# CHEMICAL COMPOSITION OF THE GREEN BIOMASS OF INDIGENOUS TREES AND SHRUBS IN THE HIGHLANDS OF CENTRAL ETHIOPIA: IMPLICATIONS FOR SOIL FERTILITY MANAGEMENT

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**KINDU, M., GLATZEL, G., SIEGHARDT, M., BIRHANE, K. & TAYE, B. 2008. Chemical composition of the green biomass of indigenous trees and shrubs in the highlands of Central Ethiopia: implications for soil fertility management.** The use of green biomass of indigenous trees and shrubs to supply nutrients to agricultural crops is a traditional practice in the highlands of Central Ethiopia. A study was carried out from 2004 till 2006 to characterize the quality of the green biomass of indigenous trees and shrubs based on the content of water, macronutrients, lignin and soluble phenolics. The tree and shrub species studied were *Senecio gigas*, *Hagenia abyssinica, Dombeya torrida, Buddleja polystachya* and *Chamaecytisus palmensis*. The first four are indigenous species, while the last is an exotic species. The water content of the foliage in *S. gigas* was the highest. The N content of the foliage of the indigenous species was comparable with *C. palmensis*. The highest K content was found in the foliage, flower bud and stem of *S. gigas*. The lignin content in the foliage and flower bud of *H. abyssinica* was the lowest. Based on the N content, lignin and soluble phenolics, indigenous species had intermediate to high quality, whereas exotic species had high quality green biomass for managing soil fertility.

Keywords: Foliage, flower bud, macronutrient, lignin, soluble phenolics

**KINDU, M., GLATZEL, G., SIEGHARDT, M., BIRHANE, K. & TAYE, B. 2008. Komposisi kimia biojisim hijau pokok asli dan pokok renek di tanah tinggi Ethiopia Tengah: implikasi terhadap pengurusan kesuburan tanah.** Penggunaan biojisim hijau pokok asli dan pokok renek sebagai nutrien kepada tanaman pertanian merupakan amalan tradisi di tanah tinggi Ethiopia Tengah. Kajian dijalankan dari tahun 2004 hingga tahun 2006 untuk menilai kualiti biojisim hijau pokok asli dan pokok renek berdasarkan kandungan air, makro nutrien, lignin dan fenol larut. Spesies pokok dan pokok renek yang dikaji ialah *Senecio gigas, Hagenia abyssinica, Dombeya torrida, Buddleja polystachya* dan *Chamaecytisus palmensis*. Empat spesies yang pertama merupakan spesies asli manakala spesies yang akhir ialah spesies eksotik. Kandungan air dedaun *S. gigas* paling tinggi. Kandungan N dalam dedaun spesies asli agak serupa dengan nilai *C. palmensis*. Kandungan K adalah tertinggi dalam dedaun, kudup bunga dan batang *S. gigas*. Kandungan lignin dalam dedaun dan kudup bunga *H. abyssinica* adalah terendah. Berdasarkan kandungan N, lignin dan fenol larut, kualiti biojisim hijau spesies asli adalah antara pertengahan dengan tinggi manakala spesies eksotik adalah berkualiti tinggi dari segi pengurusan kesuburan tanah.

## INTRODUCTION

The high altitude (> 2900 m above sea level) areas of Central Ethiopia encounter a multitude of problems such as soil degradation, poor crop productivity and limited vegetation diversity (German *et al.* 2005). The local people in the high altitude areas utilize both indigenous and introduced practices to manage soil degradation. The use of green biomass of tree and shrub species is one of the traditional practices that are currently in use to improve soil fertility and thereby increase crop productivity. This type of approach helps to sustain agricultural production in tropical regions where the use of mineral fertilizers is limited. Green biomass

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of trees and shrubs provides nutrient input by nutrient uptake from the subsoil and the organic matter serves as a substrate for the synthesis of humus in the soil. *Hagenia abyssinica*, *Dombeya torrida* and *Senecio gigas* are common tree and shrub species used in high altitude areas as sources of nutrients for cereal and tuber crops (Kindu *et al.* 2006a).

Characterizing the quality of the green biomass of trees can be important to backup the traditional knowledge on soil fertility management strategies. Lignin, soluble carbon, total nitrogen, total phosphorous and soluble phenolics serve as useful indicators to characterize the quality of the green biomass of trees and shrubs (Palm & Rowland 1997). Green biomass of trees and shrubs can be classified into high quality, intermediate–high quality, intermediate–low quality and low quality (Palm *et al.* 2001). A high quality green biomass contains N > 25 mg $g^{-1}$, lignin < 150 mg $g^{-1}$ and soluble phenolics < 40 mg $g^{-1}$; intermediate–high quality green biomass contains N > 25 mg $g^{-1}$, lignin > 150 mg $g^{-1}$ or soluble phenolics > 40 mg $g^{-1}$; intermediate–low quality green biomass contains N < 25 mg $g^{-1}$, lignin < 150 mg $g^{-1}$ and polyphenol < 40 mg $g^{-1}$; and low quality green biomass contains N < 25 mg $g^{-1}$, lignin > 150 mg $g^{-1}$ or soluble phenolics > 40 mg $g^{-1}$. The capacity of the high quality biomass to supply N is high and immediate. The low quality green biomass has a low direct nutrient effect and a high indirect mulching effect (Kumar *et al.* 2003).

The ratios of C to N, lignin to N, soluble phenolics to N and soluble phenolics + lignin to N are also used as indices for predicting nutrient release patterns of green biomass resources from tree and shrub species (Anthofer *et al.* 1998, Mafongoya *et al.* 1998). According to Mafongoya *et al.* (1998), the ratio of soluble phenolics + lignin to N is the most robust indicator for predicting mass loss and nitrogen release in the green biomass of trees and shrubs. Plant materials with a soluble phenolics + lignin to N ratio of less than 10 are regarded as valuable for the release of N.

So far, there is a scarcity of scientific information on the quality of the green biomass of those trees and shrubs in the Ethiopian highlands, which are considered potential sources of plant nutrients. Previous studies of nutrient concentrations and other plant quality characteristics have focused more on exotic tree and shrub species. Therefore, the objective of this study was to characterize the quality of the green biomass of indigenous trees and shrubs based on the content of water, macronutrient, lignin and soluble phenolics.

## MATERIALS AND METHODS

### Site description

The study area was situated in the upper plateaus of the Dendi and Jeldu districts, West Shewa zone, Central Ethiopia (9° 02' 47" to 9° 15' 00" N and 38° 05' 00" to 38° 12' 16" E and 2900 to 3200 m asl). Chilmo state forest borders the study area in the south. The rainfall pattern is bimodal. The main rainy season is from June till September and the short rainy season from March till April with a mean annual rainfall of 1399 mm. Barley is the most dominant crop followed by potato and enset (*Ensete ventricosum*). Cattle, sheep and horses are dominant livestock in the area. The soil is characterized as Haplic Luvisols. The physical and chemical properties of the soil are presented in Table 1.

### Selection and description of trees and shrubs

A total of 150 farm households were interviewed to identify indigenous trees and shrubs that are important as sources of plant nutrients. Farmers preferred tree and shrub species that regularly

**Table 1** Physical and chemical properties of the soil in the study area

| Depth (cm) | pH ($H_2O$) | C (mg $g^{-1}$) | N (mg $g^{-1}$) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| 0–18 | 6.28 | 48.280 | 4.796 | 11.7 | 46.9 | 41.4 |
| 18–60 | 6.19 | 15.290 | 1.316 | 10.7 | 37.3 | 52.0 |
| 60–125 | 5.66 | 4.356 | 0.459 | 3.9 | 34.5 | 61.6 |
| 125–160 | 5.97 | 2.027 | 0.198 | 27.7 | 33.0 | 39.3 |

shed their leaves, have fast decomposing leaves, grow fast, propagate easily, produce high biomass and prevent soil erosion. The top tree and shrub species as a source of plant nutrients include *Senecio gigas*, *Hagenia abyssinica*, *Dombeya torrida* and *Buddleja polystachya*. *Chamaecytisus palmensis* was included in the study for the purpose of comparison with indigenous species. It is a recently introduced exotic woody species.

The exotic species fixes N whereas the four indigenous species do not. *Hagenia abyssinica*, *D. torrida*, *B. polystachya* and *C. palmensis* are useful fodder species for cattle and small ruminants. *Hagenia abyssinica*, *D. torrida* and *B. polystachya* produce high biomass after pollarding and *C. palmensis* and *S. gigas*, after cutting. In addition to the fodder and soil fertility improving value, the bark from *D. torrida* is useful to produce ropes. Propagation of *S. gigas* is easier than in other species as it propagates from stem and root cuttings. The location of the trees and shrubs is in the hedges of the homesteads. The trees and shrubs were found in the hedges as clusters as well as pure stands. None of the tree and shrub species have thorns. Additional information of the species is given in Table 2.

## Methods of plant collection, sample preparation and laboratory analysis

The criteria for the selection of sample plants were based on comparable age, management practices and growing locations. Intensive site selection was carried out in the homesteads of 14 different villages. Three villages that have all the species required for the study were identified. Each village was considered as a replication. The foliage, stem and flower bud samples were collected from 15 to 20 plants of each species in each village. The flower bud samples were included in the sampling, since most species produce a high biomass of flower bud that can be used as sources of plant nutrients.

The total number of composite foliage, stem and flower bud samples was 45 [soil improving tree and shrub species (5) × sampled parts of plants (3) × replications (3)]. Sub-samples were collected from all samples for the water content determination. The fresh mass of each sub-sample was immediately recorded in the field. All the foliage, stem and flower bud samples and sub-samples were oven dried at 80 °C for 24 hours. The dry mass of the sub-samples was recorded and the moisture percentage was calculated. The samples collected for macronutrients, lignin and soluble phenolics were ground with a Cyclotec mill and sieved using a 1 mm diameter mesh.

The total N content of the foliage, stem and flower bud was determined by the Kjeldahl digestion using $Na_2SO_4$ and $CuSO_4$ as catalysts. Digests were made alkaline and ammonia was determined by steam distillation, trapping in boric acid and titrating with 0.1 N HCl. Oven-dried foliage, flower bud and stem samples were extracted with a mixture of $HNO_3$ and $HClO_4$. The total P, K, Ca, Mg and S content of the extracts was determined by the use of a simultaneous ICP-OES with an axial plasma and SCD (Perkin Elmer, OPTIMA 3000 XL).

Lignin was determined by the methods of Van Soest and Robertson (1985). Soluble phenolic compounds were measured by organic solvent extraction and precipitation by trivalent ytterbium (Reed *et al.* 1985). $Yb^{+++}$ forms a complex with free phenolic OH-groups and this complex precipitates. This precipitate is determined gravimetrically and the results are reported as mg phenolics $g^{-1}$ plant material. This method yields quantitative data for total phenolics.

**Table 2** Description of the tree and shrub species included in the foliage, flower bud and stem sampling

| Species | Family | Estimated age (years) | Propagation | Height (m) |
|---|---|---|---|---|
| *Buddleja polystachya* | Loganiaceae | 5–9 | Seed, cutting | 3.1–4.6 |
| *Chamaecytisus palmensis* | Fabaceae | 4–5 | Seed | 4.5–4.9 |
| *Dombeya torrida* | Sterculiaceae | 6–8 | Seed | 4.3–5.0 |
| *Hagenia abyssinica* | Rosaceae | 5–8 | Seed | 4.0–4.6 |
| *Senecio gigas* | Asteraceae | 5–8 | Cutting | 2.7–3.5 |

## Data management and analysis

A one-way analysis of variance (ANOVA) was conducted on the water contents of different aboveground tree components, macronutrients, lignin and soluble phenolics using SAS (SAS Institute 1999). The significance between the means was tested using the least significant difference (LSD). A level of $p < 0.05$ was chosen as the minimum for significance.

## RESULTS AND DISCUSSION

### Water content of the aboveground plant tissues

The indigenous tree and shrub species in general and *S. gigas* in particular had higher water contents in the green biomass, whereas *C. palmensis* had the lowest water content in the foliage, flower bud and stem (Table 3). The higher water content of *S. gigas* resulted from the fact that this is a herbaceous species and, additionally, its slightly succulent character resulting from the presence of specialized cells in the leaves and stems that assist the storage of water. The high water content in *S. gigas* can be important in enhancing decomposition if the green biomass of the tree species is used for soil fertility improvement. On the other hand, higher amount of green biomass can be required from *S. gigas* to fulfil the nutrient requirement of agricultural crops. The water content result of our investigation is in line with the findings of Bashir *et al.* (2000). According to them, the water content of 60 samples of green stems plus leaves collected from hedges of *Tithonia diversifolia* in western Kenya during the dry and wet seasons ranged from 80 to 90%.

### Macronutrient composition of tree species

The macronutrients content in foliage, flower bud and stem differed depending on the species (Table 4). The N contents of the four indigenous species were comparable to that of *C. palmensis*. *Chamaecytisus palmensis* as a N-fixing species was expected to have a higher content of N in its leaves. However, climatic and edaphic factors may affect the nutrient content of the tree and shrub species (Palm 1995). Nevertheless, the N content of foliage and stem of *C. palmensis* from the present study was higher by 5.78 and 2.76 mg $g^{-1}$ than those of *C. palmensis* reported on Nitisols in the central highlands of Ethiopia (Kindu *et al.* 2006b). Likewise, the foliage and stem of *H. abyssinica* had a high content of N as compared with the foliage (21.92 mg $g^{-1}$) and stem (2.49 mg $g^{-1}$) of *H. abyssinica* grown in the central highlands of Ethiopia.

*Chamaecytisus palmensis* tended to have low contents of P in its foliage, flower bud and stem as compared with the other four species (Table 4). The P content in the foliage and flower bud of *S. gigas* and *B. polystachya,* and the K content in the foliage, flower bud and stem of *S. gigas* were higher than those typically found in shrubs and trees. For instance, the P and K content in the foliage of *S. gigas* from the present study was higher by 1.05 and 14.5 mg $g^{-1}$ than the P and K content in the foliage reported for *T. diversifolia* in western Kenya (Bashir *et al.* 2000). The high content of P and K in *S. gigas* may be traced back to the scavenging of these nutrients in a

**Table 3** Water content in the different aboveground parts of the five tree and shrub species

| | Water content (%) | | |
|---|---|---|---|
| Species | Foliage | Flower bud | Stem |
| *B. polystachya* | 76 b | 71 b | 67 b |
| *C. palmensis* | 60 c | 53 c | 39 c |
| *D. torrida* | 73 b | 78 ba | 70 ba |
| *H. abyssinica* | 78 b | 75 ba | 69 ba |
| *S. gigas* | 88 a | 81 a | 78 a |
| SEM | 2.54 | 2.82 | 3.79 |

SEM = standard error of the means (n = 15)
Means with different letters within a column are significantly different ($p < 0.05$).

**Table 4** Macronutrient composition of the foliage, flower bud and stem in the five tree and shrub species

| Foliage | *B. polystachya* | *C. palmensis* | *D. torrida* | *H. abyssinica* | *S. gigas* | SEM |
|---|---|---|---|---|---|---|
| N | 36.66 a | 36.50 a | 37.47 a | 30.07 b | 34.20 ba | 0.94 |
| P | 4.71 a | 2.50 b | 3.76 a | 3.71 ba | 4.75 a | 0.27 |
| K | 21.55 c | 14.93 d | 27.00 b | 21.22 c | 55.50 a | 3.83 |
| Ca | 10.93 b | 9.30 b | 22.97 a | 9.69 b | 11.94 b | 1.42 |
| Mg | 2.07 b | 1.97 b | 2.81 a | 2.38 ba | 2.57 ba | 0.11 |
| S | 3.46 b | 2.55 c | 3.62 ba | 2.03 d | 4.01 a | 0.20 |
| Flower bud | | | | | | |
| N | 27.23 a | 19.78 b | 26.40 a | 27.20 a | 29.75 a | 1.10 |
| P | 5.37 ba | 2.24 d | 4.33 c | 4.54 bc | 5.98 a | 0.36 |
| K | 16.52 c | 10.35 d | 24.59 b | 22.04 b | 31.53 a | 2.01 |
| Ca | 5.64 b | 2.08 c | 10.59 a | 5.54 b | 11.86 a | 1.01 |
| Mg | 1.67 c | 0.80 d | 2.34 b | 2.53 b | 3.21 a | 0.23 |
| S | 2.98 b | 1.73 c | 3.74 a | 2.70 b | 3.84 a | 0.22 |
| Stem | | | | | | |
| N | 6.88 ba | 6.06 b | 8.10 ba | 12.94 a | 9.26 ba | 1.01 |
| P | 1.11 ba | 0.45 b | 1.81 ba | 1.54 ba | 2.53 a | 0.26 |
| K | 9.49 b | 4.64 b | 15.30 b | 16.05 b | 41.30 a | 3.94 |
| Ca | 3.15 cb | 0.96 c | 16.73 a | 8.57 b | 7.68 b | 1.63 |
| Mg | 0.85 bc | 0.39 c | 1.44 ba | 1.68 a | 1.50 ba | 0.15 |
| S | 1.41 cb | 0.43 c | 2.23 b | 1.50 cb | 3.78 a | 0.34 |

N, P, K, Ca, Mg and S are in mg $g^{-1}$ dry matter.
SEM = standard error of the means (n = 15)
Means with different letters within a row are significantly different ($p < 0.05$).

large soil volume and their accumulation in the aboveground organs. According to Garrity and Mercado (1994), members of the Asteraceae, to which *S. gigas* belongs, are effective nutrient scavengers.

The Ca content in the foliage of *D. torrida* was higher than that in the other species. The high Ca content in *D. torrida* could be due to the high water consumption and transpiration rate of the species. Accumulation of Ca depends on water consumption and rate of transpiration (Barber 1995, Marschner 1995). *Dombeya torrida* has large-sized leaves that may be important to increase the rate of transpiration.

*Dombeya torrida*, *S. gigas* and *H. abyssinica* had a relatively higher content of Mg in the foliage, flower bud and stem than *B. polystachya* and *C. palmensis*. The Mg content in the foliage, flower bud and stem of the five species ranged from 1.97 to 2.81, 0.80 to 3.21 and 0.39 to 1.68 mg $g^{-1}$ respectively. The Mg content in the foliage of *S. gigas* is within the Mg sufficiency levels. Nutrient concentration sufficiency values for Ca and Mg in the leaves of crops range from 3 to 30 and 2.5 mg $g^{-1}$ respectively (Jones 1998).

The S content of the foliage in *S. gigas, D. torrida* and *B. polystachya* was comparable. The S content in the foliage of *S. gigas* exceeded that of *H. abyssinica* by more than 1.98 mg $g^{-1}$ and that of *C. palmensis* by 1.46 mg $g^{-1}$. Similarly, the S content in the foliage of *S. gigas* from the present study was much higher than the S content in the foliage of six tree species reported by Hagen-Thorn *et al.* (2004). The high concentration of most nutrients in *S. gigas* biomass is one of the indicators of the usefulness of this species as a source of plant nutrients.

## Lignin and soluble phenolics

The content of lignin and soluble phenolics in the foliage and flower bud differed from species to species. The foliage lignin content was high in *B. polystachya* (173 mg $g^{-1}$) and relatively low in *H. abyssinica* (53 mg $g^{-1}$) (Table 5). The flower bud lignin content in *H. abyssinica* was the lowest (73 mg $g^{-1}$). Generally, the foliage lignin contents of most of the tree and shrub species were below the critical level of 150 mg $g^{-1}$ dry matter. Lignin content above 150 mg $g^{-1}$ impairs the decomposition of tree foliages, since lignin protects the cellulose in the cell wall from microbial attack (Chesson 1997, Palm & Rowland 1997).

Unlike the content of lignin, soluble phenolics were high in the foliage and flower bud of *H. abyssinica*. *Chamaecytisus palmensis* had the lowest foliage soluble phenolics content. The variation between species for soluble phenolics in the foliage was from 10 to 169 mg $g^{-1}$ and in the flower bud from 9 to 234 mg $g^{-1}$ (Table 5). According to Constantinides and Fownes (1994), the soluble phenolics content of green foliage of tree and shrub species can reach as high as 100 mg $g^{-1}$. Soluble phenolics content > 30 to 40 mg $g^{-1}$ results in the immobilization of N (Palm 1995).

## Ratios of C, lignin and soluble phenolics to N

The foliage C to N ratio was highest for *H. abyssinica* (15.49) (Table 6). The flower bud C to N ratio for *C. palmensis* was higher than that of all the other species. The C to N ratios of the five species were within the range of the C to N ratios investigated by Anthofer *et al.* (1998) for nine tree species, and compiled and reported by Mafongoya *et al.* (1998) for 27 N-fixer and

**Table 5** Lignin and soluble phenolics composition of the foliage and flower bud in the five tree and shrub species

| Composition | *B. polystachya* | *C. palmensis* | *D. torrida* | *H. abyssinica* | *S. gigas* | SEM |
|---|---|---|---|---|---|---|
| Foliage | | | | | | |
| Lignin | 173 a | 124 ba | 100 bc | 53 c | 80 bc | 12.37 |
| Soluble phenolics | 82 b | 10 c | 54 b | 169 a | 79 b | 14.41 |
| Flower bud | | | | | | |
| Lignin | 161 b | 98 dc | 199 a | 73 d | 106 c | 12.84 |
| Soluble phenolics | 14 c | 9 c | 15 c | 234 a | 38 b | 23.16 |

Lignin and soluble phenolics are in mg $g^{-1}$ dry matter.
SEM = standard error of the means (n = 15)
Means with different letters within a row are significantly different ($p < 0.05$).

**Table 6** Ratios of C, lignin and soluble phenolics to N for the five tree and shrub species

| Composition | *B. polystachya* | *C. palmensis* | *D. torrida* | *H. abyssinica* | *S. gigas* | SEM |
|---|---|---|---|---|---|---|
| Foliage | | | | | | |
| C:N | 12.93 b | 13.34 ba | 12.17 b | 15.49 a | 12.84 b | 0.41 |
| Lignin:N | 4.76 a | 3.42 ba | 2.68 bc | 1.79 c | 2.34 bc | 0.33 |
| Soluble phenolics:N | 2.22 b | 0.28 c | 1.43 cb | 5.71 a | 2.33 b | 0.51 |
| (Soluble phenolics + lignin):N | 6.98 a | 3.70 b | 4.11 b | 7.50 a | 4.66 b | 0.47 |
| Flower bud | | | | | | |
| C:N | 17.60 b | 24.36 a | 18.31 b | 17.99 b | 15.11 b | 0.93 |
| Lignin:N | 5.92 b | 4.93 b | 7.56 a | 2.84 c | 3.57 c | 0.47 |
| Soluble phenolics:N | 0.50 b | 0.45 b | 0.58 b | 8.80 a | 1.29 b | 0.89 |
| (Soluble phenolics + lignin):N | 6.42 cb | 5.39 cb | 8.14 b | 11.64 a | 4.86 c | 0.73 |

SEM = standard error of the means (n = 15)
Means with different letters within a row are significantly different ($p < 0.05$).

non-fixer tree species. *Hagenia abyssinica* and *S. gigas* had low lignin to N ratios in the foliage and flower bud. On the other hand, *B. polystachya* and *D. torrida* showed higher ratio of lignin to N in the foliage and flower bud. As opposed to the lignin to N ratio, the foliage and flower bud soluble phenolics to N ratio of *H. abyssinica* was higher than that of all the other species. *Chamaecytisus palmensis* had the lowest soluble phenolics to N ratio in the foliage. Due to the moderately high lignin content in *C. palmensis* (Table 5), the phenolics + lignin to N ratio of *C. palmensis* was of the same order as that of *D. torrida*. The ratio of soluble phenolics + lignin to N in foliage and flower bud from *S. gigas* was relatively low as compared with the other species. The lignin + soluble phenolics to N ratios of the foliage and flower bud in most tree and shrub species of the present study were below 10. Plant materials with a soluble phenolics + lignin to N ratio of less than 10 are regarded as valuable for the release of N.

## CONCLUSIONS

The four studied indigenous species in general and *S. gigas* in particular showed superiority in terms of the amount of macronutrients in the foliage, stem and flower bud. The exotic species studied had a reasonable amount of soluble phenolics in the foliage. Based on the content of N, lignin and soluble phenolics, the four indigenous species have intermediate to high quality foliage and flower bud whereas the exotic species, *C. palmensis,* has high quality foliage and flower bud for managing soil fertility.

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