III. Chemical composition of the green biomass of indigenous tree and shrub species in Galessa-Jeldu areas, Ethiopia: Implications for soil fertility management

3.1. Introduction

The high altitude (> 2900 m. a. s. l.) 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 problems. 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 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 the high altitude areas as sources of nutrients for cereal and tuber crops (KINDU et al. 2006).

Understanding the nutrient and chemical composition 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 and 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}; 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.

So far, there is a scarcity of scientific information on the mineral nutrient and chemical composition of the green biomass of those tree and shrub species in the Ethiopian highlands, which are traditionally 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. The objective of this study was to evaluate the potential of the green biomass of indigenous and exotic tree and shrub species for soil fertility improvement based on the content of water, macronutrient, lignin and soluble phenolics.

3.2. Materials and methods

3.2.1. Study site

The study area is situated in the upper plateaus of the Dendi and Jeldu districts, western Shewa zone, central Ethiopia (Appendix 1). The altitude ranges from 2900 to 3200 m.a.s.l. Chilmo state forest borders the study area in the south. The rainfall pattern is bimodal. The main rainy season is from June to September 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 study area. The soil is characterized as Haplic Luvisols. The physical and chemical properties of the soil are presented in Appendix 2.

3.2.2. Characteristics of the tree and shrub species

Senecio gigas Vatke (basionym: *Solanecio gigas* (Vatke) C.Jeffrey; Kew Bull. 41(4): 923 (1986)), *Hagenia abyssinica* (Bruce) J.F. Gmel.*, Dombeya torrida* (J.F. Gmel.) P. Bamps and *Buddleja polystachya* Fres. are indigenous tree and shrub species. *Chamaecytisus palmensis* (Christ) Bisby & K. Nicholls was a recently introduced an exotic N-fixing woody species. *Chamaecytisus palmensis (tree lucerne)* was included in the study for the purpose of comparison. The location of the trees and shrubs is in hedges of homesteads. The trees and shrubs occur in the hedges as clusters as well as pure stands. None of the tree and shrub species have thorns. A more detailed description of the species is given in Appendix 3.

3.2.3. Methods of plant sample collection, sample preparation and laboratory analysis

The criteria for selection of sample plants were based on comparable age, management practices and growing locations. Intensive site selection was carried out in homesteads of 14

different villages. Three villages where all species present were identified. Each village was considered as replication. Five tree and shrub species were demarcated in each village. Foliage, stem and flower bud samples were collected from each tree and shrub species in each village. The foliage samples were collected from all sides of the tree and shrub species. Flower bud samples were included in the sampling scheme, since most species produce a high biomass of flower bud that can be used as sources of plant nutrients.

A representative and sufficient amount of foliage, stem and flower bud samples was collected to evaluate moisture content, nutrient concentration, lignin and soluble phenolics. Three replicate samples of foliage, stem and flower bud were collected. 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 water content determination. The fresh mass of each sub-sample was immediately recorded in the field. All foliage, stem and flower bud samples and sub-samples were oven-dried at 80 ^{o}C for 24 h. 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 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 0.1N 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.

3.2.4. Data management and analysis

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

3.3. Results

3.3.1. Water content of the aboveground plant tissues

The foliage and flower bud water content was higher in *S. gigas* than that of *C. palmensis* (Table 3.1). *Senecio gigas*, *D. torrida* and *H. abyssinica* showed comparable water content in their flower buds and stems. The water content pattern in *H. abyssinica*, *B.polystachya*, *S. gigas* and *C. palmensis* was in the following order: foliage > flower bud > stem. Unlike other species, *D. torrida* had more water content in the flower bud than in foliage and stem.

Table 3.1. Water content in different aboveground parts of five tree and shrub species.

	Moisture content (%)		
Species	Foliage	Flower bud	Stem
Hagenia abyssinica	78^{b}	75^{ba}	69^{ba}
Dombeya torrida	73^{b}	78^{ba}	70^{ba}
Buddleja polystachya	76^{b}	71^{b}	67^{b}
Chamaecytisus palmensis	60^{c}	53^{c}	39^{c}
Senecio 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 ($p < 0.05$).

3.3.2. Macronutrient composition of tree species

The macronutrients content in foliage, flower bud and stem differed depending on the species. The foliage N content in *C. palmensis, B. polystachya* and *D. torrida* was comparable (Figure 3.1). On the other hand, *C. palmensis* had a low N content in its flower bud and stem as compared to the other four tree and shrub species. *Chamaecytisus palmensis* followed by *B. polystachya* had a higher C content in the foliage. The foliage C content in *H. abyssinica* and *D. torrida* was comparable. *Chamaecytisus palmensis* tended to have low contents of P in its foliage, flower bud and stem as compared to the other four species (Figure 3.1). The foliage, flower bud and stem P content in *S. gigas* was higher although it was not statistically different from *B. polystachya* and *D. torrida* (Figure 3.1). Unlike N, the P content was higher in the flower bud than in the foliage and stem for most tree and shrub species.

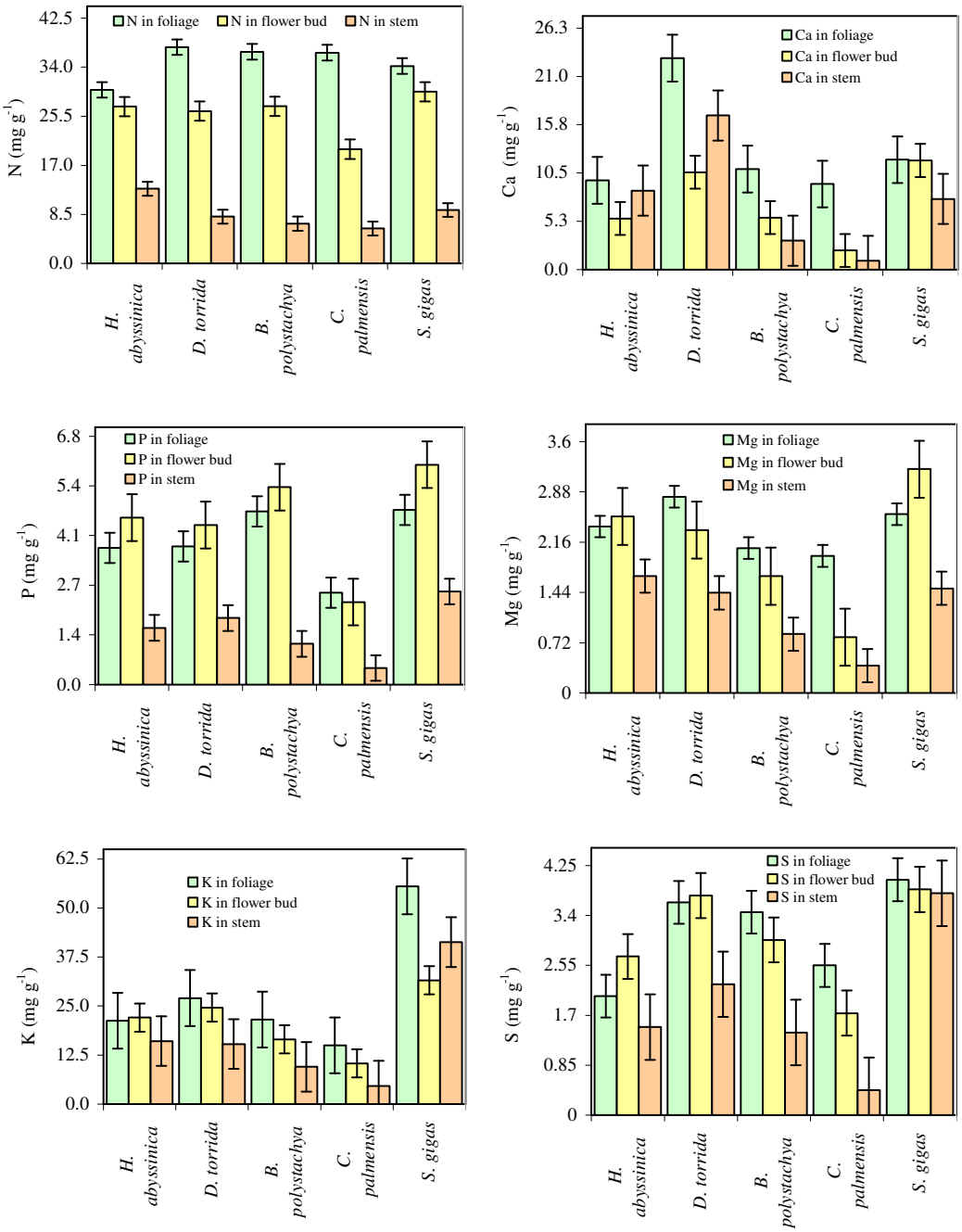

Figure 3.1. Trends of macronutrients in different aboveground parts of five tree and shrub species. Error bars are SEM with n=15.

Senecio gigas showed a higher K content in its foliage, flower bud and stem than all other tree species (Figure 3.1). On the other hand, *C. palmensis* contained the least K content in its foliage, flower bud and stem. The foliage Ca content in *D. torrida* was exceptionally high. *Dombeya torrida*, *S. gigas* and *H. abyssinica* had a relatively higher content of Mg in the foliage, flower bud and stem, respectively. The Mg content in the foliage, flower bud and

stem of the five species ranged from 1.97 to 2.81, 0.08 to 3.21 and 0.39 to 1.68 mg g^{-1}, respectively. The foliage and stem S content in *S. gigas* was higher than the other species. The flower bud S content in *S. gigas* and *D. torrida* was comparable.

3.3.3. Contents of lignin and soluble phenolics

The lignin and soluble phenolics content varied markedly from species to species (Table 3.2). *Hagenia abyssinica* and *C. palmensis* had the lowest lignin and soluble phenolics content, respectively. On the other hand, *B. polystachya* and *D. torrida* had more lignin content in their foliage and flower bud, respectively. The lignin content of *H. abyssinica*, *D. torrida* and *S. gigas* was lower in the foliage than in the flower bud. Except for *H. abyssinica*, the other four tree and shrub species contained little soluble phenolics in the foliage as compared to the flower bud.

Table 3.2. Lignin and soluble phenolics composition of the foliage and flower bud in five tree and shrub species.

Foliage	*Hagenia abyss-inica*	*Dombeya torrida*	*Buddleja polyst-achya*	*Chamaec-ytisus palmensis*	*Senecio gigas*	SEM
Lignin	53^{c}	100^{bc}	173^{a}	124^{ba}	80^{bc}	12.37
Soluble phenolics	169^{a}	54^{b}	82^{b}	10^{c}	79^{b}	14.41
Flower bud						
Lignin	73^{d}	199^{a}	161^{b}	98^{dc}	106^{c}	12.84
Soluble phenolics	234^{a}	15^{c}	14^{c}	9^{c}	38^{b}	23.2

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 ($p < 0.05$).

3.3.4. Ratios of C, lignin and soluble phenolics to N

The foliage C to N ratio was higher for *H. abyssinica* (15.49) (Table 3.3). Likewise, the flower bud C to N ratio for *C. palmensis* was higher than that of all the other species. *Hagenia abyssinica* and *S. gigas* had a low lignin to N ratio in the foliage and flower bud. On the other hand, *B. polystachya* and *D. torrida* showed a higher ratio of lignin to N in the foliage and flower bud, respectively. 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. The ratio of soluble phenolics + lignin to N in foliage and flower bud from *S. gigas* was relatively low as compared to all other species.

Table 3.3. Ratios of C, lignin and soluble phenolics to N for five tree and shrub species.

Foliage	*Hagenia abyss-inica*	*Dombeya torrida*	*Buddleja polyst-achya*	*Chamaec-ytisus palmensis*	*Senecio gigas*	SEM
C:N	15.49^{a}	12.17^{b}	12.93^{b}	13.34^{ba}	12.84^{b}	0.41
Lignin:N	1.79^{c}	2.68^{bc}	4.76^{a}	3.42^{ba}	2.34^{bc}	0.33
Soluble phenolics:N	5.71^{a}	1.43^{cb}	2.22^{b}	0.28^{c}	2.33^{b}	0.51
(Soluble phenolics + lignin):N	7.50^{a}	4.11^{b}	6.98^{a}	3.70^{b}	4.66^{b}	0.47
Flower bud						
C:N	17.99^{b}	18.31^{b}	17.60^{b}	24.36^{a}	15.11^{b}	0.93
Lignin:N	2.84^{c}	7.56^{a}	5.92^{b}	4.93^{b}	3.57^{c}	0.47
Soluble phenolics:N	8.80^{a}	0.58^{b}	0.50^{b}	0.45^{b}	1.29^{b}	0.89
(Soluble phenolics + lignin):N	11.64^{a}	8.14^{b}	6.42^{cb}	5.39^{cb}	4.86^{c}	0.73

SEM - Standard error of the means (n = 15).

Means with different letters within a row are significantly different ($p < 0.05$).

3.4. Discussion

The indigenous tree and shrub species in general and *S. gigas* in particular had higher water contents in the green biomass (Table 3.1). 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 when the green biomass of the tree species is incorporated into the soil. On the other hand, higher amount of green biomass can be required from *S. gigas* to fulfill the nutrient requirement of spatially or temporally associated crops. The water content result of our investigation is in line with the findings of JAMA et al. (2000).

The N contents of the four indigenous species are comparable to that of *C. palmensis*. *Chamaecytisus palmensis* as N-fixing species was expected to have a higher content of N in its leaves. However, climatic and edaphic factors may have a share in affecting the nutrient content of tree and shrub species (PALM 1995). Nevertheless, the N content of the foliage and stem of *C. palmensis* from the present study was higher by 5.78 and 2.76 mg g^{-1} than that of *C. palmensis* reported on Nitisols in the central highlands of Ethiopia (KINDU et al. 2006). Likewise, *H. abyssinica* foliage and stem had high content of N as compared to the foliage and stem of *H. abyssinica* growing in the central highlands of Ethiopia.

The foliage, flower bud and stem P and K contents in *S. gigas* are higher than those typically found in shrubs and trees. For instance, the foliage P and K content in *S. gigas* from

the present study is higher by 1.05 and 14.5 mg g^{-1} than the foliage P and K content reported for *Thitonia diversifolia* in western Kenya (JAMA 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 large soil volume and their accumulation in the aboveground organs. According to GARRITY and MERCADO (1994), members of the Asteraceae family, to which *S. gigas* belongs, are effective nutrient scavengers.

The high Ca content of the foliage in *D. torrida* could be due to the high water consumption and transpiration rate of the species. Accumulation of Ca in the foliage and stem depends on water consumption and rate of transpiration (BARBER 1995; MARSCHNER 1995). The transpiration rate is directly related to the uptake of Ca. *Dombeya torrida* has large-sized leaves that might be important to increase the rate of transpiration.

The foliage Mg content in *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 in the foliage of *S. gigas* exceeds 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 foliage S content in *S. gigas* from the present study is much higher than the foliage S content in the 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 the species as sources of plant nutrients. *Senecio gigas* grows fast and propagates very easily from its stem and root.

The foliage and flower bud lignin and soluble phenolics content differed from species to species. However, the foliage lignin content in most of our tree and shrub species is 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 and ROWLAND 1997). The foliage and flower bud soluble phenolics content in the five species varied from 10 to 169 and 9 to 234 mg g^{-1}, respectively (Table 2.3). According to CONSTANTINIDES and FOWNES (1994), green biomass of tree and shrub species soluble phenolics 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).

The C to N ratios of the five species are 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 non-fixer tree species. The lignin + soluble phenolics to N ratios of the foliage and flower bud in the present study are below 10. A plant material with a soluble phenolics + lignin to N ratio of less than 10 decomposes faster and releases N for use to rapidly growing annual crops (Brady and WEIL 2002).

3.5. Conclusions

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 had a reasonable amount of soluble phenolics in the foliage. Based on the content of N, lignin and soluble phenolics, indigenous species have intermediate to high quality foliage and flower bud whereas exotic species have high quality foliage and flower bud for managing soil fertility. Hence, the indigenous and exotic species can be potential sources of plant nutrients in the high altitude areas where there are limited soil fertility improving options.