ELEMENTAL AND NUTRIENT COMPOSITION OF COTTON PLANT PARTS

Zhongqi He
USDA-ARS, Southern Regional Research Center
New Orleans, LA
Haile Tewolde
USDA-ARS, Crop Science Research Laboratory
Mississippi State, MS
Mark Shankle
Pontotoc Ridge-Flatwoods Branch Experiment Station, Mississippi State Univ.
Pontotoc, MS
Hailin Zhang
Dept. of Plant and Soil Sciences, Oklahoma State University
Stillwater, OK
Yongliang Liu
USDA-ARS, Southern Regional Research Center
New Orleans, LA

Abstract

To increase the knowledge on chemical composition of different cotton plant parts, cotton plants collected in mid-season and just before harvest (pre-defoliation) were analyzed for elemental and nutritional contents in different biomass parts. The plant samples were separated into six (mid-season) or eight (pre- defoliation) biomass fractions: main stems, leaf blades, branches, petioles, roots, and the reproductive part (or bur, peduncles+bracts, and seeds). The contents of macro (P, Ca, K, Mg, Na, and S) and micro (Fe, Zn, Cu, and Mn) elements, crude protein, acid detergent fiber, neutral detergent fiber, and acid detergent lignin in these biomass fractions were determined following standard procedures. We found that the growth stage affected the relative contents of some, but not all, measured parameters. Regression analysis revealed that the contents of certain parameters were well correlated with each other, but other parameters rather independent. The information reported in this work would be helpful in assessing nutrient management practices for cotton production. It also provides some insight on utilizing cotton crop byproducts as animal feed, soil amendments, and other off-field industrial raw materials.

Introduction

The most valuable product of a cotton crop is the lint. However, biomass materials from other parts of the cotton plant are also useful as a soil amendment, animal feed, bioenergy sources, and industrial raw materials. In this study, field-grown whole cotton plants collected at mid-season and just before defoliation were analyzed for selected chemical composition in roots, main stems, branches, petioles, leaf blades, and reproductive parts (burs, peduncles, and seeds). The objectives are (1) to document the chemical characteristics of the individual biomass components in terms of plant nutrients and animal feed quality and (2) to increase understanding of the accumulation mechanism with plant growth and development. The information presented in this work would be helpful to the cotton industry in making decisions to maximize profitability through better use of cotton biomass resources.

Materials and Methods

Random cotton plants were taken from tetraplicate cotton plots of a long-term cropping management trials at the Mississippi Agricultural and Forest Experiment Station near Pontotoc, MS (34°8′20″ N, 88°59′33″ W). The site had ~5% slope gradient and an Atwood silt loam soil (Fine-silty, mixed, semiactive, thermic Typic Paleudalfs) (Tewolde et al., 2015). Whole cotton plants including roots were collected in mid-season (August 2014) and just prior to defoliation (September 2014) from four plots that received standard inorganic fertilization. The plants were placed in large plastic bags, transported to the laboratory and stored in a walk-in cooler (5.5°C) until further processed. In the laboratory, the plants were separated into roots and shoots and rinsed in tap water. The shoots were loaded into new plastic bags, returned to the cooler overnight to drain water, and further separated into main stems, branch stems, leaf blades, petioles, and reproductive parts. All separated plant parts were placed in paper bags and dried in a forced-air oven at 80°C to constant weight. Following drying, the reproductive parts (bolls) of the samples collected at pre-defoliation were further separated to burs, peduncles+bracts, seed, and lint. The reproductive parts of samples taken in the mid-season consisted of squares, flowers, and small immature bolls and were not further separated. All dry plant parts were ground to 1-mm particle size and analyzed for macro (P, Ca, K, Mg, Na, and S) and trace (Fe, Zn, Cu, and Mn) elements and feed quality parameters including crude protein, acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL) (He et al., 2013, 2016)

Results and Discussion

The results of elemental and fiber analysis are listed in Table 1. The ash contents of the cotton plant parts harvested in the mid-season followed the order: leaf blades >petioles > reproductives > branches > roots > main stems. The contents of both macro and trace elements were also in the same order. These results reflect that much of the mineral elements in the cotton plant are concentrated in leaves and reproductive parts and that stems and roots are more carbonaceous. This trend did not change with the cotton plants collected at the harvesting stage (per-defoliation). The reproductive parts collected in the later phase could be further separated into fiber, burs, peducles/bracts, and seed. Elemental analysis was conducted for bur, penduncles/bracts, and seed. The element contents were not equally distributed in the three reproductive parts: the highest ash content was with peduncles/bracts (equivalent to that of petioles).

A previous study characterized the compositional features of these biomass parts by attenuated total reflection Fourier transform infrared (ATR-FTIR) spectroscopy (Liu et al., 2016). Principal component analysis of these ATR-FTIR data revealed that those biomass parts could be separated into two clusters: 1) Stem cluster including main stems, roots, branches, and petioles, and 2) Leaf cluster including leaf blades, reproductive, burs and bracts. In this work, we further analyzed the contents of Cu, K, Ca and ash by radar plotting (Fig. 1). These plots could not give a clear clue on the clusters. However, these radar plots visually demonstrated significant changes in nutrition symptoms during growth. For example, the highest decrease of K content was observed with petioles whereas the K content in other biomass was relative unchanged between the two sampling growth stages. On the other hand, the Fe content was mainly concentrated in the roots, accumulating with growth.

Table 1. Concentrations of macro and trace elements, ash, and feed quality characteristics of cotton plant biomass at two growth stages

Plant Part	P	Ca	K	Mg	Na	S	Ash	Fe	Zn	Cu	Mn	Protein	ADF	NDF	ADL
	------------------g/kg------------							-----------mg/kg-----------				----------------%-------------			
Mid season															
Roots	0.9	2.7	7.9	1.8	0.2	0.7	28.2	232.4	8.8	5.3	14.1	4.7	46.4	60.5	9.7
Main stems	1.0	4.2	8.0	1.4	0.3	0.6	25.8	30.0	10.0	4.3	12.4	4.8	52.1	64.7	10.8
Branches	1.2	8.0	13.0	2.4	0.4	0.9	45.3	18.5	16.1	4.7	17.0	8.0	47.5	58.3	8.6
Petioles	1.4	17.7	24.2	5.1	0.5	1.0	94.6	16.0	13.9	3.1	35.7	10.4	34.6	43.4	3.7
Leaf Blades	2.9	34.4	12.6	4.3	0.3	3.6	110.9	80.8	32.7	8.6	108.3	24.9	26.2	28.6	12.8
Reproductive	4.0	10.0	17.4	3.6	0.1	2.4	62.5	33.3	24.1	6.6	34.4	16.8	28.4	28.0	13.0
Pre-defoliation															
Roots	0.5	4.7	7.0	1.4	0.4	0.5	51.0	611.3	9.1	3.5	38.6	3.9	56.6	72.7	12.3
Main stems	1.0	8.5	11.4	1.3	0.5	1.0	46.7	22.2	8.1	4.2	30.2	5.9	55.8	65.7	13.9
Branches	0.7	7.1	7.8	1.4	0.8	0.7	35.7	17.4	9.3	4.0	23.9	5.9	58.2	71.3	14.3
Petioles	2.0	31.0	11.0	5.8	0.9	2.5	111.4	69.3	28.5	4.2	89.1	12.4	46.8	52.9	16.2
Leaf Blades	4.2	43.9	11.4	6.7	0.9	5.1	145.0	122.2	46.2	7.5	113.9	21.9	32.6	35.8	14.8
Reproductive	3.7	4.6	18.8	2.9	1.4	3.0	59.6	46.7	34.7	5.2	22.0	16.1	43.7	53.6	13.8
Bur	1.7	7.8	23.7	2.2	0.3	2.0	71.0	21.5	11.9	3.3	30.6	8.1	54.7	62.9	15.9
Peduncles/bracts	2.0	17.5	19.3	2.6	0.3	2.3	101.2	356.9	12.7	4.5	60.1	9.7	52.8	57.5	17.4
Seed	4.9	1.8	16.3	3.3	2.0	3.5	50.2	32.5	48.1	6.2	14.5	20.6	37.4	48.6	12.4

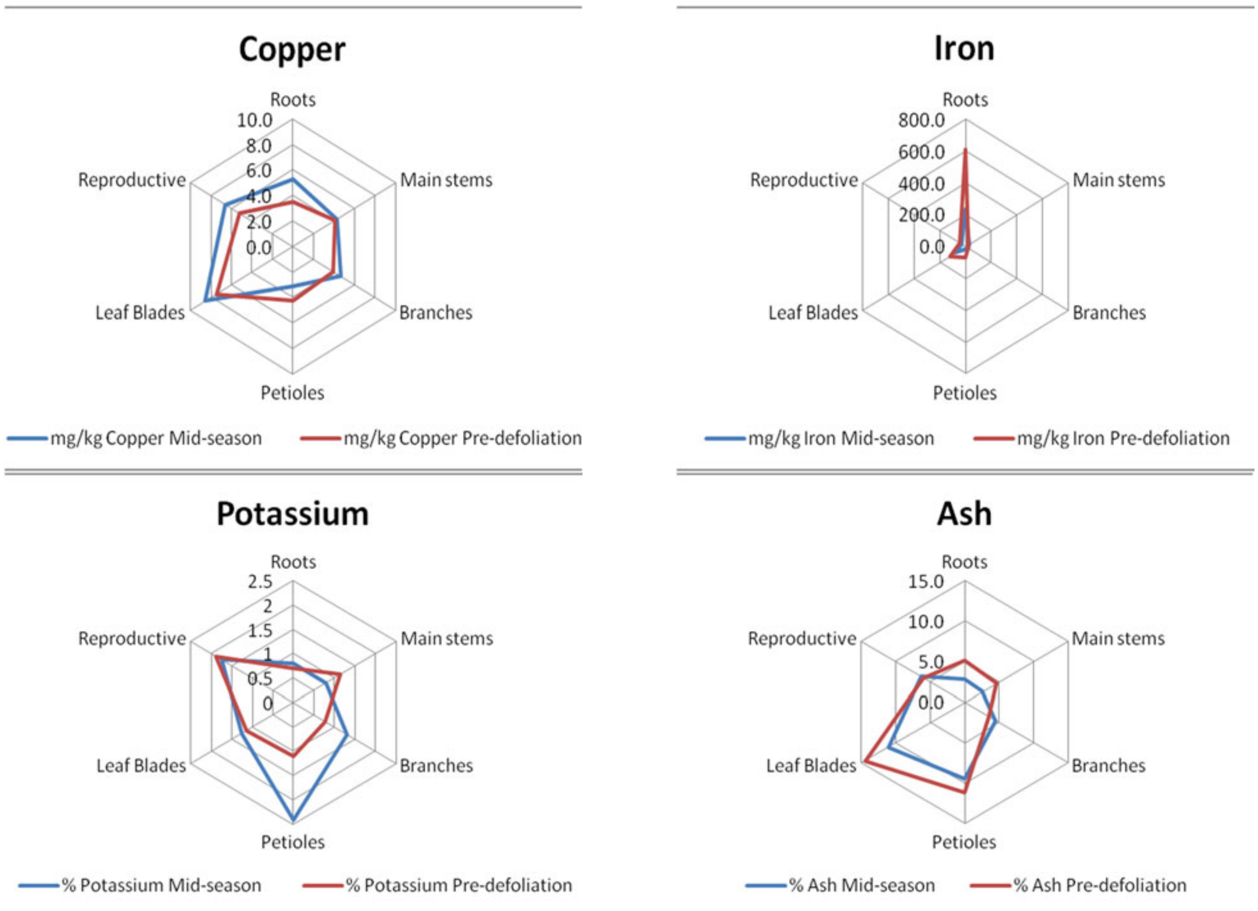

Figure 1. Radar plots displaying the change of nutrient concentration in different plant parts at the middle and end of the growing season

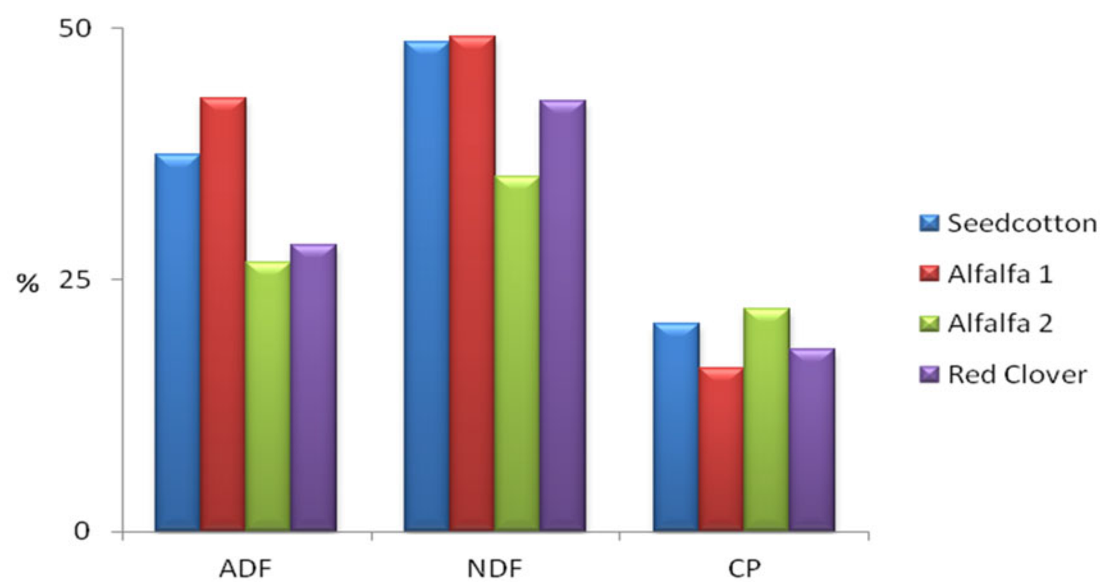

Figure 2**.** Comparison of feed quality of cotton seed with forage crops (Data sources: Alfalfa 1 – Yari et al. 2012 Alfalfa 2 & Red Clover – Hymes-Fecht et al. 2013). ADF, acid detergent fiber; NDF, neutral detergent fiber; CP, crude protein.

The pattern of protein content is similar to those of ash and minerals. Especially the content of protein was highly related to the contents of S, Zn and Mn, with correlation coefficients of 0.988, 0.984 and 0.927, respectively. This observation implies that these elements could be part of proteins in the form of protein S-S bond and metalloproteins. On the other hand, the contents of ADF, NDF, and ADL varied among these biomass parts in a reverse mode to protein and minerals (Table 1). For example, in the mid-season samples, the content of ADF was in the order: main stems >branches >roots >petioles > reproductives >leave blades. With the maturity of the crop, the contents of ADF, NDF, and ADL all increased in these biomass parts collected at pre-defoliation. Contents of protein and fibers are used for evaluating the feed values of agricultural products and byproducts (He et al., 2014; 2015). Data in Fig. 2 indicated that cottonseed possessed the feed values comparable to those of alfalfa and clover.

Summary

Roots and stems of the cotton plant had the lowest concentration of the measured elements at both growth stages with the exception of iron and copper. Leaf blades and petioles had the most ash at both growth stages, suggesting much of the mineral elements in the cotton plant are concentrated in these plant parts. Concentrations of most of the macro elements (except potassium) increased in leaves (blades and petioles) and decreased in stems (main stems and branches) from mid-season to pre-defoliation. The fiber and lignin contents increased in all parts with the growth. Per the protein and fiber contents, cotton seed has feed quality characteristics that are comparable to those observed in forage crops such as alfalfa and red clover. The information reported in this work would be helpful in exploring and optimizing management practices and processing strategies in utilization of these cotton plant biomass materials as renewable natural resources.

Acknowledgements

We thank Jay Munyon for the radar plotting work. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

References

He, Z., M. Shankle, H. Zhang, T.R. Way, H. Tewolde, and M. Uchimiya. 2013. Mineral composition of cottonseed is affected by fertilization management practices. Agron. J. 105:341-350.

He, Z., H. Zhang, D.C. Olk, M. Shankle, T.R. Way, and H. Tewolde. 2014. Protein and fiber profiles of cottonseed from upland cotton with different fertilizations. Modern Appl. Sci. 8(4):97-105.

He, Z., H. Zhang, and D.C. Olk. 2015. Chemical composition of defatted cottonseed and soy meal products. PLoS One 10(6): e0129933. DOI:10.1371/journal.pone.0129933.

He, Z., K.T. Klasson, D. Wang, N. Li, H. Zhang, D. Zhang, and T.C. Wedegaertner. 2016. Pilot-scale production of washed cottonseed meal and co-products. Modern Appl. Sci. 10 (2):25-33.

Hymes-Fecht, U.C., G.A. Broderick, R.E. Muck, and J.H. Grabber. 2013. Replacing alfalfa or red clover silage with birdsfoot trefoil silage in total mixed rations increases production of lactating dairy cows. J. Dairy Sci. 96:460-469.

Liu, Y., Z. He, M. Shankle, and H. Tewolde. 2016. Compositional features of cotton plant biomass fractions characterized by attenuated total reflection Fourier transform infrared spectroscopy. Ind. Crop. Prod. 79:283-286.

Tewolde, H., M.W. Shankle, T.R. Way, A. Adeli, J.P. Brooks, and Z. He. 2015. Managing fall-applied poultry litter with cover crop and subsurface band placement in no-till cotton. Agron. J. 107:449-458.

Yari, M., R. Valizadeh, A.A. Naserian, G.R. Ghorbani, P.R. Moghaddam, A. Jonker, and P. Yu. 2012. Botanical traits, protein and carbohydrate fractions, ruminal degradability and energy contents of alfalfa hay harvested at three stages of maturity and in the afternoon and morning. Animal Feed Sci. Technol. 172:162-170.