)

variations between 1.2 and 1.8 g/cm^3. However, bulk density above 1.75 g/cm^3 for sands and from 1.46 to 1.63 g/cm^3 for silts and clays are reported as causing hindrance to root penetration and soil aeration in different soil horizons (Landon, 1996). In this study, except soil samples from Gratkasu (1.86 g/cm^3) and Freweini (1.78 g/cm^3) which contained BD above the optimum limit for the respective soil texture types, the rest study sites had soil bulk density within the optimum standard for the respective soil texture type (Fig. 5). In the above two study sites, root penetration might be restricted; however, since *A. sisalana* and *A. americana* have shallow root system (UNIDO, 2006; Decker *et al*., 2001) it would not be a problem for sisal and century plant cultivation.

In this study, clay soil textural class is the dominant soil texture type (Adigrat, Enticho, Wukromaray, Adwa, Hawzen, Freweini, Endaselasie and Endabaguna) followed by sandy loam textural class (Gratkahsu, Mekelle, Maichew, Axum and Wukro). Clay loam (Selekleka and Zibanmelat) and loamy sand (Hintalo) textural classes were also found. On the other hand, soil moisture content at Field Capacity (FC), Permanent Wilting Point (PWP) and Available Water Capacity (AWC) was high at Adigrat, Adwa, Hintalo, Wukromaray, Selekleka and Endaselassie study sites. Nevertheless, Wukro, Freweini and Maichew study sites

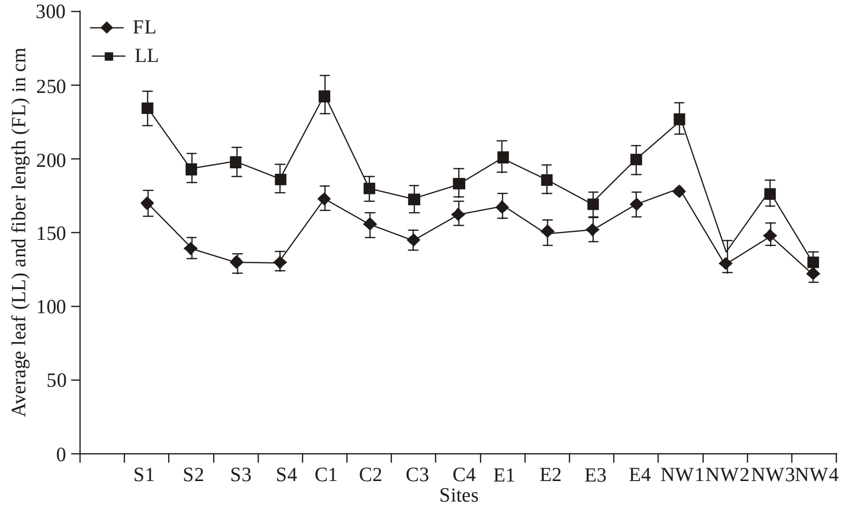

Fig. 6: Average Fiber Length (FL) and average Leaf Length (LL) of leaf samples collected from different study sites. (S_1= Gratkahsu, S_2= Hintalo, S_3= Mekelle, S_4= Maichew, C_1= Axum, C_2= Enticho, C_3= Adwa, C_4= Wukromaray, E_1= Hawzen, E_2= Freweini, E_3= Wukro, E_4= Adigrat, NW_1= Selekleka, NW_2= Zibanmelat, NW_3= Endaselasse and NW_4= Mihrae Seitan)

had the least soil moisture content at FC, PWP and AWC. The remaining study sites possessed moderate soil moisture content at FC, PWP and AWC. The different soil moisture retention levels in most of the study sites ranged from moderate to high. Thus along with the optimal bulk densities such soil moisture regimes and soil textural classes may lead to favorable soil physical situations for the growth and development of *A. sisalana* and *A. americana*. In general, almost all the study sites had optimum soil physical conditions for cultivation of *A. sisalana* and *A. americana*. As Kimaro *et al*. (1994) reported sisal could thrive well on a variety of soils, provided that they are friable, freely draining, well structured and adequately porous.

Both *A.sisalana* and *A.americana* require a minimum of 10ºC temperature, plenty of sunshine and annual rainfall of 1200-1500 mm which is fairly distributed, with a maximum and dry season months (with less than 70mm of rainfall). According to the information from the National Meteorological Agency, NMA (2008), Mekelle branch; Adwa (Central Zone), Maichew (Southern Zone), Endaselasse (N. Western Zone), and Freweini (Eastern Zone) had 10 years average temperature, sunshine, and rainfall of 20.15, 16.24, 20.65 and 18.03ºC; 4.48 h, 7.37, 8.23 and 8.6 h; 814.84, 814.84, 1016.47 and 571.84 mm, respectively. Thus this implies that the climatic situations of almost all the study sites found to be favorable for *A. sisalana* and *A. Americana* cultivation in most of the study sites.

Plant attributes:

Leaf Length (LL): One way ANOVA for average leaf length (LL) with respect to sites and blocks showed statistical significance at $p<0.0001$ and $p<0.001$, respectively. Agave species leaves sampled from Hawzen, Selekleka, Gratkahsu and Axum possessed average length of 2.01, 2.27, 2.34 and 2.43 m, respectively. On the other hand, Agave species (*A. americana* and *A. sisalana*) leaves collected from all other study sites had average leaf length in the range 1.30 to 1.99 m (Fig. 6).

Fiber Length (FL): One way ANOVA for Average Fiber Length (FL) with respect to blocks was statistically insignificant ($p>0.05$) but it showed statistical significance with respect to sites ($p<0.05$). Agave species (*A. americana and A. sisalana*) fibers extracted from leaves collected from Freweini, Wukro, Enticho, Wukromaray, Hawzen, Adigrat, Gratkahsu, Axum and Selekleka contained a length of 1.5, 1.52, 1.55, 1.62, 1.67, 1.69, 1.7, 1.73 and 1.78 m, respectively. On the one hand, Agave species fibers obtained from sisal leaves sampled from all the rest study sites possessed average fiber length from 1.22 to 1.48 m (Fig. 6).

Tensile Strength (TS): One way ANOVA for average tensile strength (TS) of Agave species(*A. americana and A sisalana*) fiber with respect to blocks and sites displayed statistical significance at $p<0.0001$. Agave species fibers extracted from leaf samples collected from Enticho, Hawzen, Mekelle, Hintalo, Gratkahsu, Freweini, Axum, Wukromaray, Adwa , Zbanmelat and Mihrae Seitan had Tensile Strength (TS) of 1.03,1.03, 1.03,1.13, 1.17,1.20, 1.23, 1.57, 2.73, 5.93 and 6.20 Kg/mm^2 respectively. Agave species fibers extracted from leaf samples from all the rest study sites had tensile strength from 0.53 to 0.77 Kg/mm^2.

Leaf Biomass (LB): One way ANOVA for average Agave species leaf biomass (LB) showed statistical significance with respect to sites ($p<0.0001$) and blocks ($p<0.05$). Agave species leaf samples collected from Adigrat, Wukromaray, Maichew, Hawzen, Hintalo, Selekleka and Gratkahsu had average leaf biomass of 6.00, 6.67, 6.83, 7.00, 7.17, 9.33 and 9.33, respectively. On the other hand, Agave species leaves sampled from all other study sites contained average leaf biomass from 1.00 to 5.55 Kg.

The Agave species (*A. americana* and *A. sisalana*) fiber length lied above one meter which is much beyond the factory standard ($\geq$90 cm) in all the study sites. Moreover, Leaf Biomass (LB) in all the study sites had above 1Kg fresh weight. This ascertains the presence of quite fertile ground to cultivate *A. americana* and *A. sisalana* for industrial consumption. That is to produce ropes and binder twine (from long fibers) padding, mat and stair carpet, paper and building panels. Furthermore, the residue (waste matter) could be used to produce cattle feed, fertilizer, methane and so on.

CONCLUSION

The suitable climatic situations (rainfall, sunshine and temperature), soil chemical attributes such as Sodium Adsorption Ratio (SAR), Exchangeable Sodium Percentage (ESP), pH, the Electrical Conductivity (EC), exchangeable cations, total nitrogen, organic carbon, available phosphorus, available boron, CEC; and soil physical attributes like Field Capacity (FC), Permanent Wilting Point (PWP), Available Water Capacity (AWC) and Bulk Density (BD) had ideal and optimum value for plant growth in most of the study sites. Therefore, they are the likely reasons for the unique growth and development of *A. americana* and *A. sisalana* crop plants in Tigray, Ethiopia.

On the other hand, the average Fiber Length (FL) and Leaf Biomass (LB) lied above 1meter and 1kg respectively. Thus this indicates the presence of a huge potential to cultivate *A. americana* and *A. sisalana* for industrial consumption in the study area especially study sites like Mekelle, Freweini, Wukro, Adigrat, Axum, Selekleka and Zibanmelat.

ACKNOWLEDGMENT

I would like to express my heartfelt thanks to NORAD II Research Award, for its financial assistance. Moreover, I am greatly indebted to Mekelle University (MU), Department of Biology for its assistance in providing laboratory and laboratory equipments. My thanks also extends to the general manager of G-Seven Trading & Industry P.L.C., Meher Fiber Products Factory and the National Meteorological Agency, Mekelle Branch for their contribution in measuring Tensile Strength (TS), and providing ten years meteorological data respectively. Furthermore, I would like to thank Mr. Solomon Heshi for his assistance in study sites graphical representation and also Mr. Gidey Yirga for his contribution during data analysis. Finally my great gratitude and thanks goes to Mr. Hayal Lemma and Mr. Gebru Equar for their genuine technical support during field data collection.

REFERENCES

Alam, S.M., 1994. Nutrient Uptake by Plants under Stress Conditions. In: Pessarakli, M. (Ed.), Handbook of Plant and Crop Stress, Marcel Dekker, Inc., New York, pp: 227-246.

Alemayehu Mengistu, 2006. Retrieved from: http://www.fao.org/AG/agp/agpc/doc/countprof/Ethiopia/Ethiopia.htm/, (Accessed on: November 9, 2006).

Arizona Board of Regents, 2006. Retrieved from: http://cals.arizona.edu/pima/gardening/aridplants/Agave_americana.html, (Accessed on: November 22, 2006).

Bachthaler, G., 2006. Retrieved from: http://www.nnfcc.co.uk/Crops/info/Sisal.htm/, (Accessed on: June 25, 2006).

Deckers, J., L.E. Ngatunga and E.H. Msafiri, 2001. Sisal: Agave Sisalana Perrine. In: Raemaekers, H.R. (Ed.), Crop Production in Tropical Africa, Brussels, Belgium, pp: 1076-1082.

Esser, K., T.G. Vagen, Y. Tilahun and M. Haile, 2002. Soil conservation in Tigray, Ethiopia. Noragric Report No.5, Noragric, Center for International Environment and Development studies, Agricultural University of Norway (NLH), Norway.

Faucon, P., 2005. Retrieved from: http://www.desert-tropicals.com/Plants/Agavaceae/Agave_americana.html, (Accessed on: December 20, 2005).

Gebre, H. and K. Georgis, 1988. Sustaining crop production in the semi-arid areas of Ethiopia. Eth. J. Agric. Sci. 10(1-2): 99-107.

Gibbon, D. and A. Pain, 1985. Crops of the Drier Regions of the Tropics. Longman Group Ltd., London, pp: 157.

Hagos, F., J. Pender and N. Gebreselassie, 2002. Land Degradation and Strategies for Sustainable Land Management in the Ethiopian Highlands: Tigray Region. 2nd Edn., Socio-economics and Policy Research Working Paper 25. ILRI (International Livestock Research Institute), Nairobi, Kenya, pp: 80.

Haregeweny, N., J. Poesen, J. Nyssen, J. Dewit, M. Haile, G. Govers and S. Deckers, 2006. Reservoirs in Tigray (Northern Ethiopia): Characteristics and Sediment deposition problems. Land Degrad. Dev., 17: 211-230.

Hartemink, E.A. and M.E. Bridges, 1995. The influence of parent material on soil fertility degradation in the coastal plain of Tanzania. Land Degradation and Rehabilitation, 6: 215-221.

Hartemink, E.A., F.J. Osborne and A. Ph Kips, 1996. Soil fertility decline and fallow effects in ferralsols and acrisols of sisal plantations in Tanzania. Expt. Agric., 32: 173-184.

Hossain, M.F., F.S. Elahi and M. Khondaker, 2003. A Comparison Between Ecological and Conventional Rice Farming Systems in Bangladesh. Diffuse Pollution Conference, Dublin.

Kimaro, N.D., M.B. Msanya and Y. Takamura, 1994. Review of sisal production and research in Tanzania. Afr. Stud. Monogr., 15(4): 227-242.

Landon, J.R., 1996. Booker Tropical Soil Manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Booker Tate Limited, London, pp: 474.

Moore, H., 2008. Retrieved from: http://www.coopext.colostate.edu/TRA/PLANTS/chinlecactus.html, (Accessed on: March 15, 2008).

Mycological Society of America (MSA), 2004. Retrieved from: http://www.mycologia.org/cgi/content/full/96/2/197, (Accessed on: April 13, 2004).

NMA, 2008. National Metrological Agency, Mekelle Branch.

OC, 1996. Soil Organic Carbon (OC) content and soil fertility level rating is based on Booker Tropical Soil Manual.

Reda, F. and A. Deressa, 1997. Profile: Melkassa Agricultural Research Center, pp: 17.

Ross, R.J., A.N. Slaton, R.K. Brye and E.R. Delong, 2006. Boron fertilization influences on soybean yield and leaf and seed Boron concentrations. Agron. J., Vol. 98.

Shorrocks, M.V., 1997. The occurrence and correction of boron deficiency. Plant Soil, 193: 121-148.

TRFEDB, 1995. Tigray Regional State Finance and Economic Development Bureau, Physical Planning Department, GIS Center. Mekelle.

UNIDO, 2006. Retrieved from: http://www.unido.org/doc/8447, (Accessed on: February 11, 2006).

Wang, Z., C.A. Chang, L. Wu and D. Crowley, 2003. Assessing the soil quality of long-term reclaimed wastewater-iirigated cropland. Geoderma, 114: 261-278.

Wienk, F.J. and A. van Schendellaan, 1979. Sisal and Relatives. In: Simmonds, W.N. (Ed.), Evolution of Crop Plants. Longman Group Ltd., London, pp: 1-4.

Wikipedia, 2008. Retrieved from: http://www.en.wikipedia.org/wiki/Agave_americana, (Accessed on: 25 January, 2008).