CARBON AND HYDROGEN CONTENTS OF SHORT-ROTATION BIOMASS OF FIVE HARDWOOD SPECIES

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ABSTRACT

Carbon, hydrogen, and ash contents were determined on three-year-old, short-rotation trees of autumn olive, black alder, black locust, eastern cottonwood, and sycamore. These plantations were established on marginal agricultural land that was not suitable for food production in Midwestern United States. Test results indicated that elemental analysis varied among species, planting site, and spacing. Black locust had the highest hydrogen content, black alder had the highest carbon content, and eastern cottonwood possessed the greatest ash content. The hydrogen content was higher at bottomland than upland, while the carbon content and ash content were both higher on upland as opposed to bottomland sites. The hydrogen content was higher at narrow spacing, while carbon content was higher at wide spacing. Conversely, hydrogen was not significantly affected by the stem portion, while both carbon and ash contents of the wood, bark, and branches mixture portion were higher than those of the wood portion.

Keywords: Carbon, energy, hardwoods, hydrogen, plantation.

INTRODUCTION

Statement of problems

Woody biomass plays a unique role as a renewable and expandable resource and as one of the world's important raw materials. Since it is a versatile material, mankind has used it in many ways for a long time. It is essential and important, however, to provide further information for the utilization of woody biomass. This study is primarily related to the acceptability of woody biomass for fuel use, and to how environmental factors affect the characteristics of the selected biomass materials.

Although many people think of it as a fuel of the past, wood is rapidly emerging as an important source of energy for the future in North America (Smith 1981). The emergence of wood as a significant source of energy since the early 1970s is due to the increasing cost and the exhaustible nature of fossil fuels (Haygreen and Bowyer 1982). Therefore, the extension of knowledge on the conversion of wood as an energy source is becoming a matter of public interest. Elemental analysis,

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which is one of the important characteristics influencing the energy value of wood, is the main focus on this study.

Nine-tenths of the people in most undeveloped countries today depend on firewood as their chief source of fuel (Eckholm 1975). In remote areas of many developing countries, forests of fast-growing hardwood species are specifically managed as renewable sources of fuel for home and industry (Chow 1977). Some of the important characteristics of wood that is used as fuel are heating value, ultimate analysis (carbon and hydrogen), proximate analysis, moisture content, particle size, and bulk density (Arola 1977 and Karchesy and Koch 1979). Not enough work has been done, however, on ultimate analysis for wood, especially in regard to short-rotation hardwood species.

The carbon and hydrogen analysis can be used to calculate the air required for the combustion of wood. In order to burn any fuel, a certain amount of air is theoretically required to supply the oxygen needed to chemically combine with the fuel (Koch 1972). In practice, some additional air needs to be supplied to insure that all the fuel will come into contact with the oxygen required for combustion. Air supplied in addition to that theoretically required is called excess air (EPA 1976). Nitrogen does not play a significant role in the combustion calculations and can be left out (Koch 1986).

Objectives

The basic experiment conducted in this study was the ultimate analysis of five selected juvenile hardwood species obtained from different sites and spacings at Illinois Agricultural Experimental Station, Dixon Springs, southern Illinois, U.S.A. The objectives of the investigation were:

1. To determine the elemental composition of selected juvenile hardwood samples.
2. To determine the effects of different growth conditions on the carbon (C), hydrogen (H), and ash content characteristics of the five juvenile hardwood materials.

EXPERIMENTAL DESIGN AND METHOD

Factorial design

The main goal of the experiment was to determine if significant differences occur between species, planting site, density, and tree portion on ultimate analysis (C, H, and ash content). The treatment means were undertaken by completely randomized design and considered as separate factors (Snedecor and Cochran 1980 and Huntsberger and Billingsley 1981). A factorial analysis was also conducted.

Factor A (species) had 5 levels: Al = Autumn Olive (*Elaeagnus umbellata* Thumb.), A2 = Black Alder (*Alnus glutinosa* L.), A3 = Black Locust (*Robinia pseudoacasia* L.), A4 = Eastern Cottonwood (*Populus deltoides* Bartr.), and A5 = Sycamore (*Plantanus occidentalis* L.).

Factor B (site) had 2 levels: Bl = Bottomland, and B2 = Upland.

Factor C (spacing) had 2 levels: C1 = narrow (23 cm × 23 cm), and C2 = Wide (31 cm × 46 cm).

Factor D (portion) had 2 levels: D1 = Stemwood, and D2 = Mixture. Thus, the overall design of the experiment was a 5×2×2×2 factorial, which can be illustrated in the following model:

$$\begin{aligned}\gamma_{ijklm} = {} & \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_k + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} \\ & + (\alpha\beta\gamma)_{ijk} + \delta_l + (\alpha\delta)_{il} + (\beta\delta)_{jl} + (\alpha\beta\delta)_{ijl} \\ & + (\gamma\delta)_{kl} + (\alpha\gamma\delta)_{ikl} + (\beta\gamma\delta)_{jkl} + (\alpha\beta\gamma\delta)_{ijkl} + \epsilon_{ijklm}\end{aligned}$$

where,

γ_{ijklm} = dependent variables of hydrogen content, carbon content, and ash content (percent), μ = overall mean, α_i = factor A effect (5 species), β_j = factor B effect (2 sites), γ_k = factor C effect (2 spacings), δ_l = factor D effect (2 portions), m = 1,—6 replications, and ϵ_{ijklm} = experiment error: i = 1,—5 levels of A, j = 1,2 levels of B, k = 1,2 levels of C, l = 1,2 levels of D, and m = 1,—6 replications of each treatment combination.

Method

The method, which was described in the American Society for Testing and Materials (ASTM) Method D3178 (ASTM 1980), covered the determination of total hydrogen, carbon, and ash in the sample of biomass, in one operation by burning a weighed quantity of sample in a closed system. All hydrogen is converted to water and all carbon to carbon dioxide. The combustion was carried out using high purity oxygen that had been passed through a purifying train, while the water and carbon dioxide were recovered in an absorption train. The combustion tube packing was used to remove any interfering substance such as oxides of sulfur.

MATERIALS AND PROCEDURES

Collection and preparation of samples

Three-year-old tree specimens were obtained from plots in Dixon Springs, Illinois, U.S.A. The trees were air-dried, then bundled up by individual species, and stored in a dry location until removed for analyses.

Six test samples were collected from each species. The bark-free stemwood was cut from the top, middle, and bottom of the stem into 25-cm segments. These segments were cut into 12 pieces, and then reduced to particles by passing them through a 40-mesh screen in a Wiley mill. Similarly, the branches and barks were also converted to particles. The mixture samples were made by mixing wood, branch, and bark particles according to their calculated weight percentages (approximately 70% of stemwood, 30% of branch and bark). Test samples were oven-dried and weighed prior to beginning the analysis to minimize variation in moisture, which would introduce error in the hydrogen analysis.

Combustion and determination

A combustion unit consisting of three electrically heated furnace sections was used. The three furnace sections are individually controlled and mounted on rails for easy movement. The upper part of each furnace is hinged so that it can be opened for inspection of the combustion tube or to facilitate cooling. The combustion tube is made of fused silica (quartz), a transparent material that allows observation of the sample.

To determine the composition of the analyzed sample, the percentage of hydrogen, carbon, and ash were calculated using the following formulas:

$$H\% = (W1 \times 11.19)/S$$
$$C\% = (W2 \times 27.289)/S$$
$$Ash\% = W3/S \times 100$$

where,

S = Oven-dry weight of sample (grams)
W1 = Weight gained by water absorber (grams)
W2 = Weight gained by carbon dioxide absorber (grams)
W3 = Weight of Ash (grams)

The guard absorber was used to indicate the capability of the chemical reagents in the water absorber and carbon dioxide absorber. The weight gained by the guard absorber was kept to less than five percent of the weight of W1 plus W2 by frequent changing or refilling the absorbents in the previous two absorbers.

RESULTS AND DISCUSSION

The results of ultimate analysis for the five woody biomasses were analyzed by the computer program, Statistical Analysis System (SAS 1982). The results of the elemental composition of stemwood and the mixture portions of selected woody biomass are given in Table 1.

Hydrogen content

The overall average hydrogen content for all samples from different species was 6.4%, which is the same as the average hydrogen content of hardwoods in previous reports (Karchesy and Koch 1979). Koch (1972) reported that the hydrogen content of southern pine is less than 6%. The analysis of variance indicated that only the species factor had a significant effect on hydrogen content within the 1% level, but other factors such as site, spacing, species × spacing interaction, site × spacing interaction, and species × portion interaction, were all significant at the 5% level. All other factors were not significant. In contrast, as shown from the results of Duncans Multiple Range Test in Table 2, only black locust vs. other species was significant at the 5% level, while the rest were non-significant at the 5% level.

Carbon content

The average carbon content of the five selected woody biomass species was 50.0%, which is quite similar to the average values of carbon content of hardwood species in a previous report (Karchesy and Koch 1979). The southern pine wood has about 52% of carbon content reported by Koch (1972). The analysis of variance indicated that the factors of species, spacing, species × spacing interaction, site × spacing interaction, portion, species × portion interaction were all significant at the 5% level; site factor was significant at the 5% level, all other factors were not significant. The contrast analysis presented in Table 2 shows that black alder vs. other species, black locust vs. other species, narrow vs. wide, and wood vs. mixture were all significant at the 5% level.

TABLE 1. *Ultimate analysis of selected woody biomass.*

Species	Site	Spacing	% Hydrogen W[a]	% Hydrogen M[b]	% Carbon W	% Carbon M	% Ash W	% Ash M
Autumn olive	Bottomland	Narrow	6.26	6.48	49.25	49.88	1.32	0.49
		Wide	6.41	6.45	49.47	49.64	1.81	1.21
	Upland	Narrow	6.41	6.45	49.35	51.02	1.87	1.62
		Wide	6.49	6.30	50.10	50.78	1.18	1.49
Black alder	Bottomland	Narrow	6.13	6.34	48.54	50.02	0.79	1.45
		Wide	6.54	6.44	51.07	52.34	1.63	2.70
	Upland	Narrow	6.31	6.43	50.43	51.18	1.81	0.84
		Wide	6.29	6.35	50.72	51.82	1.72	2.21
Black locust	Bottomland	Narrow	7.19	6.45	49.45	48.98	0.82	2.23
		Wide	6.43	6.49	49.43	49.62	0.57	2.00
	Upland	Narrow	6.83	6.43	49.37	49.53	0.84	2.05
		Wide	6.48	6.40	48.67	49.08	2.29	2.68
Eastern cottonwood	Bottomland	Narrow	6.55	6.64	50.46	48.73	1.55	1.87
		Wide	6.53	6.22	50.38	50.42	0.43	1.42
	Upland	Narrow	6.45	6.39	50.42	50.62	1.89	2.72
		Wide	6.28	5.88	49.91	50.29	1.19	2.95
Sycamore	Bottomland	Narrow	6.62	6.42	48.61	49.49	0.98	1.80
		Wide	6.28	6.35	50.28	50.41	0.93	0.93
	Upland	Narrow	5.90	6.52	49.63	49.62	1.17	1.29
		Wide	6.16	6.15	49.31	50.19	0.70	1.71

[a] Wood portion.

[b] Mixture of wood, bark, and branches.

TABLE 2. *Duncan's Multiple-Range Tests.*[1]

a) Species =

H	S5	S2	S4	S1	S3
C	S3	S5	S1	S4	S2
Ash	S5	S1	S2	S3	S4

S1 = Autumn olive, S2 = Black alder, S3 = Black locust, S4 = Eastern cottonwood, S5 = Sycamore.

b) Site =

H	U (upland)	B (bottomland)
C	B	U
Ash	B	U

c) Spacing =

H	W (wide)	N (narrow)
C	N	W
Ash	N	W

d) Portion =

H	M (mixture)	W (wood)
C	W	M
Ash	W	M

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[1] Means with same line are not significantly different, significant level = 5%. The results of the analysis of variance indicated that species, site, spacing, and wood portion significantly (5% level) affected the C, H, and ash contents, except that the ash and hydrogen content were not affected by planting spacing and the wood portion, respectively.

Ash content

The average values of ash content in all samples investigated was 1.5%, which is close to the average ash content of hardwood species reported in a previous study (Chow 1980). The ash content of the two-year-old tree was 1.1%. The percentage of ash was greater in bark than in wood, branches, and mixtures of these parts. Furthermore, mineral content in these sycamores was greater than in matured sycamore wood. The analysis of variance indicated that the effects of factors such as species, site, species × spacing interaction, portion, and species × portion interaction on ash content were significant at the 5% level.

The results of contrast analysis are shown in Table 2. The only composition that was significant at the 5% level was wood vs. mixture. The contrast analysis of both sycamore or autumn olive vs. other species and bottomland vs. upland were significant at the 5 percent level.

CONCLUSIONS

Based on the test results, the following comments can be made:

1) Elemental analysis varied among species. Black locust had the highest hydrogen content, black alder had the highest carbon content, and eastern cottonwood had the highest ash content. Also, all elements varied by site, with the hydrogen content higher at bottomland than upland. The carbon content and ash content were both higher on the upland as opposed to bottomland. The hydrogen content was higher at narrow spacing, while carbon content was higher at wide spacing.

2) Both carbon and ash contents of the stem mixture portion were higher than those of the stemwood portion, while hydrogen content was not significantly affected by stem portion.

3) The carbon content of each species was more consistently affected by the three main factors than the hydrogen and ash content. However, no individual species concurrently had the highest hydrogen and carbon contents, and the lowest ash content that would be an ideal wood species for energy use.

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