Caloric Analyses of the Distribution of Energy in Ripened Cotton (*Gossypium hirsutum* L.)

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Caloric analyses of the distribution of energy were carried out for Suregrow 125 and DPL-50 cotton plants 40, 101, and 115 days after emergence and for ripened cotton. For these analyses, plants were harvested, dried, weighed, and subsequently analyzed for protein, crude fat, lignin, cellulose, hemicellulose, nitrogen-free solubles, and total gossypol according to standard AOAC methods. In ripened cotton, approximately twice as much caloric energy was found to be released in the combustion of seed in comparison with lint. About half of the caloric content was constituted in lint and seed, the remainder apportioned to vegetative tissues. With 40-day-old plants, the content of nitrogen-free solubles was high and decreased steadily through the 101st and 115th days after emergence with a concomitant increase in cellulose, hemicellulose, and lignin.

Keywords: *Caloric analysis; Gossypium hirsutum L.; ripened cotton; energy distribution*

INTRODUCTION

Research has shown that each square (fruiting structure) on the cotton plant does not contribute equally to lint yield. Bolls from first-position squares (first potential boll on all fruiting branches) contribute 66−75% and bolls from second-position squares contribute 18−21% to total yield of modern cultivars when plants are spaced three to four per row foot (Jenkins et al., 1990a,b; Kerby et al., 1987).

Modern cultivars, as compared to obsolete cultivars, make an earlier transition from vegetative to reproductive development during the time when maximal leaf mass and area are present (Wells and Meredith, 1984a,b). Management of cotton growth and development can be greatly aided by a quantification of the contribution of various fruiting sites in cultivars of various maturities. The weight of seed cotton (lint plus seed weight) in a boll also varies among fruiting sites in a cotton plant. In a study of eight cultivars, bolls from position 1 were 14% larger than bolls from position 3 (Jenkins et al., 1990b). Boll weights at each fruiting position also varied among nodes. Weights of bolls at position 1 increased from node 6 to node 12 and then decreased for the remaining nodes (Jenkins et al., 1990b). Meredith and Bridge (1973) reported that as the season progresses, the bolls that set and mature are smaller. Recently, Jenkins and McCarty (1995) compared selected current cultivars, experimental lines, and selected F_2's from hybrid lines for the contribution of each fruiting site to yield using data generated from plant maps of plants at harvest. They confirmed the previous findings and also showed that differences among their lines for yield distribution by position were not significant. The need for full-season management was confirmed to maximize yields.

In this study, previous data on weights of lint, seed, burs, stems, and branches were integrated with analyses of these plant parts for protein, fat, lignin, cellulose, hemicellulose, and nitrogen-free solubles to provide a caloric analysis of the distribution of energy in ripened cotton. This information could contribute to the development of a cotton plant in which the ratios of lint, seed, and vegetative tissues might be manipulated to develop optimal relationships. Since lint has the higher economic value, a shift in favor of lint over seed and vegetative tissues would increase returns to the cotton producer. For comparison and as background, caloric analyses of tissues from cotton plants at 40, 101, and 115 days after emergence were also carried out.

MATERIALS AND METHODS

Plant tissues were harvested at 40, 101, 115, and 130 days (ripened) after emergence, weighed, and analyzed for protein, crude fat, lignin, hemicellulose, cellulose, nitrogen-free solubles (extract), and gossypol. The cotton lines were Suregrow 125 and DPL-50. The 40-day-old plants were dissected to give leaves, stems, squares, and roots. The 101- and 115-day-old plants were dissected to give opened burs, green burs, unopened bolls, lint, seed, branches, main stem, leaves, and squares. The 130-day-old ripened plants were dissected to give lint, seed, and burs, respectively, at positions 1, 2, 3, and 4 (vegetative) and also main stem and branches.

The 130-day-old ripened plant samples consisted of 20 plants each replicated four times. The tissues were grouped according to plant structure and location on the plants as stated above. The position refers to the order in which buds (potential bolls) are produced on a fruiting branch. Position 1 refers to the first potential boll on all fruiting branches. Samples collected at 40, 101, and 115 days also consisted of 20 plants each, but they were not replicated. Plant weights were the only data that were processed using ANOVA procedures (SAS Institute, 1991). Association of Official Analytical Chemists (AOAC) methods (Horwitz, 1975) were used for the following analyses: total solids (moisture), 14.083; crude fat, 14.019; ash, 14.114; total protein, 2.049 (% N × 6.25); nitrogen-free extract (NFE) by difference from 100%. AOAC methods were also used for analysis of acid detergent fiber (973.18) and lignin (by loss on ignition, 973.18C) (Helrich, 1990). Neutral detergent fiber was determined according to the methods of Van Soest and Wine (1967). From these procedures, lignin, cellulose, and hemicellulose were determined directly and soluble cell wall contents by difference from 100%. Total gossypol was determined by the aniline test (Pons et al., 1958). Caloric calculations were based on standard caloric values per

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Table 1. Caloric Analysis of Energy Distribution in Ripened Cotton[a,b]

tissue[c]	normalized plant wt[d] (100 g)	protein %	total cal protein	fat %	total cal fat	lignin %	total cal lignin	cellulose %	total cal cellulose	hemicellulose %	total cal hemicellulose	N-free solubles %	total cal NFS	total cal (100 g/plant)	free gossypol %	total gossypol %	total cal gossypol
lint																	
1	10.59a	2.65	1.58	0.64	0.63	0.64	0.29	95.65	43.92	0.42	0.19	0	0	46.61 (9.9%)	0	0	0
2	3.99b	1.33	0.30	0		0.85	0.15	97.82	16.55	0	0	0	0	17.00 (3.6%)	0	0	0
3	1.94c	2.65	0.29	0		2.54	0.21	94.81	7.90	0	0	0	0	8.40 (1.8%)	0	0	0
4 (veg)	2.98	2.65	0.44	0		0	0	97.35	12.69	0	0	0	0	13.13 (2.9%)	0	0	0
	19.50		2.61 (5.1%)		0.63 (1.3%)		0.65 (1.2%)		81.06 (35.2%)		0.19 (0.9%)		0	85.14 (18.3%)			
seed																	
1	16.70a	16.43	15.37	14.13	21.95	10.73	7.71	34.60	24.85	2.20	1.58	21.91	15.73	87.19 (18.7%)	0.27	1.20	1.58
2	6.44b	18.50	6.67	13.70	8.21	10.08	2.79	35.70	9.89	2.60	0.72	19.42	5.38	33.66 (7.2%)	0.19	1.29	0.66
3	3.01c	26.01	4.38	14.13	3.96	8.98	1.16	32.00	4.14	5.70	0.74	13.18	1.71	16.09 (3.4%)	0.23	1.55	0.37
4 (veg)	5.00	21.82	6.11	17.35	−8.07	9.60	2.06	23.10	4.97	13.50	2.90	14.63	3.15	27.26 (5.8%)	0.44	1.28	0.61
	31.14		32.53 (64.2%)		42.19 (92.0%)		13.72 (25.4%)		43.85 (19.0%)		5.94 (28.1%)		25.97 (40.0%)	164.20 (35.2%)			3.32
Burs																	
1	10.29a	4.26	2.45	0.91	0.87	19.75	8.74	48.40	21.39	1.82	0.81	24.86	11.02	45.28 (9.7%)	0.11	0.12	0.10
2	4.06b	4.95	1.13	1.02	0.39	20.36	3.55	45.90	8.02	2.26	0.39	25.47	4.45	17.93 (3.8%)	0.11	0.11	0.04
3	1.72c	6.40	0.62	1.02	0.16	21.15	1.56	44.30	3.28	2.73	0.20	24.32	1.80	7.62 (1.6%)	0.11	0.11	0.02
4 (veg)	2.83b	4.23	0.67	1.24	0.33	20.53	2.50	46.70	5.68	2.03	0.25	25.27	3.07	12.50 (2.6%)	0.11	0.12	0.03
	18.91		4.87 (9.6%)		1.75 (3.8%)		16.35 (30.3%)		38.37 (16.6%)		1.65 (7.8%)		20.34 (31.3%)	83.33 (17.8%)			0.19
main stem[e] and branches	30.45	6.24	10.63 (21.0%)	0.44	1.25 (2.9%)	17.73	23.20 (43.1%)	51.20	66.99 (29.2%)	10.19	13.33 (63.2%)	14.21	18.60 (28.7%)	134.00 (28.7%)	0.11	0.12	0.29
totals	100.00		50.64		45.82		53.92		230.27		21.11		64.91	466.67			3.70[e]

[a] Calories per gram: protein, 5.6; fat, 9.3; soluble and insoluble carbohydrates, 4.3; cellulose and hemicellulose, 4.3 (estimate); gossypol, 7.9 (estimate). [b] Analyses by AOAC Methods; see Materials and Methods. [c] Position 1, nodes 5−25; positions 2, 3, and vegetative (veg) refer to bolls on nodes 5−25 beyond position 1. [d] Means followed by a common letter are not statistically different. [e] Analyses were performed only on mainstem tissue but assumed to be similar for fruiting and vegetative branches.

Table 2. Caloric Analysis of Energy Distribution of Cotton Plants 40 Days after Emergence[a,b]

tissue	normalized plant wt (100 g)	protein %	total cal protein	fat %	total cal fat	lignin %	total cal lignin	cellulose %	total cal cellulose	hemicellulose %	total cal hemicellulose	N-free solubles %	total cal NFS	total cal (100 g/plant)	total gossypol %	total cal gossypol
leaves	52.5	18.5	54.4	2.1	10.4	2.4	5.4	8.4	18.9	7.8	17.6	60.8	137.3	244.1	0.15	0.62
stems	28.4	4.4	7.0	0.6	1.6	11.0	13.4	35.0	42.7	11.0	13.4	38.0	46.4	124.6	0.05	0.11
squares	0.3	22.5	0.4	2.7	0.1	4.0	0.1	10.4	0.1	2.6	0.1	57.8	0.7	1.4	0.33	0.01
roots	18.8	15.6	16.4	2.2	3.8	8.3	6.7	31.1	25.1	11.3	9.1	31.5	25.5	86.7	0.25	0.37
totals			78.2		15.9		25.6		86.8		40.2		209.9	456.8		1.11

[a] Calories per gram: protein, 5.6; fat, 9.3; soluble and insoluble carbohydrates, 4.3; cellulose and hemicellulose, 4.3 (estimate); gossypol, 7.9 (estimate). [b] Analysis by AOAC Methods; see Materials and Methods.

Table 3. Caloric Analysis of Energy Distribution of Cotton Plants 101 Days after Emergence[a,b]

tissue	normalized plant wt (100 g)	protein %	total cal protein	fat %	total cal fat	lignin %	total cal lignin	cellulose %	total cal cellulose	hemi-cellulose %	total cal hemicellulose	N-free solubles %	total cal NFS	total cal (100 g/plant)	total cal gossypol	total cal gossypol
opened burs	3.3	8.1	1.5	1.7	0.5	12.6	1.8	37.2	5.3	4.6	0.7	35.8	5.1	14.9	0.24	0.06
green burs[c]	11.5	8.8	5.7	2.1	2.2	8.4	4.2	28.8	14.2	7.6	3.8	44.3	21.9	52.0	0.14	0.13
unopened bolls[c]	23.0	8.8	11.3	10.9	23.3	2.0	2.0	45.0	44.5	10.4	10.3	22.9	22.6	114.0	0.36	0.65
lint	2.7	0	0	0	0	0.6	0.1	89.2	10.4	2.2	0.3	8.0	0.9	11.7	0	0
seed	5.3	13.8	4.1	5.2	2.6	6.6	1.5	45.8	10.4	0	0	28.6	6.5	25.1	0.89	0.37
branches	12.3	6.3	4.3	0.7	0.8	9.2	4.9	33.0	17.5	11.6	6.1	39.2	20.7	54.3	0.01	0.01
main stem	20.4	4.4	5.0	0.6	1.1	10.4	9.1	37.0	32.4	11.0	9.6	36.6	32.1	89.3	0.01	0.02
leaves	20.7	16.3	18.9	4.0	7.7	17.2	15.3	10.4	9.3	3.0	2.7	49.1	43.7	97.6	0.06	0.10
squares	0.8	22.5	1.0	2.7	0.2	4.0	0.1	10.4	0.4	2.6	0.1	57.8	2.0	3.8	0.33	0.02
			51.8		38.4		39.0		144.4		33.6	155.5	462.7		1.36	

[a] Calories per gram, protein, 5.6; fat, 9.3; soluble and insoluble carbohydrates, 4.3; cellulose and hemicellulose, 4.3 (estimate); gossypol, 7.9 (estimate). [b] Analysis by AOAC Methods; see Materials and Methods. [c] Green bolls were dissected to separate green burs (column 2) from the inner lint and seed (column 3).

Table 4. Caloric Analysis of Energy Distribution of Cotton Plants 115 Days after Emergence[a,b]

tissue	normalized plant wt (100 g)	protein %	total cal protein	fat %	total cal fat	lignin %	total cal lignin	cellulose %	total cal cellulose	hemi-cellulose %	total cal hemicellulose	N-free solubles %	total cal NFS	total cal (100 g/plant)	total gossypol %	total cal gossypol
opened burs	7.9	5.6	2.5	1.4	1.0	15.6	5.3	44.0	13.9	1.8	0.6	34.6	26.6	49.9	0.11	0.06
green burs[c]	11.3	7.5	4.7	1.4	1.5	9.8	0.6	29.8	14.5	6.8	3.3	44.7	21.7	46.3	0.26	0.23
unopened bools[c]	15.9	8.8	6.4	9.9	14.6	1.4	0.6	52.8	36.1	8.2	5.6	8.9	6.1	69.4	0.80	1.00
lint	8.7	0	0	0	0	0.8	0.3	90.6	33.9	1.2	0.4	7.4	2.8	37.4	0	0
seed	15.2	13.8	11.7	4.5	6.4	8.2	1.6	38.6	25.2	0	0	34.9	22.8	67.7	1.32	1.58
branches	11.1	5.6	3.5	1.0	1.0	9.6	0.4	36.2	17.3	10.6	5.1	37.0	17.7	45.0	0.02	0.02
main stem	15.5	3.8	3.3	0.6	0.9	11.8	0.3	40.6	27.1	12.6	8.4	30.6	20.4	60.4	0.02	0.03
leaves	14.1	14.4	11.4	3.2	4.2	16.8	2.3	10.4	6.3	4.0	2.4	51.2	31.0	57.6	0.29	0.32
squares	0.3	22.5	0.4	2.7	0.1	4.0	0.1	10.4	0.1	2.6	0.1	57.8	0.7	1.5	0.33	0.08
			43.9		29.7		11.5		174.4		25.9		149.8	435.2		3.32

[a] Calories per gram, protein, 5.6; fat, 9.3; soluble and insoluble carbohydrates, 4.3; cellulose and hemicellulose, 4.3 (estimate); gossypol, 7.9 (estimate). [b] Analysis by AOAC Methods; see Materials and Methods. [c] Green bolls were dissected to separate green burs (column 2) from the inner lint and seed (column 3).

gram: protein = 5.6, crude fat = 9.3, insoluble carbohydrates (lignin, hemicellulose, cellulose) = 4.3, soluble carbohydrates = 4.3 (Crampton and Harris, 1969). No published value was available for gossypol, a minor constituent, the structure of which suggested a value of about 7.9, above protein but less than crude fat.

RESULTS AND DISCUSSION

Table 1 presents a caloric analysis of energy distribution in ripened cotton (130 days). Column 1 gives the normalized plant part weights on a 100 g basis. Burs and branches account for about 49% of the weight, with seed (31%) and lint (20%) accounting for the remainder.

As expected, the lint is about 95% cellulose and accounts for about 17% of the total calories of the ripened cotton plant. Seed accounts for about 35% of the total calories (164/466), apportioned mainly as 44 cal of cellulose, 42 cal of fat, 33 cal of protein, and 26 cal of the nitrogen-free solubles. About twice as many calories (164) are used by the plant for seed production as for lint production (85). Only 3.7 cal was apportioned to gossypol production, suggesting that lint yield should not be appreciably decreased by apportionment of energy to gossypol biosynthesis. In fact, high-yield cultivars with elevated levels of gossypol, which offer some insect resistance, have been developed and are currently being grown by producers.

Tables 2, 3, and 4 give caloric analyses of energy distribution of cotton plants at 40, 101, and 115 days after emergence, respectively. Information about roots is included in Table 2 of plants at 40 days when they can still be harvested relatively efficiently. In 40-day-old plants, the normalized energy distribution is apportioned mostly to leaves (244 cal) and stems (125 cal), with 19% apportioned to roots (87 cal). At this stage, nitrogen-free solubles (210 cal), cellulose (87 cal), and protein (78 cal) are most prevalent.

Tables 3 and 4 give caloric energy apportionments at 101 and 115 days, times when the plant is nearing completion of lint and seed production. As could be expected, total cellulose calories are higher in lint at 115 days (37 versus 12 cal) but lower in unopened bolls (the dissected lint and seed less burs) as compared with 101-day-old plants. At both dates, much of the caloric energy is still present as nitrogen-free solubles, but further conversion to cellulose calories will occur as the plant ripens.

The total caloric content per 100 g is nearly constant over the period from 40 days until ripening at about 460. This reflects a fairly constant ratio of constituents (protein, fat, and the several categories of carbohydrates), with cellulose increasing as the plant reaches maturity. It is noteworthy that about twice as many calories (164 versus 85; Table 1) are apportioned to seed as to lint. Increased lint production might result if seed production could be decreased (Jenkins et al., 1990a,b, 1995). This outcome conceivably could be achieved by a plant-breeding strategy that results in the selection of lines producing smaller or fewer seeds per boll.

These calculations are made with the tacit assumption that energy released from the combustion of cotton tissues is a direct measure of the energy expended by the plant in producing this tissue. However, the energy released in combustion of these tissues is only the absolute minimum necessary to create them. The actual amount of energy needed to create each tissue likely depends upon the biochemical paths utilized. It likely involves many more calories per tissue than are released in combustion and may well differ among the tissue types sampled (Kirschner, 1961).

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