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# RELATIONSHIPS BETWEEN VEGETATION COMPOSITION AND ENVIRONMENTAL VARIABLES IN THE BORANA RANGELANDS, SOUTHERN OROMIA, ETHIOPIA

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**ABSTRACT**: Topography, climate and soil are the three important environmental abiotic factors that affect vegetation composition in rangelands. Determination of environmental factors that are responsible for the spatial distribution and abundance of vegetation is useful in ecological restorations and grazing land use planning. This study was conducted in the Borana lowlands to quantitatively explore relationships between vegetation composition and abiotic environmental factors. A combination of stratification and systematic random sampling techniques were employed to collect vegetation and environmental data in 58 plots of 500 m$^2$ size. Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCA) were used to detect patterns of vegetation variation that were explained by the assessed environmental variables. CCA and RDA ordination diagrams revealed that the composition and distribution of both woody and herbaceous vegetation were mainly determined by altitude, soil pH, calcium, cation exchange capacity and magnesium. Density of woody plants was negatively correlated with altitude. Species richness was positively correlated with sand and altitude but negatively correlated with soil nutrients and clay content. It is concluded that the measured environmental variables significantly account for variation in the composition and distribution of the plant species composition in the Borana lowlands. Therefore, rangeland managers should incorporate environmental factors in planning and implementing restoration activities and planning grazing land use.

**Key words/phrases:** *Abiotic environmental factors, Borana rangelands, spatial distribution*

## INTRODUCTION

Semi-arid rangelands are complex ecosystems characterized by erratic rainfall and a high rate of vegetation dynamics. Vegetation dynamics is change in composition and stand structure of plant species over time (Herlocker, 1999; Dahdouh-Guebas *et al.*, 2002) and it affects biological diversity and rangeland productivity (Herlocker, 1999). This change in composition of vegetation is the result of continuous and complex interactions of plant communities with their environment.

Vegetation is an important source of food, medicine, forage, firewood and construction. For a pastoral community, like the Borana pastoralists, plants are key resources on which livestock production depends. For sustainable livestock production, development workers or rangeland managers need to know the existing plant communities of a given site, changes in plant communities as a result of certain management interventions, the relative value of each plant community for wildlife and livestock production and what factors or combination of factors will change the vegetation (Herlocker, 1999). Therefore, quantitative data on vegetation is crucial in detecting change, planning and resource management. Despite the high significance of vegetation data for livestock production and biodiversity conservation, quantitative descriptions of vegetation composition in relation to environmental variables are lacking in the Borana lowlands. Even for the whole Borana region, studies on the plant-environment interactions are scanty (Zerihun Woldu and Sileshi Nemomissa, 1998).

When climate is more stressful for the plant life, species respond to smaller scale variations in substrate, topography and biotic interactions (Ohmann and Spies, 1998). Heikkinen *et al.* (1998) and Korvenpää *et al.* (2003) also pointed out that species composition is mainly determined by fine-scale local factors. Therefore, in the stressful semi-arid rangeland of the Borana lowlands, vegetation-environment relationships were analysed at local levels.

Ellison *et al*. (2000) suggested that identifying patterns of species distribution and abundance and determining the underlying mechanisms of these patterns have been major preoccupations of community ecologists. In the complex ecosystem, abiotic and biotic components directly and/or indirectly interact and canonical ordination techniques such as Redundancy Analysis (RDA) or Canonical Correspondence Analysis (CCA) are useful to detect these interactions between species and environmental variables (ter Braak, 1987).

Previous vegetation studies of the Borana lowlands focused mainly on taxonomic descriptions (Haugen, 1992; Zerihun Woldu and Sileshi Nemomissa, 1998) and rangeland condition assessments (Coppock, 1994, Ayana Angassa and Baars, 2000, Oba *et al.*, 2000; Oba and Kotile, 2001). The relationships between biophysical variables and vegetation have been described in a qualitative and descriptive manner and quantitative data were found to be little. To contribute towards filling the existing data gap, this study used multivariate techniques for the quantitative analysis of the relationship between abiotic environmental factors and vegetation composition. The objectives of this study were, therefore, to (1) determine the relationship between vegetation composition and abiotic environmental factors and (2) identify abiotic environmental factors that accounted for the spatial distribution, abundance and diversity of herbaceous and woody plants in the Borana ecosystem.

## MATERIALS AND METHODS

### *Study area and sampling techniques*

The study was conducted in Dida Hara Pastoral Association (PA) in Yaballo district and Web PA in Arero district of the Borana lowlands, southern Oromia, Ethiopia (Fig. 1). Yaballo town is 570 km south of Addis Ababa. Dida Hara PA (04°47′24″.8 N and 038°19′46″.2 E) and Web PA (04°31′88″.9 N and 038°41′56″.4 E) are located about 30 km northeast and 85 km southeast of Yaballo town, respectively.

*Combretum-Terminalia* and *Acacia-Commiphora* woodlands characterize the lowlands of Borana zone. Haugen (1992) pointed out that the woodlands of Borana rangelands are characterized by species from the genera *Combretum* and *Terminalia*, whereas the bushlands and thickets, which cover major parts of the Borana lowlands, are dominated by *Acacia* and *Commiphora* species. Gemedo Dalle *et al.* (2005) identified eight plant communities in the study area: (i) *Acacia drepanolobium-Pennisetum mezianum,* (ii) *Bidens hildebrandtii-Chrysopogon aucheri,* (iii) *Chrysopogon aucheri-Commiphora africana,* (iv) *Cenchrus ciliaris-Chrysopogon aucheri,* (v) *Acacia bussei-Pennisetum mezianum,* (vi) *Commiphora erythraea-Sansevieria ehrenbergii,* (vii) *Acacia melliphera-Setaria verticillata,* and (viii) *Heterpogon contortus-Hildebrandtia obcordata.*

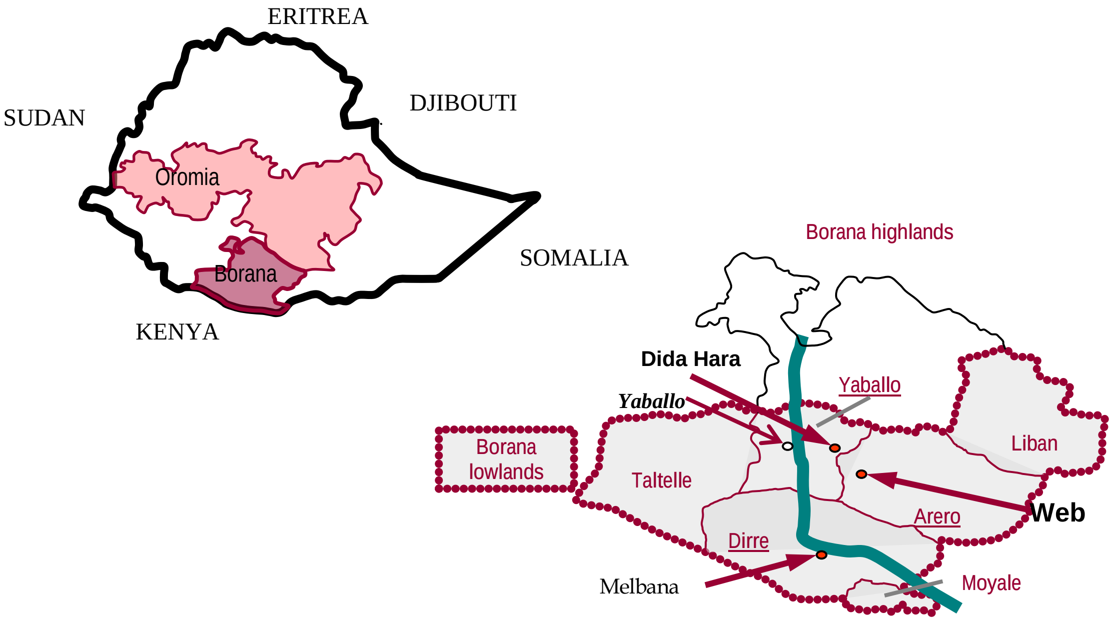

**Figure 1. Location of Borana lowlands and study localities in Oromia National Regional State, Ethiopia**.

Rainfall in the Borana lowlands is bimodal, with the long rains between March and May and short rains between October and November. Mean annual rainfall between the years 1988–2001 is 566 mm and 412 mm in Dida Hara and Web, respectively (Gemedo Dalle *et al*. 2005), corresponding to the 400–600 mm rainfall range reported by Coppock (1994).

The soils in the study area are granitic and volcanic soils and their mixtures (Coppock, 1993). Bottomlands of the Borana rangelands are dominated by Vertisols.

In establishing the sampling plots, combinations of stratification and systematic random sampling were used. Stratification was used to sample from the two districts and different land use units. However, within each land use unit, the first sampling unit was established randomly and the subsequent units were established at 200 m intervals on a linear transect.

### Data collection

A total of 58 plots of 50 m x 10 m were used for collecting data on both abiotic environmental factors and vegetation (Table 1). Density of trees/shrubs was determined in the entire 500 $m^2$ area. Within each plot, herbaceous samples were taken from five subplots of 0.25 $m^2$ (four at the corners and one at the centre of the main plot) for the determination of herbage mass and frequency of each species. Samples from the five subplots were pooled. Species richness (the total number of species) was determined in the entire 500 $m^2$ plot for woody plants and from the five subplots for the herbaceous species.

The environmental data included altitude, slope, soil nutrients, pH and texture. A hand-held Global Positioning System (GPS) was used to determine the location of the sample plots, an altimeter for measuring altitudes and a clinometer for measuring ground slope.

Soil samples were collected from the topsoil (surface soil from 0–15 cm) of the five subplots used for sampling herbaceous species. The soil samples from the subplots were also pooled and analysed for total nitrogen (N), available phosphorus (P), organic matter (OM), pH (pH_$H_2O$), potassium (K), calcium (Ca), magnesium (Mg), cation exchange capacity (CEC) and texture (sand, silt and clay) at the International Livestock Research Institute (ILRI) laboratory, Addis Ababa, Ethiopia. N, OM and soil texture were measured in percent, P in ppm (parts per million), pH in 1:1 suspension (pH_$H_2O$), and K, Ca, Mg, and CEC results in meq/100g (milli-equivalents per 100 grams).

The methods used for the analyses of soil samples were ammonium acetate (at pH 7) extraction method for exchangeable bases, ammonium replacement method for CEC, 1:1 soil to water ratio for pH, Keltec or $H_2SO4$ wet digestion titration method for total N, Walkley-Black titration method for OM, Bray II method for available P, and hydrometer method for texture.

### Data analysis

Different multivariate techniques of CANOCO, version 4.0 (ter Braak and Šmilauer, 1998) were employed for analysis of the relationships between vegetation and environmental variables. In the analysis, both herb and shrub layers (trees/shrubs) were considered. Density of trees/shrubs (number per ha) was used for the analysis of the relationship between woody plants and abiotic environmental factors, whereas for herbaceous species, frequency was used. Because of this difference in input data, results for the two species groups were presented separately. On the other hand, mean number of species per 500 $m^2$ plot, called alpha diversity (Ohmann and Spies, 1998), was used to determine the relationship between environmental variables and species richness.

**Table 1. Number of samples taken at each land use unit, locations, abbreviations and descriptions of land use units studied in the Borana lowlands.**

| Land use unit | Abbreviation | Explanation | District | Sample size per each land use unit (n) |
|---|---|---|---|---|
| Dida Hara *Kalo* | DHK | Dida Hara grazing land for calves | Yabello | 12 |
| Dida Hara *Worra* | DHW | Dida Hara grazing land for lactating livestock | Yabello | 10 |
| Web *Kalo* | WBK | Web grazing land for calves | Arero | 8 |
| Web *Worra* | WBW | Web grazing land for lactating livestock | Arero | 10 |
| *Foora* | FOR | Grazing land for dry livestock in Dida Hara | Yabello | 18 |

The ordination methods used for the vegetation and environmental data analysis were Detrended Correspondence Analysis (DCA), Redundancy Analysis (RDA), and Canonical Correspondence Analysis (CCA). In CCA, biplot-scaling was used and in RDA the centre and standardize option was followed as recommended by ter Braak and Šmilauer (1998).

Most important environmental variables at each land use unit and over the entire area were identified using the "Manual Forward Selection" option of CANOCO 4.0. These variables were considered as most important based on the "Extra fit" value of each and when their contribution was significant ($P \leq 0.05$) to the model.

In the ordination diagrams, species names are abbreviated using eight letters from the scientific name of each plant by combining the four initial letters for the genus and specific epithet. For example, "Cenccili" is an abbreviation for *Cenchrus ciliaris*. Botanical and vernacular names of the species are presented in Appendix 1.

## RESULTS

### *Abiotic environmental factors and land use units*

Table 2 summarizes the physical and chemical properties of soil characteristics in the different land use units of the study area. Bottomlands of the Borana rangelands are dominated by Vertisols. Dida Hara soils are lighter, containing the highest proportion of sand, whereas Web soils have higher levels of available P, Ca, Mg, CEC and pH (Table 2). Mean available P ranges from 2.01 ppm in *Foora* to 24.04 ppm in Web. P, Ca and CEC contents are highly variable in both Dida Hara and Web. Despite the high variability, the difference in available P and Ca contents of soils in Dida Hara and Web is highly significant. Mean OM content ranges from 1.69 in Web to 2.1% in Dida Hara.

To identify potential differences in the contribution of abiotic environmental factors in different land use units, vegetation-environment analyses were performed separately for each land use unit (Tables 3 and 4). Table 3 summarizes the important environmental variables that significantly accounted for the spatial distribution and abundance of both woody and herbaceous species in these land use units of the study area. Altitude and organic matter content were the two most important factors affecting vegetation composition.

### *Relationships between woody plants and environmental variables*

Figure 2 shows the spatial distribution of woody species in relation to environmental variables. The first CCA axis is strongly positively correlated with pH, Ca and Mg, and strongly negatively correlated with altitude. The correlation between the second axis and the environmental variables (N, OM, K, Ca, Mg, CEC and altitude) is negative and relatively weak. The first axis is a gradient of pH whereas the second axis is a gradient of OM.

**Table 2. Mean values of the soil nutrients and texture in different land use units of the Borana lowlands.** The number of samples per each land use unit (n) is indicated in parenthesis.

| | DHK | | DHW | | Dida Hara | | WBK | | WBW | | Web | | Foora | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD (12) | Mean | SD (12) | Mean | SD (12) | Mean | SD (12) | Mean | SD (12) | Mean | SD (12) | Mean | SD (12) |
| N | 0.10 | 0.02 | 0.11 | 0.04 | 0.10 | 0.03 | 0.11 | 0.04 | 0.11 | 0.02 | 0.1 | 0.03 | 0.08 | 0.02 |
| P | 6.45 | 10.45 | 1.99 | 1.37 | 4.67 | 8.33 | 7.91 | 9.23 | 29.97 | 28.34 | 20.53 | 24.04 | 2.01 | 1.36 |
| OM | 2.05 | 0.58 | 2.17 | 0.93 | 2.10 | 0.73 | 1.69 | 0.82 | 1.72 | 0.40 | 1.69 | 0.6 | 1.73 | 0.59 |
| pH | 6.11 | 0.32 | 5.61 | 0.11 | 5.91 | 0.36 | 6.59 | 0.52 | 7.19 | 0.29 | 6.93 | 0.49 | 6.20 | 0.51 |
| K | 3.08 | 1.56 | 2.72 | 0.80 | 2.93 | 1.30 | 1.38 | 0.80 | 2.74 | 1.01 | 2.16 | 1.12 | 2.30 | 1.13 |
| Ca | 9.61 | 11.72 | 5.66 | 2.72 | 8.03 | 9.32 | 14.11 | 14.45 | 23.14 | 15.16 | 19.74 | 14.94 | 5.66 | 1.78 |
| Mg | 2.09 | 0.92 | 1.91 | 0.66 | 2.02 | 0.82 | 3.19 | 1.16 | 3.53 | 1.60 | 3.46 | 1.39 | 2.46 | 1.01 |
| CEC | 24.20 | 15.48 | 19.76 | 4.63 | 22.42 | 12.36 | 27.33 | 16.48 | 37.19 | 16.71 | 33.47 | 16.67 | 18.39 | 4.34 |
| Sand | 60.46 | 10.15 | 52.02 | 12.77 | 57.08 | 11.8 | 50.01 | 7.22 | 53.26 | 14.18 | 50.74 | 11.68 | 55.29 | 9.56 |
| Silt | 14.40 | 3.58 | 16.96 | 8.33 | 15.42 | 5.93 | 20.29 | 5.75 | 20.05 | 6.43 | 20.66 | 6.00 | 18.04 | 4.15 |
| Clay | 25.14 | 7.31 | 31.02 | 6.53 | 27.49 | 7.47 | 29.70 | 2.70 | 26.69 | 12.04 | 28.6 | 9.20 | 26.67 | 7.31 |

t test for some of the differences between Dida Hara and Web (df = 41)

| | t-value | P |
|---|---|---|
| P | 3.07 | 0.01 |
| Ca | 3.18 | 0.01 |
| CEC | 2.5 | 0.02 |
| Silt | 2.85 | 0.01 |
| Sand | 1.75 | 0.10 |

**Table 3. The environmental variables identified per each land use unit in order of importance in the Borana lowlands.**

| Variable | DHK | DHW | WBK | WBW | FOR | DH | WB | DH & WB | Consistency as most important<br>Out of 16 | Percentage |
|---|---|---|---|---|---|---|---|---|---|---|
| Altitude | + + | + - | - + | -+ | + - | + - | + + | + + | 11 | 69 |
| N | + - | + + | + - | + - | + - | + + | + + | - - | 10 | 63 |
| Ca | - + | - - | + + | + - | + - | - - | + + | + + | 9 | 56 |
| OM | + - | + + | + - | + - |  | + - | + - |  | 7 | 44 |
| CEC | - - | - - | + - | + + | - - | - - | + + | + + | 7 | 44 |
| Mg | - - | + - | - - | + - | + - | - - | + - | + + | 6 | 38 |
| Clay | + - | + - | - + | - - | - - | + + | - - | - - | 5 | 31 |
| pH | - - | + - | - - | - - | + - |  | + - | + + | 5 | 31 |
| Sand | - - | + - | + - | - - | - - | + - | - - | - + | 4 | 25 |
| K | - - | - - | - - | - - | + - | - + | + + | - - | 4 | 25 |
| Slope | - - | - + | - - | - + | - - | - - | - - | - + | 3 | 19 |
| P | + - | + - | + - | - - | - - | - - | - - | - - | 3 | 19 |
| Silt | + - | + - | - - | - - | - - | - - | - - | - - | 2 | 13 |

| Land use unit | Woody plants-environment | Herbaceous plants-environment |
|---|---|---|
| DHK | altitude, P, N, OM, silt and clay | K and altitude |
| DHW | altitude, sand, OM, clay, pH, P, N and silt | slope, Mg, N and OM |
| WBK | Ca, N, OM, P, CEC and sand | altitude, clay and Ca |
| WBW | N, Ca, Mg, OM, and CEC | altitude, sloped and CEC |
| FOR | K, altitude, pH, N, Ca and Mg | clay, Ca, OM, altitude and sand |
| DH | altitude, OM, Clay and N |  |
| WB | Ca, N, altitude, OM, CEC, pH, Mg and K |  |
| Combined (DH & WB) | altitude, pH, Ca, Mg and CEC |  |

+ + = most important for both woody and herbaceous species; + - = most important for only woody plants; + = most important for only herbaceous species; - - = not important for both woody and herbaceous species

**Table 4. Summary of CCA analysis of the relationship between environmental variables and woody plants in different land use units of Borana lowlands.**

| Land use unit | Eigenvalues for Axis 1 | 2 | 3 | 4 | Species-environment relations for Axis 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|
| DHK | 0.664 | 0.447 | 0.414 | 0.308 | 0.995 | 0.994 | 0.997 | 0.970 |
| DHW | 0.436 | 0.358 | 0.308 | 0.257 | 0.932 | 0.919 | 0.902 | 0.925 |
| WBK | 0.828 | 0.543 | 0.428 | 0.397 | 1.000 | 1.000 | 1.000 | 1.000 |
| WBW | 0.774 | 0.428 | 0.307 | 0.228 | 1.000 | 1.000 | 1.000 | 1.000 |
| FOR | 0.683 | 0.644 | 0.453 | 0.325 | 0.989 | 0.986 | 0.974 | 0.935 |
| DH | 0.436 | 0.358 | 0.308 | 0.257 | 0.932 | 0.919 | 0.902 | 0.925 |
| WB | 0.787 | 0.446 | 0.371 | 0.258 | 0.993 | 0.946 | 0.979 | 0.947 |
| DH & WB | 0.696 | 0.464 | 0.291 | 0.246 | 0.960 | 0.922 | 0.889 | 0.852 |

| Land use unit | Cumulative percentage variance of:<br>Species for Axis 1 | 2 | 3 | 4 | Species-environment relation for Axis 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|
| DHK | 23.6 | 39.5 | 54.2 | 65.2 | 24.6 | 41.2 | 56.5 | 67.9 |
| DHW | 13.8 | 25.2 | 35.0 | 43.1 | 21.7 | 39.4 | 54.7 | 67.5 |
| WBK | 29.4 | 48.7 | 63.9 | 78.0 | 29.4 | 48.7 | 63.9 | 78.0 |
| WBW | 36.4 | 56.5 | 70.9 | 81.7 | 36.4 | 56.5 | 70.9 | 81.7 |
| FOR | 18.6 | 36.1 | 48.4 | 57.3 | 21.1 | 41.1 | 55.1 | 65.1 |
| DH | 13.8 | 25.2 | 35.0 | 43.1 | 21.7 | 39.4 | 54.7 | 67.5 |
| WB | 21.5 | 33.7 | 43.8 | 50.8 | 28.0 | 43.9 | 57.1 | 66.2 |
| DH & WB | 12.8 | 21.4 | 26.7 | 31.3 | 28.4 | 47.3 | 59.2 | 69.2 |

| Land use unit | Monte Carlo test of significance of:<br>First canonical axis<br>F-ratio | P-value | All canonical axes<br>F-ratio | P-value |
|---|---|---|---|---|
| DHK | 0.31 | 0.190 | 1.977 | 0.005 |
| DHW | 1.77 | 0.170 | 1.624 | 0.005 |
| WBK | 0.00 | 1.000 | 0.000 | 1.000 |
| WBW | 0.00 | 1.000 | 0.000 | 1.000 |
| FOR | 0.68 | 0.210 | 1.820 | 0.020 |
| DH | 1.77 | 0.150 | 1.624 | 0.005 |
| WB | 1.37 | 0.005 | 1.375 | 0.045 |
| DH & WB | 4.26 | 0.005 | 1.99 | 0.005 |

The eigenvalues for the first and second axes are 0.696 and 0.464, respectively, demonstrating that there is good dispersion of species along the pH gradient. CCA triplot of samples, species and environmental variables based on the first two axes explained 21.4% of the variance in the species data and 47.3% of the variance in the weighted averages and class total of the species with respect to the environmental variables (Table 4). Test of significance of both the first axis and all canonical axes resulted in P values of 0.005 (Table 4), demonstrating that the relationship between species and environmental variables is highly significant. Altitude, pH, Ca, Mg and CEC are the most important environmental variables that accounted for the spatial distribution and abundance of woody plants at the two study sites (Fig. 2).

Woody plants that are positively correlated with altitude include *Acacia goetzei* (005), *Acokanthera schimperi* (014), *Combretum molle* (022), *Commiphora africana* (023), *Pappea capensis* (050) and *Solanum somalense* (055). On the other hand, *Acacia oerfota* (008), *Balanites rotundifolia* (017), *Euphorbia cuneata* (036) and *Kedrostis pseudogijef* (045) are negatively correlated with altitude (Fig. 2). Note that the above numbers in parenthesis indicate the code used in the CCA ordination diagram.

### *Relationship between herbaceous species and abiotic environmental factors*

DCA analyses for each data set revealed that length of the gradient was less than 3 standard units (SD) and, therefore, RDA (linear model) was used for the analysis of the relationship between herbaceous species and environmental variables. Figure 2 summarizes the overall relationship between herbaceous species and environmental variables across the two study sites. The first axis is positively correlated with altitude, slope and sand and negatively correlated with N, P, pH, K, Ca, Mg, silt, clay and CEC. Similarly, the second axis is positively correlated with K, Ca, N, OM and CEC. The first axis is a gradient of altitude and the second a gradient of K. The first two axes of RDA cumulatively explain 17.3% of the variance in the species data and 46.4% of the variance in the species-environment relationship (Table 5).

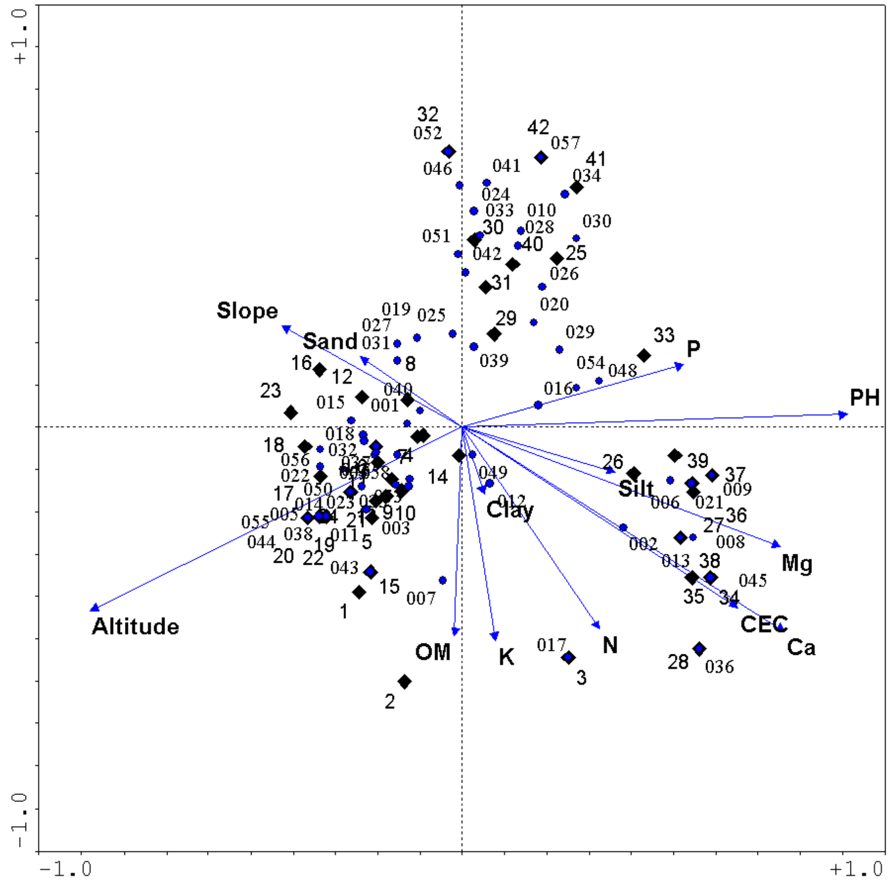

**Figure 2.** CCA **ordination diagram of the relationship between woody plants and environmental variables in the Borana lowlands.** Black dots represent the species; black diamonds represent plots. Note that the numbers *e.g.*, 015 represents species, whereas *e.g.*, 15 represents plot number.

**Table 5. Summary of RDA analysis of the relationship between environmental variables and herbaceous species composition in different land use units of Borana lowlands.**

| Land use unit | Eigenvalues for Axis | | | | Species-environment relations for Axis | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| DHK | 0.229 | 0.171 | 0.132 | 0.097 | 0.986 | 0.925 | 0.992 | 1 |
| DHW | 0.243 | 0.213 | 0.172 | 0.139 | 1.000 | 1.000 | 1.000 | 1.000 |
| WBK | 0.336 | 0.239 | 0.188 | 0.127 | 1.000 | 1.000 | 1.000 | 1.000 |
| WBW | 0.264 | 0.261 | 0.17 | 0.118 | 1.000 | 1.000 | 1.000 | 1.000 |
| FOR | 0.236 | 0.148 | 0.116 | 0.083 | 0.889 | 0.98 | 0.889 | 0.955 |
| DH | 0.138 | 0.094 | 0.074 | 0.061 | 0.956 | 0.878 | 0.914 | 0.919 |
| WB | 0.229 | 0.128 | 0.105 | 0.093 | 0.96 | 0.989 | 0.918 | 0.934 |
| DH & WB | 0.106 | 0.067 | 0.053 | 0.038 | 0.879 | 0.843 | 0.844 | 0.717 |

| Land use unit | Cumulative percentage variance of: | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Species for Axis | | | | Species-environment relation for Axis | | | |
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| DHK | 22.9 | 40.1 | 53.2 | 63 | 24.9 | 43.5 | 57.9 | 68.4 |
| DHW | 24.3 | 45.6 | 62.8 | 76.7 | 24.3 | 45.6 | 62.8 | 76.7 |
| WBK | 33.6 | 57.5 | 76.3 | 89 | 33.6 | 57.5 | 76.3 | 89.0 |
| WBW | 26.4 | 52.5 | 69.6 | 81.3 | 26.4 | 52.5 | 69.6 | 81.3 |
| FOR | 23.6 | 38.4 | 50 | 58.3 | 31.7 | 51.7 | 67.3 | 78.5 |
| DH | 13.8 | 23.2 | 30.6 | 36.7 | 25.6 | 43.0 | 56.8 | 68.0 |
| WB | 22.9 | 35.7 | 46.1 | 55.4 | 29.8 | 46.5 | 60.1 | 72.3 |
| DH & WB | 10.6 | 17.3 | 22.6 | 26.4 | 28.5 | 46.4 | 60.7 | 71.0 |

| Land use unit | Monte Carlo test of significance of: | | | |
|---|---|---|---|---|
| | First canonical axis | | All canonical axes | |
| | F-ratio | P-value | F-ratio | P-value |
| DHK | 0.298 | 0.7650 | 0.962 | 0.5600 |
| DHW | 0.000 | 1.0000 | 0.000 | 1.0000 |
| WBK | 0.000 | 1.0000 | 0.000 | 1.0000 |
| WBW | 0.000 | 1.0000 | 0.000 | 1.0000 |
| FOR | 0.924 | 0.8600 | 0.720 | 0.8950 |
| DH | 1.767 | 0.0150 | 1.075 | 0.3100 |
| WB | 1.482 | 0.2100 | 1.372 | 0.0750 |
| DH & WB | 3.445 | 0.0050 | 1.434 | 0.0150 |

Altitude, Ca, CEC, pH, Mg, sand and slope are important environmental factors that significantly contributed to the model. RDA ordination diagram in Figure 3 revealed that altitude is the major factor that determined the spatial distribution of herbaceous species. Species that are positively and closely associated with altitude include *Themeda triandra, Heteropogon contortus, Harpachne schimperi, Indigofera volkensii, Eragrostis papposa, Chrysopogon aucheri* and *Cyperus* species. On the other hand, *Cynodon dactylon, Ischaemum afrum, Bothrichloa radicans, Pennisetum mezianum, Chloris roxburghiana* and *Setaria verticillata* are more abundant at the lower altitude areas, where silt and clay contents of soils are also high.

### *Relationships between abiotic environmental factors and species richness*

Species richness of both woody and herbaceous plants is negatively correlated with P, pH, Ca, CEC, Mg and silt (Fig. 4). On the other hand, richness is positively correlated with altitude, slope and sand content of the soil.

RDA triplot based on the first two axes explaine 32.9% of the variance in species data and 85.2% of the species-environment relationships. Monte Carlo test confirmed that the relationship between environmental variables and species richness, density of woody plants and herbage mass is statistically significant (P = 0.01).

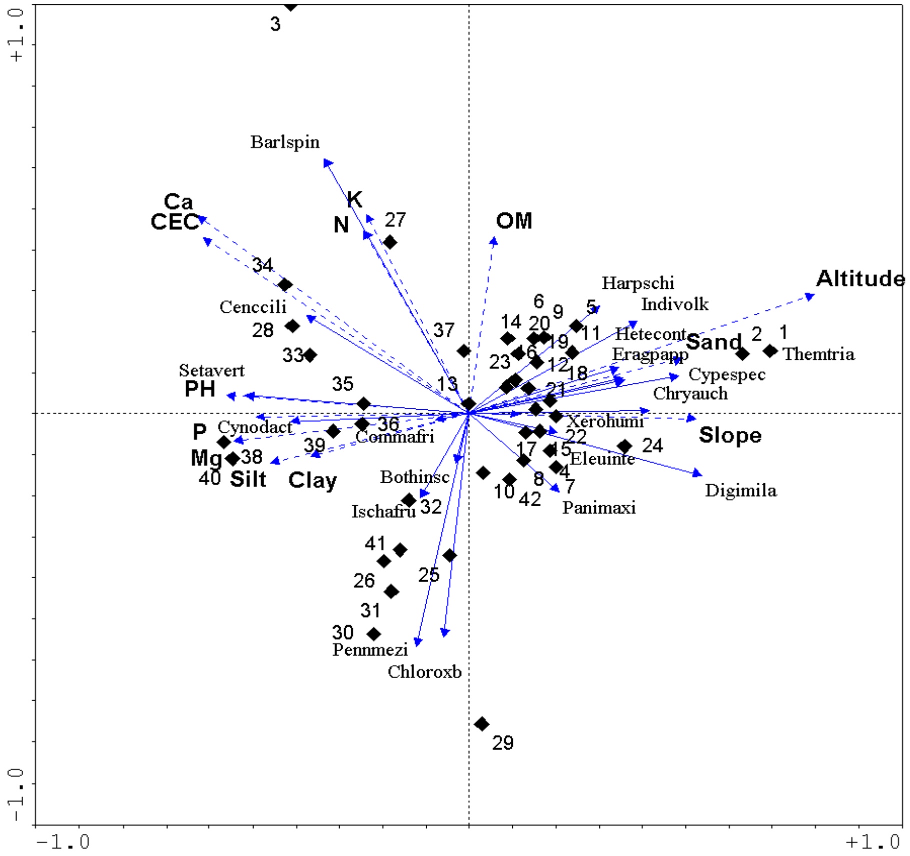

Figure 3. RDA ordination diagram of the relationship between herbaceous species and environmental variables in Dida Hara and Web, Borana lowlands (see Appendix 1 for species names).

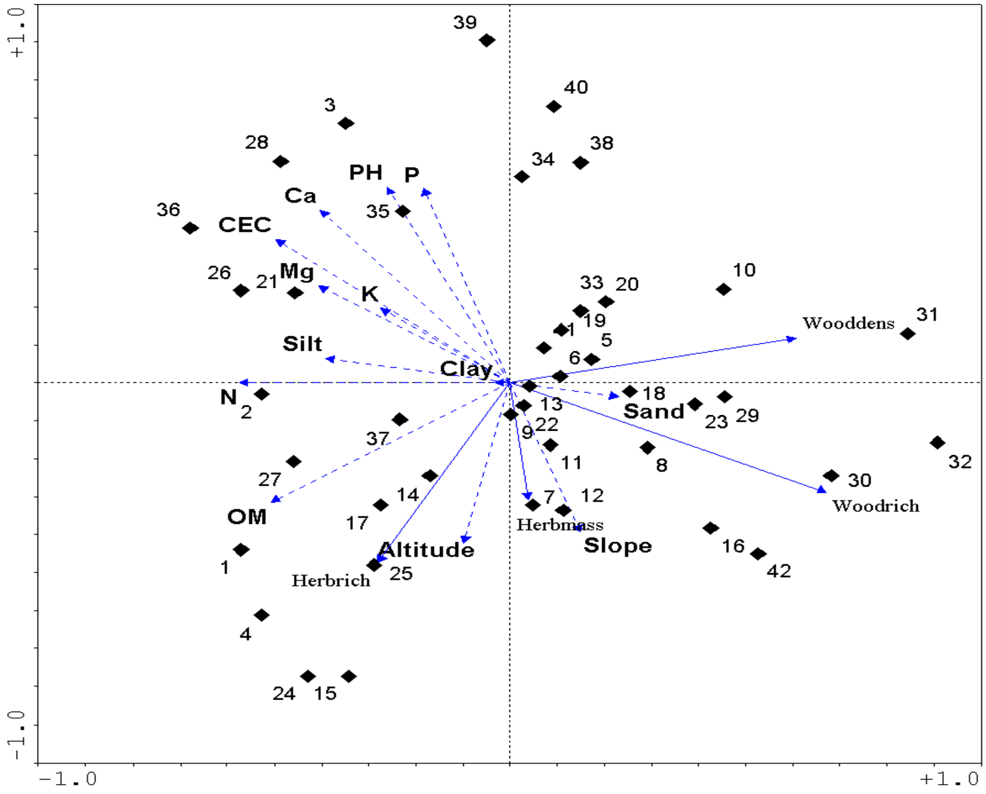

Figure 4. RDA ordination diagram of the relationship between environmental variables and richness in Dida Hara and Web districts, Borana lowlands (see Appendix 1 for species names). Abbreviations: Wooddens = density of woody plants, Woodrich = species richness of woody plants, Herbrich = species richness of herbaceous species.

## DISCUSSION

### *Impact of elevation and edaphic factors on vegetation composition*

Vegetation-environment correlation result of the ordination output is a measure of the association between vegetation composition and environment. The importance of the association is best expressed by the eigenvalue because it measures how much variation in the vegetation data is explained by the environmental variables (ter Braak, 1987; ter Braak and Šmilauer, 1998). The fact that all eigenvalues were > 0.5 indicates that there is good dispersion of woody species along the respective environmental gradients. Furthermore, the length of the first DCA axis is >3 SD indicating a substantial turnover of taxa along the main environmental gradients (Korvenpää *et al*., 2003).

The explained total variance in species data by the first two axes is 21.4% for woody plants. Accordingly, there is significant change in vegetation composition along the environmental gradients. Therefore, it is concluded that the environmental variables account for the variation in the woody species composition of the land use units studied. This result contradicts with previous report by Zerihun Woldu and Sileshi Nemomissa (1998), who discussed that there was no clear relationship between floristic gradients in CCA ordination and the measured environmental factors (slope, soil pH, OM, P and texture).

Similarly, the relationship between herbaceous species and environmental variables is significant. However, the explained variability is small (17.3%). Reed *et al*. (1993) reported that plant-plant interactions might result in the decline of the correlation between vegetation and environment at small scales and such interactions are most likely to moderate vegetation-environment correlations where the plant species are in physical contact or are competing for the same resources. They further discussed that the decline in vegetation-environment correlation might be most pronounced for herbs and seedlings of woody plants because their small root systems constrain physical interactions to small area.

Important environmental variables that significantly determine the spatial distribution of species should be consistent across all land use units because ecological processes that determine community structure and function are more likely to be similar at different spatial and temporal scales (Reed *et al*., 1993).

Hejcmanovā-Nežerková and Hejcman (2006) reported that soil type and topography were the main factors that affected the diversity and distribution of woody vegetation in the Niokolo Koba National Park in Senegal. In accordance with this result and many others (*e.g.*, Reed *et al*., 1993; Zerihun Woldu and Feoli, 2001; Vogiatzakis *et al*., 2003) altitude and soil Ca, CEC, Mg and pH are identified as the most important environmental factors that contribute significantly to the differences in spatial distribution of both herbaceous and woody species in the Borana rangelands. Vogiatzakis *et al*. (2003) pointed out that elevation affects the amount of precipitation and temperature and, therefore, indirectly affects plant growth further explaining the significant impact of altitude on vegetation distribution and abundance.

### *Relationship between species richness and environmental variables*

The richness of both herbaceous and woody species is positively correlated with sand content and altitude and negatively correlated with soil nutrients. This result concurs with the report by Abbadi and El-Sheikh (2002). Abdel-Fattah and Ali (2005) also reported relatively high species richness in valleys and sand plain habitats. The negative correlation between soil nutrients and species richness may be due to the dominance of few species on the relatively nutrient rich areas. This result is in agreement with Hahs *et al*. (1999) who reported that species diversity was lower on sites with higher basic cation concentrations and higher on sites with lower nutrient contents.

### *Ecological preferences of some species*

Woody plants that showed consistent preferences for soils with higher proportion of clay are *Acacia drepanolobium, Euclea divinorum, Grewia bicolor, Grewia tembensis, Pappea capensis, Rhus natalensis,* and *Acacia mellifera*. Others, such as *Commiphora africana, Commiphora* sp., *Acacia etabaica, Acacia brevispica,* and *Dalbergia microphylla,* are more abundant on sandy soils at higher elevations. *Acacia drepanolobium* and *Euclea divinorum* are dominant on Vertisols at the bottomlands. Similar results were reported by Haugen (1992) and Zerihun Woldu and Sileshi Nemomissa (1998). *Acacia drepanolobium-Acacia seyal* community type was reported to occur in depressions that may be waterlogged during the rainy seasons (Zerihun Woldu and Sileshi Nemomissa, 1998). Haugen (1992) also pointed out that *Acacia drepanolobium* often forms almost pure stands on poorly drained soils of valley bottoms, which was also commonly observed during this study.

Herbaceous species that closely correlate with nutrient-rich soils with relatively high proportions of clay include *Pennisetum mezianum, Cynodon dactylon, Setaria verticillata, Commelina africana, Barleria spinisepala* and *Heteropogon contortus,* as opposed to those closely associated with sandy soils at higher elevation, including *Themeda triandra, Panicum maximum, Digitaria milanjiana* and *Harpachne schimperi.* Zerihun Woldu and Sileshi Nemomissa (1998) also reported that *Setaria pumila*, *Sorghum purpureum* and *Commelina* sp. were important herbaceous species in the depressions in association with the *Acacia drepanolobium-Acacia seyal* plant community.

## CONCLUSION

Understanding abiotic environmental factors that affect rangeland plant species composition and distribution is important for planning and implementing rangeland resources management. The data are useful in planning for climate change adaptation, rangeland restoration and also for identifying places for intensified utilization. This study has shown that the measured environmental variables account for the main variation in the composition of plant species in the Borana lowlands. Altitude and soil pH are the most significant factors in determining the spatial distribution of vegetation in the Borana rangeland ecosystems. Finally, rangeland managers and development planners need to integrate and use different data such as abiotic environmental factors, biotic factors and indigenous knowledge of local communities in planning and implementing sustainable rangeland management.

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### REFERENCES

1. Abbadi, G.A. and El-Sheikh, M.A. (2002). Vegetation analysis of Failaka Island (Kuwait). *Journal of Arid Environments* **50**:153–165.
2. Abdel-Fattah, Ragab, I. and Ali, Akram, A. (2005). Vegetation-Environment relationships in Taif, Saudi Arabia. *International Journal of Botany* **1(2)**:206-211.
3. Ayana Anagassa and Baars, R.M.T. (2000). Ecological condition of encroached and non-encroached rangelands in Borana, Ethiopia. *African Journal of Ecology* **38**:321–328.
4. Coppock, D.L. (1993). Vegetation and pastoral dynamics in the southern Ethiopian rangelands: Implications for theory and management. **In**: *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaptation in African Savannas,* pp. 42–61, (Behnke, R.H.Jr., Scoones, I. and Kerven, C. eds). Overseas Development Institute, London, UK.
5. Coppock, D.L. (1994). The Borana plateau of southern Ethiopia: synthesis of pastoral research, development and change, 1980–1991. ILCA, Addis Ababa.
6. Dahdouh-Guebas, F., Kairo, J.G., Jayatissa, L.P., Cannicci, S. and Koedam, N. (2002). An ordination study to view vegetation structure dynamics in disturbed and undisturbed mangrove forests in Kenya and Sri Lanka. *Plant Ecology* **161**:123–135.
7. Ellison, A.M., Mukherjee, B.B. and Karim, A. (2000). Testing patterns of zonation in mangroves: scale dependence and environmental correlates in the Sundarbans of Bangladesh. *Journal of Ecology* **88(5)**:813–824.
8. Gemedo Dalle, Maass, B.L. and Isselstein, J. (2005). Plant communities and their species diversity in the semi-arid rangelands of Borana lowlands, southern Oromia, Ethiopia. *Community Ecology* **6(2)**:167–176.
9. Hahs, A., Enright, N.J. and Thomas, I. (1999). Plant communities, species richness and their environmental correlates in the sandy heaths of Little Desert National Park, Victoria. *Australian Journal of Ecology* **24(3)**:249–257.
10. Haugen, T. (1992). Woody vegetation of Borana, south Ethiopia. A study on the main vegetation types of the area. *SINET: Ethiop. J. Sc.* **15(2)**:17–130.
11. Hejcmanovā-Nežerková, P. and Hejcman, M. (2006). A canonical correspondence analysis (CCA) of the vegetation–environment relationships in Sudanese savannah, Senegal. South African *Journal of Botany* **72**:256–262.
12. Heikkinen, R., Birks, H.J.B and Kalliola, R. (1998). A numerical analysis of the mesoscale distribution patterns of vascular plants in the subarctic Kevo Nature Reserve, northern Finland. *Journal of Biogeography* **25(1)**:123–146.
13. Herlocker, D.J. (1999). Rangeland ecology and resource development in eastern Africa. GTZ, Nairobi.
14. Korvenpää, T., von Numers, M. and Hinneri, S. (2003). A mesoscale analysis of floristic patterns in the south-west Finnish Archipelago. *Journal of Biogeography* **30(7)**:1019–1031.
15. Oba G. and Kotile, D.G. (2001). Assessment of landscape level degradation in southern Ethiopia: Pastoralists versus ecologists. *Land Degradation and Development* **12**:461–475.
16. Oba G., Post, E., Syvertsen, P.O. and Stenseth, N.C. (2000). Bush cover and range condition assessments in relation to landscape and grazing in southern Ethiopia. *Landscape Ecology* **15**:535–546.

17. Ohmann, J.L. and Spies, T.A. (1998). Regional gradient analysis and spatial pattern of woody plant communities of Oregon Forests. *Ecological Monographs* **68(2)**:151–182.
18. Reed, R.A., Peet, R.K., Palmer, M.W. and White, P.S. (1993). Scale dependence of vegetation-environment correlations: A case study of a North Carolina piedmont woodland. *Journal of Vegetation Science* **4**:329–340.
19. ter Braak, C. J. F. (1987). Ordination. **In**: *Data Analysis in Community and Landscape Ecology*, pp. 91–173, (Jongman, R.H., ter Braak, C.J.F. and van Tongeren, F.R., eds). Pudoc, Wageningen.
20. ter Braak, C.J.F. and Šmilauer, P. (1998). CANOCO reference manual and user`s guide to Canoco for windows: software for canonical community ordination (version 4.0). Microcomputer Power, Ithaca, NY, USA.
21. Vogiatzakis, I.N., Griffiths, G.H., and Mannion, A.M. (2003). Environmental factors and vegetation composition, Lefka Ori massif, Crete, S. Aegean. *Global Ecology and Biogeography* **12(2):**131–146.
22. Zerihun Woldu and Feoli, E. (2001). The shrub vegetation of Adwa, northern Ethiopia. *Biol. Skr.* **54**:319–333.
23. Zerihun Woldu and Sileshi Nemomissa. (1998). Vegetation change in the central Borana plateau region of southern Ethiopia. *COENOSES* **13(3):**137–148.

**Appendix 1. Botanical and vernacular names of plant species with their growth forms.**

Abbreviations: Growth form: T/S = trees/shrubs or woody plants; G = grass; F = Forb and S = sedges.

| Code | Name | | Growth form |
|---|---|---|---|
| | Scientific | Vernacular | |
| Acacbrev | *Acacia brevispica* | Hammaressa | T/S |
| Acacbuss | *Acacia bussei* | Halloo | T/S |
| Acacdrep | *Acacia drepanolobium* | Fuleensa | T/S |
| Acacetab | *Acacia etabaica* | Alqabeessa | T/S |
| Acacgoet | *Acacia goetzei* | Burra | T/S |
| Acacmell | *Acacia melliphera* | Saphansa gurraacha | T/S |
| Acacnilo | *Acacia nilotica* | Burquqqee | T/S |
| Acacoerf | *Acacia oerfota* | Waangaa | T/S |
| Acacrefi | *Acacia reficiens* | Sigirsoo | T/S |
| Acacsene | *Acacia senegal* | Hidhaadhoo | T/S |
| Acacseya | *Acacia seyal* | Waacuu | T/S |
| Acactort | *Acacia tortilis* | Dhaddacha | T/S |
| Acaczanz | *Acacia zanzibarica* | Riiga | T/S |
| Acokschi | *Acokanthera schimperi* | Qaraaruu | T/S |
| Albiamar | *Albizia amara* | Ondoddee | T/S |
| Balaaegy | Balanites aegyptiana | Baddana luòo | T/S |
| Balarotu | *Balanites rotundifolia* | Baddana okolee | T/S |
| Barlspin | *Barleria spinisepala* | Qilxiphee | F |
| Boscmoss | *Boscia mossambicensis* | Qalqacha | T/S |
| Boswnegl | *Boswellia neglecta* | Dakkara | T/S |
| Bothinsc | *Bothriochloa insculpta* | Luucolee | G |
| Cenccili | *Cenchrus ciliaris* | Mata guddeessa | G |
| Chiolati | *Chionothrix latifolia* | Garbicha | T/S |
| Chloroxb | *Chloris roxburghiana* | Hiddoo luucolee | G |
| Chryauch | *Chrysopogon aucheri* | Alaloo | G |
| Cladhild | *Cladostigma hildebrandtiodes* | Gaalee | T/S |
| Combmoll | *Combretum molle* | Rukeessa | T/S |
| Commafri[1] | *Commiphora africana* | Hammeessa dhiroo | T/S |
| Commafri | *Commelina africana* | Qaayyoo | F |
| Commeryt | *Commiphora erythraea* | Agarsuu | T/S |
| Commhabe | *Commiphora habessinica* | Callanqaa | T/S |
| Commschi | *Commiphora schimperi* | Hammeessa qayyoo | T/S |
| Commspec | *Commiphora* sp | Hoomachoo | T/S |
| Commtere | *Commiphora terebinthina* | Sangaigguu | T/S |
| Cordghar | *Cordia gharaf* | Madheera hiddoo | T/S |
| Cordoval | *Cordia ovalis* R. BR. | Madheera hoffee | T/S |
| Cynodact | *Cynodon dactylon* | Sardoo | G |

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[1] Note that the codes for *Commiphora africana* and *Commelina africana* are the same, however they can be identified by their growth forms.

| Code | Name | | Growth form |
|---|---|---|---|
| | Scientific | Vernacular | |
| Cypespec | *Cyperus sp* | Saattuu | S |
| Dalbmicr | *Dalbergia microphylla* | Wolchaamala | T/S |
| Dichcine | *Dichrostachys cinerea* | Jirimee | T/S |
| Digimila | *Digitaria milanjiana* | Hiddoo | G |
| Eleuinte | *Eleusine intermedia* | Coqorsa | G |
| Entalept | *Entada leptostachya* | Handaada | T/S |
| Eragpapp | *Eragrostis paposa* | Saamphillee | G |
| Erytmela | *Erythrina melanacantha* | Weleensuu | T/S |
| Eucldivi | *Euclea divinorum* | Mièssaa | T/S |
| Euphcune | *Euphorbia cuneata* | Bursa | T/S |
| Euphnubi | *Euphorbia nubica* | Annoo woraabessaa | T/S |
| Euphtiru | *Euphorbia tirucalli* | Annoo surree | T/S |
| Grewbico | *Grewia bicolor* | Harooressa | T/S |
| Grewtemb | *Grewia tembensis* | Dheekkaa | T/S |
| Grewtena | *Grewia tenax* | Saarkama | T/S |
| Grewvill | *Grewia villosa* | Ogomdii | T/S |
| Harpschi | *Harpachne schimperi* | Biilaa | G |
| Hetecont | *Heteropogon contortus* | Seericha | G |
| Hibispec | *Hibiscus* sp. | Bungaala | T/S |
| Indivolk | *Indigofera volkensii* | Gurbii hoolaa | F |
| Ipokitu | *Ipomoea kituensis* | Osilee | T/S |
| Ischafru | Ischaemum afrum | Guuree | G |
| Kedrpseu | *Kedrostis pseudogijef* | Gaalee adii | T/S |
| Kirkburg | *Kirkia burgeri* | Bisdhugaa | T/S |
| Lannriva | *Lannea rivae* | Handaraka | T/S |
| Maertrip | *Maerua triphylla* | Dhumasoo | T/S |
| Ormotric | *Ormocarpum trichocarpum* | Buutiyyee | T/S |
| Panimaxi | *Panicum maximum* | Loloqaa | G |
| Pappcape | *Pappea capensis* | Biiqqaa | T/S |
| Pennmezi | *Pennisetum mezianum* | Ogoondhichoo | G |
| Plecigna | *Plectranthus ignarius* | Barbaaressa | T/S |
| Premschi | *Premna schimperi* | Xaaxessaa | T/S |
| Rhusnata | *Rhus natalensis* | Daboobeessaa diidaa | T/S |
| Setavert | *Setaria verticillata* | Raphuuphaa | G |
| Solainca | *Solanum incanum* | Hiddii waatoo | T/S |
| Solasoma | *Solanum somalense* | Hiddii gaagaa | T/S |
| Stegaral | *Steganotaenia araliceae* | Luqaaluqqee | T/S |
| Stersten | *Sterculia stencarpa* | Qararrii | T/S |
| Themtria | *Themeda triandra* | Gaaguroo | G |
| Vernphil | *Vernonia phillipsiae* | Qaxxee kormaa | T/S |
| Xerohumi | *Xerophyta humilis* | Areedoo | F |