AN INVESTIGATION ON CALORIFIC ENERGY DISTRIBUTION IN COTTON PLANT ORGANS

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Abstract

This article presents an investigation on quantitative calorific energy distribution in cotton plant organs. This research is part of a continuing program to obtain precise thermal analysis data from different energy storage crops and agricultural by-products. Data obtained from cotton plants (Stoneville 474) that were collected before the harvest of product. A bomb calorimeter (Model C5000, IKA®-Werke) was used to determine the calorific values. There were differences in calorific energy among the cotton plant organs. The energy distribution was become as follows: root, stem, branches, bolls, leaves and terminal. Of great interest is the relatively high amount of energy involved in the bolls. The basic cotton calorific values are 17.550 J/g.

Introduction

Plants have always been the most important resource for humanity, not only for food and animal feed, but also for other important biomaterials, such as wood, oils, fibres, and energy. Plant cells produce biomass from simple chemical building blocks in the air and the soil, including carbon dioxide, nitrogen and water, using the sun as a free energy source. Fossil resources – limited in availability and a major source of greenhouse gas emissions – will need to be replaced with renewable resources. The transition to a sustainable economy based largely on renewable resources – the bio-based economy – is as inevitable as it is desirable. Energy crops may be best suited to high value energy products and services to offset costs of a dedicated biomass production system. They may also prove to be valuable as a supplementary fuel used if other biomass wastes cannot satisfy demands. Agricultural wastes are mainly vegetal materials and by-products derived from production, harvesting, transportation and processing in farming areas. It includes, among others, maize cobs and stalks, wheat stalks and husks, groundnut husks, cotton stalks, etc. [1].

The biomass available after the harvest of cotton is rich in cellulose, hemicellulose and lignin, which is alike to most of the hard woods and therefore an excellent raw material as biofuel. Greece holds first place in cotton production within the European Union and is one of the major cotton exporting countries at global level. Over the period 1980 - 1999 there was an annual average rate of increase of 7,2% in production of unginned and ginned cotton, while from 2000 - 2007 there was a downward trend. Thessaly accounts for 40% of uniginned cotton, Macedonia for 31% and Mainland Greece 17,2% [2]. About 800.000 tonnes of cotton plant stalks are generated in Greece annually. On an average about 2 to 3 tonnes of stalk are generated in one hectare of land. The bulk of the stalk is burnt in the fields after the harvest of the cotton crop although it is not desirable since it causes air pollution. At the same time, cotton stalks piled up in the field harbour pests and disease causing organisms. The yield of biomass varies from species to species. Depending upon the variety and the crop conditions, the stalks are 0,80 to 1,50 meter long and their diameter just above the ground may vary from 1 to 2,5 cm. The specific weight of short chopped stick is about 160 kg/m^3. The calorific value of cotton stalks is equivalent to poor quality wood [3].

Heating value (or calorific value) is essentially a material for burning as fire or as a thermal source of energy. The amount of thermal energy stored can be measured through the heating value or calorific value of biomass samples. The higher heating value (HHV), or gross calorific value (GCV), measures the total amount of heat that will be produced by combustion. However, part of this heat will be locked up in the latent heat of the evaporation of any water existent in the biomass sample during combustion. The lower heating value (LHV), or net calorific value (NCV), excludes this latent heat. Thus, the lower heating value is that amount of heat actually available from the combustion process for capture and use [4], [5].

Due to the versatility and diversity of biomass, sufficient data and documentation as regards its availability and consumption/utilization pattern are not easily available. Although biomass meets a major part of the total energy requirements, it does not find an appropriate place in the overall energy balance of Greece, probably due to reasons cited above. The aim of this paper is the investigation on quantitative calorific energy distribution in cotton plant organs. This research is part of a continuing program to obtain precise thermal analysis data from different energy storage crops and agricultural by-products.

Materials and Methods

Cotton is primarily an agricultural crop, but it can also be found growing wild. There are more than 30 species of cotton plants, but only few are used to supply the world market for cotton. The leaves are heart-shaped, lobed, and coarse veined, somewhat resembling a maple leaf. The plant has many branches with one main central stem. Overall, the plant is cone or pyramid-shaped. Figure 1 shows the different types of branches and the other organs on the plant. Vegetative branches grow from the bottom of the plant and produce very little cotton. Fruiting branches on the main stem of the plant produce most of the crop. The bottom fruiting branch does not produce very much, the bolls are not very heavy and the quality is often poor. Most of the top grade comes from the middle of the plant.

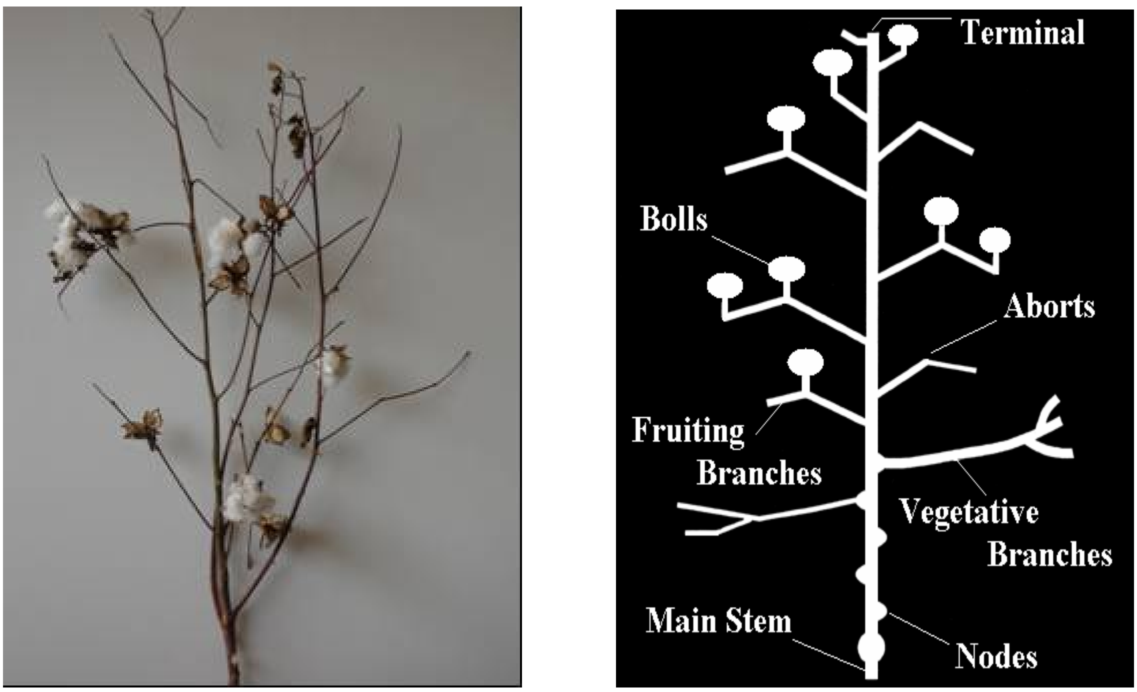

Figure 1. Cotton plant and its model [6] showing the different types of branches and the other organs

Data obtained from different cotton plants (Stoneville 474) that were collected before the harvest of product in November 2007 in the periphery of Thessaly. Before the samples were used for analysis, they were re-dried at 70ºC for 48 hours. Bomb calorimeter (Model C5000 Adiabatic Calorimeter, IKA®-Werke, Staufen, Germany) (Figure 2) was used to determine the calorific energy distribution in cotton plant organs. The calorimeter bomb and the metal container surrounding it form the kernel of the calorimetric system, which is placed in a thermally insulated jacket. A primary temperature transducer, placed inside the unit, records the change in the system temperature due to the combustion of the fuel in the bomb. The calorimeter also contains a cooling system. The bomb calorimeter enables a rapid analysis to be carried out, the basic time of which cannot be reduced, since it is related to the fuel combustion process itself. The following mathematical formulas are used to calculate results of measurements. The calorimeter system acquires the data required for the measurements partially during the combustion process and the data is partially the results of analyses of examination on cotton plant biomass samples. The calculations correspond to the applicable standards for gross calorific values:

$$H_{Oan} = \frac{C \times \Delta T - Q_Z}{m} \quad (1)$$

where: H_{Oan} is the gross calorific value in reference state analysis moist [J/g] (this is the provisional gross calorific value without acid or water correction), C is the heat capacity of the calorimeter [J/K], ΔT is the increase in temperature of the calorimeter system during a combustion experiment [K], Q_Z is the extraneous energy from ignition, combustion of the cotton thread, combustion aids [J], and m is the mass of the cotton plant biomass sample [g].

A calculated net calorific value for the cotton plant biomass samples was determined by the following formula:

$$H_{Uan} = H_{Oan} - (H_2O \times 24{,}41) \quad (2)$$

where: H_{Uan} is the net calorific value in reference state analysis moist [J/g], H_2O is the percentage [%] of water in the cotton plant biomass sample. Because cotton plants were re-dried, the gross calorific value is equal to net calorific value (H_{Oan}= H_{Uan}).

Figure 2. Bomb calorimeter C5000 IKA®-Werke

Totally, were obtained 10 measurements by each organ of cotton plants and then became statistical analysis of these data. The comparisons for the estimation of differences between the mean values were done using the Duncan's new multiple range test. All the statistical analyses were done at level of confidence 0,05.

Results and Discussion

The results of calorific energy analysis in cotton plants could be helpful in developing highly applicable and productive planning for energy policies. Some investigators have experimentally studied the ultimate and proximate analyses of cotton stalks and have also reported that the calorific values of dry cotton stalks are varying from 15.861 to 18.100 J/g.

Table 1 presents calorific energy (J/g) distribution in cotton plant organs: root, main stem, terminal, vegetative branches, fruit branches, leaves and bolls. There were significant differences in calorific energy in the different plant organs. For the root and main stem, calorific energy varied between 17.671–17.768 J/g and 17.645–17.799 J/g respectively. This result suggests that root and main stem had the same calorific energy values. The differences between main stem and branches (vegetative and fruiting) were very little significant. Specifically, for the vegetative branches were measured 17.070–17.598 J/g, while for the fruiting branches calorific values varied between 17.065–17.548 J/g. The lowest mean calorific energy value in all plant organs was observed at leaves (15.955 J/g). Furthermore, after combustion process, it was observed significant ash residue in the crucible of decomposition vessel. Great interest is the relatively low amount of energy observed in the cotton terminal. This amount was similar to that of the leaves. Obviously, it was owed to linear relationship between calorific energy and fertilizer application levels. The basic cotton terminal calorific values varied between 16.105–16.643 J/g.

Seeds have higher energy values compared to other cotton plant organs. This higher energy value of seeds (22.750–23.078 J/g) might be due to higher lipid content which reflects optimal environmental condition for the plant. The energy stored in this part is used to support growth and reproduction of plants in the following season. Furthermore, significant differences in calorific energy were observed in other organs of cotton bolls. As for the locks, calorific energy varied between 16.503–16.934 J/g, while for the cotton bur calorific values were measured 16.941–17.292 J/g.

In figure 3 there is shown an effort of mapping of calorific energy distribution in the different organs of cotton plant No 5. The mapping is based on repeated measurements per 2 cm on entire the main stem and the branches of the cotton plant. It is obvious that the higher calorific values are presented on his main stem while the lowest were measured in the upper part of the plant and mainly in his terminal.

Additionally, in figure 3 there is a presentation of the mapping of calorific energy distribution in bolls of cotton plant N_o 5. Except for the high calorific values that are presented in the region of seeds and depicted with the intense red colour, equally high calorific values are observed in bur.

The calorific energy of cotton plant material varies within the different plant organs, between plants species, and also within plants in different environment. Some of the environmental factors that have profound effects on calorific energy distribution in cotton plants include nitrogen fertilization and light intensity. Thus, the next steps of this research project will be to examine calorific energy between different plants species of cotton and under different environment conditions as nitrogen fertilization and light intensity.

Table 1. Calorific energy in cotton plant organs

Cotton Plants	Mean calorific values from different organs of cotton plants [J/g]						Mean calorific values from different parts of cotton bolls [J/g]		
	Root	***Main Stem***	***Terminal***	***Vegetative Branches***	***Fruiting Branches***	***Leaves***	Bur	Locks	Seeds
Plant No 1	17.690	17.691	16.345	17.276	17.192	16.087	17.145	16.784	22.750
Plant No 2	17.718	17.767	16.470	17.389	17.489	16.055	17.119	16.543	23.008
Plant No 3	17.682	17.671	16.178	17.378	17.361	16.034	16.993	16.665	22.895
Plant No 4	17.689	17.799	16.384	17.598	17.505	15.955	17.210	16.624	22.911
Plant No 5	17.750	17.758	16.528	17.466	17.386	16.061	17.133	16.686	22.993
Plant No 6	17.671	17.730	16.491	17.392	17.417	16.023	17.042	16.661	22.935
Plant No 7	17.768	17.795	16.643	17.435	17.452	16.102	17.292	16.724	22.750
Plant No 8	17.751	17.774	16.380	17.475	17.495	16.126	17.114	16.870	22.987
Plant No 9	17.673	17.645	16.434	17.070	17.065	16.081	17.191	16.547	23.078
Plant No 10	17.681	17.698	16.105	17.279	17.323	16.069	17.170	16.687	23.027
Plant No 11	17.699	17.711	16.230	17.387	17.411	16.036	17.199	16.579	22.930
Plant No 12	17.712	17.718	16.302	17.430	17.417	15.958	17.237	16.902	23.017
Plant No 13	17.703	17.698	16.242	17.272	17.280	16.100	17.061	16.503	22.963
Plant No 14	17.758	17.786	16.570	17.554	17.548	16.113	16.941	16.934	22.960
Plant No 15	17.739	17.728	16.305	17.491	17.440	16.081	17.117	16.545	22.978

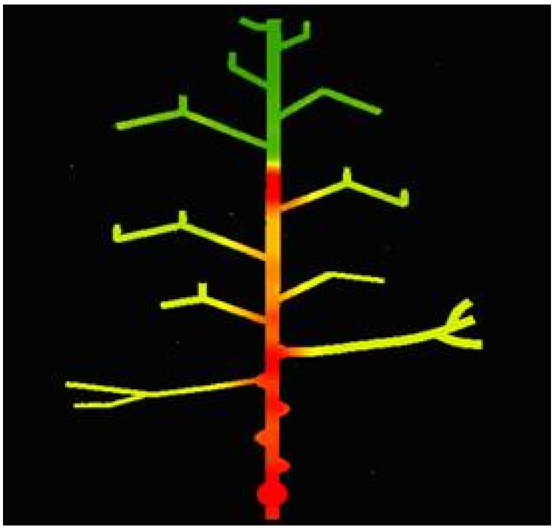

Figure 3. Mapping of calorific energy distribution in cotton and bolls of plant N_o 5

Conclusions

The main conclusions that may be drawn from the present study on the calorific energy distribution in cotton plant organs are listed below:

- Quantitative calorific energy analysis in cotton plants (Stoneville 474) showed that significant differences exist in calorific energy distribution on different cotton plant organs.
- Root and main stem had the same calorific energy values (17.645–17.799 J/g).
- Differences between main stem and branches (vegetative and fruiting) were very little significant.
- The lowest mean calorific energy value in all plant organs was observed at leaves (15.955 J/g).
- Seeds have the highest energy values (22.750–23.078 J/g).
- There is need for further investigation to determine the calorific energy between different plants species of cotton and under different environment conditions as nitrogen fertilization and light intensity.

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