Demonstration of On-Farm Production of a Dedicated Energy Crop incorporating Multiple Varieties of Switchgrass Seed

May 23, 2013

Feedstock Supply and Logistics

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Goal Statement

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- Demonstrate commercial scale production of improved herbaceous feedstocks to producers and industry and develop practical understanding of management impacts on feedstock quality

- This project seeks to showcase commercialization of dedicated energy crops at a large scale through the utilization of improved varieties and compositional analysis, both direct goals of the Bioenergy Technologies Office

- Industry adoption of this information will lead to more successful feedstock establishment and more efficient operation of biorefineries through a better understanding of the feedstock

Quad Chart Overview

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Timeline

- Start Date: March 10, 2010 (Contract dated 9/28/10)
- End Date: Dec. 31, 2013
- Progress to date: 85%

Barriers

- Barriers addressed
  - Ft-C Crop Genetics
  - Ft-G Feedstock Quality Monitoring
  - Ft-M Overall Integration

Budget

Funding for FY11 ($905,317 / $582,253)
Funding for FY12($596,084 / $1,127,633)
Funding for FY13 ($800,382 / $521,996)
Funding for FY14 Q1 ($43,508/$140,715)

Funded for 3 years

Partners

DUPONT

ceres

GENERA ENERGY
Delivering Sustainable Biomass Solutions

Project Overview

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- Establish varietal trials and plots for demonstration of switchgrass production using multiple varieties of seed.
- Analyze chemical composition, structural form, and ethanol yield of the varieties sampled.
- Assess environmental and economic sustainability of the three different varieties of switchgrass.

Management

Project Management

- University of Tennessee – farmer contracts, crop management, sampling, compositional and structural analysis
- Ceres Inc – chemical composition analysis and NIR model application
- DuPont – Ethanol yield and project advice
- Genera Energy – staff support for farm management and harvesting, sampling

Primary Objectives

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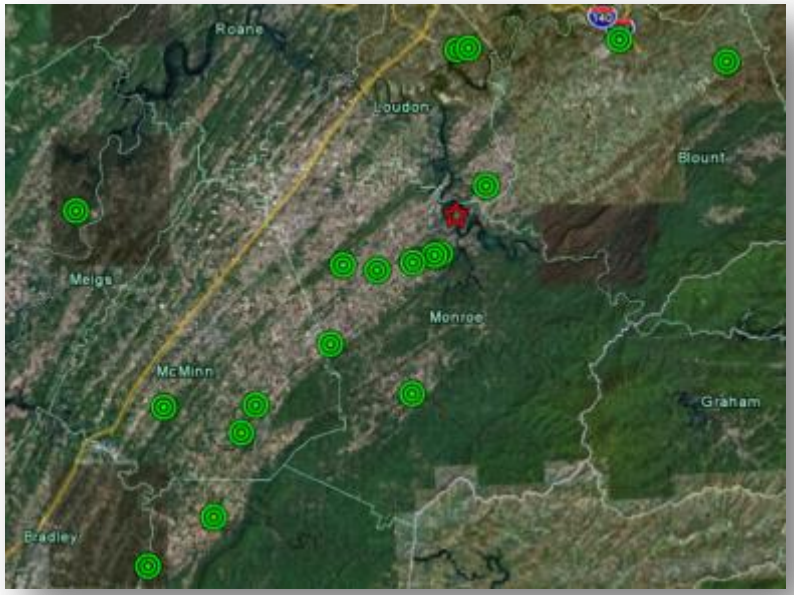
1) To establish varietal trials and plots for demonstration of switchgrass production.

2) To analyze chemical composition, structural form, and ethanol yield of the varieties sampled.

3) To assess environmental and economic sustainability of the three different varieties of switchgrass.

Technical Accomplishments

- Working with 18 local farmers, 2000 acres of switchgrass were established in 2010.
  - **1000 acres** of improved Ceres (**1101 and 1102**) seed as well as **1000 acres** of standard **Alamo** planted.
- Establishment was successful and harvests have been conducted in 2010, 2011, and 2012



Technical Accomplishments

- Two farm field demonstration events (two days each) planned and held in Oct. 2011 and Oct. 2012
- Over 1000 attendees in 2011 and over 400 in 2012
- Day One held at a switchgrass farm with seven different technical tours (3 speakers each)
- Equipment demonstrations in harvesting switchgrass

Technical Accomplishments

- Day two included:
  - Two technical tours (8 speakers)
  - Tours of Genera Energy's Biomass Innovation Park
  - Tours of DuPont's Demonstration Cellulosic Ethanol Biorefinery

Primary Objectives

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Selected Fields (11) for Variety Trial

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		Study Approx. Acres		
Field ID	Selected Fields (acres)	Alamo	EG 1101	EG1102
C19	109.7	36.5	36.5	36.5
C13	84	28	28	28
C15	24.7	8.2	8.2	8.2
C27	72.9	24.3	24.3	24.3
C04	25.6	8.5	8.5	8.5
C29	82.4	16.4	16.4	16.4
C06	28.4	9.5	9.5	9.5
C16	99.2	33	33	33
C33	82.5	10	10	10
C12	40.3	13	13	13
C08	26.1	8.7	8.7	8.7
	675.8	196.1	196.1	196.1

Field C 13

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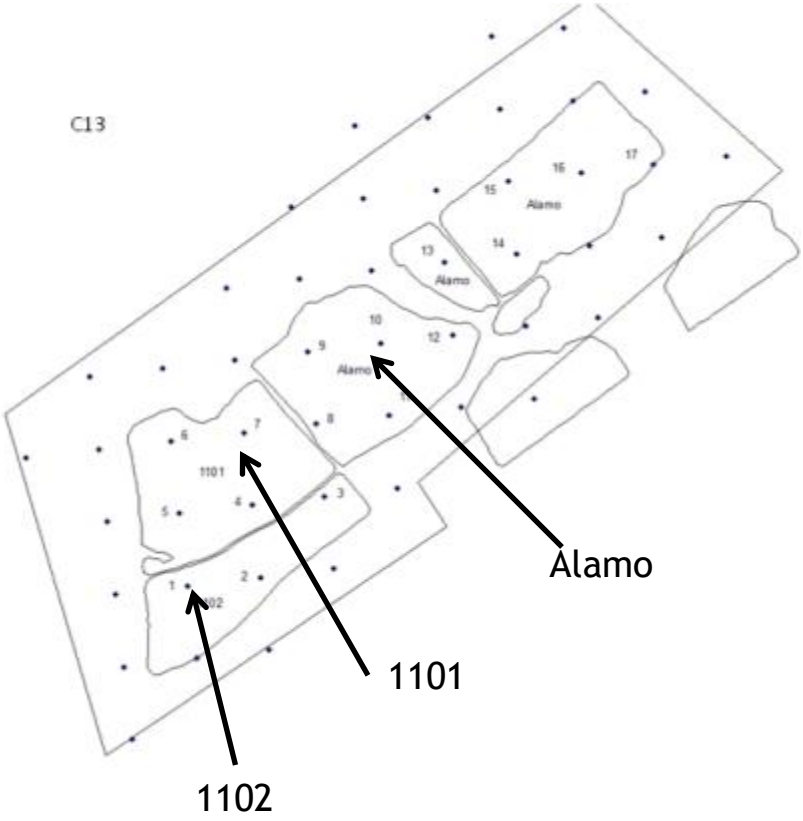
84 acres: 28 Alamo; 28 EG 1101; 28 EG 1102



Sampling Profile

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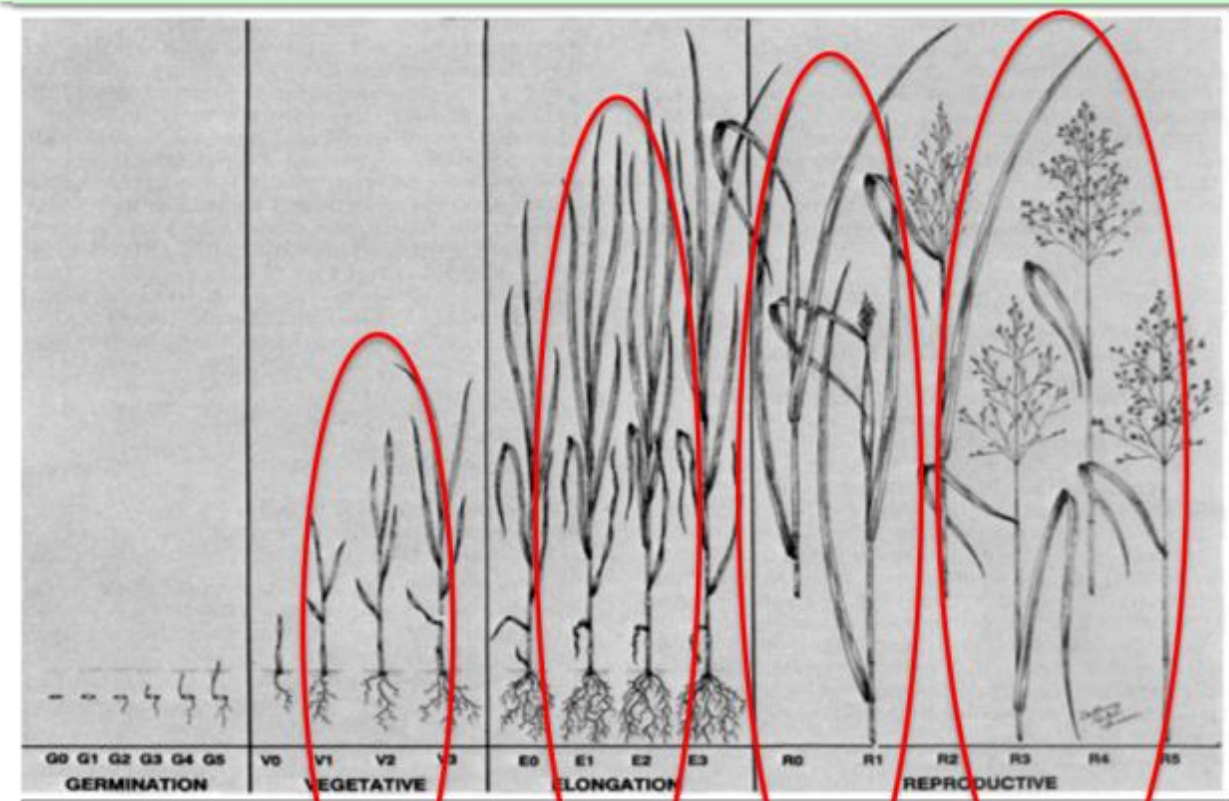
- 3 varieties of switchgrass: Alamo, EG1101, EG1102
- Sample harvest
  - 1st year (239 samples collected in 2010, 3 sampling periods)
  - 2nd year (702 samples collected in 2011, 6 sampling periods)
  - 3rd year (351 samples collected in 2012, 3 sampling periods)
- Among 11 farms, C04, C19, C33 farms were selected for focused activities

Sampling Profile



Month: May June July August Sept

Sampling : 1 2 3 4

Describing and Quantifying Growth Stages of Perennial Forage Grasses. Moore et al., 1991

Table 1. Primary and secondary growth stages and their numerical indices and descriptions for staging growth and development of perennial grasses.

Stage	Index	Description
Germination		
G0	0.0	Dry seed
G1	0.1	Imbibition
G2	0.3	Radicle emergence
G3	0.5	Coleoptile emergence
G4	0.7	Mesocotyl and/or coleoptile elongation
G5	0.9	Coleoptile emergence from soil
Vegetative-Leaf development		
VE or V0	1.0	Emergence of first leaf
V1	(1/*N*)+0.9†	First leaf collared
V2	(2/*N*)+0.9	Second leaf collared
Vn	(*n*/*N*)+0.9	Nth leaf collared
Elongation-Stem elongation		
E0	2.0	Onset of stem elongation
E1	(1/*N*)+1.9	First node palpable/visible
E2	(2/*N*)+1.9	Second node palpable/visible
En	(*n*/*N*)+1.9	*N*th node palpable/visible
Reproductive-Floral development		
R0	3.0	Boot stage
R1	3.1	Inflorescence emergence/1st spikelet visible
R2	3.3	Spikelets fully emerged/peduncle not emerged
R3	3.5	Inflorescence emerged/peduncle fully elongated
R4	3.7	Anther emergence/anthesis
R5	3.9	Post-anthesis/fertilization
Seed development and ripening		
S0	4.0	Caryopsis visible
S1	4.1	Milk
S2	4.3	Soft dough
S3	4.5	Hard dough
S4	4.7	Endosperm hard/physiological maturity
S5	4.9	Endosperm dry/seed ripe

† Where *n* equals the event number (number of leaves or nodes) and *N* equals the number of events within the primary stage (total number of leaves or nodes developed). General formula is $P + (n/N) - 0.1$; where *P* equals primary stage number (1 or 2 for vegetative and elongation, respectively) and *n* equals the event number. When $N > 9$, the formula $P + 0.9(n/N)$ should be used.

Sampling Profile

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	Farm	May	Late June-early July	Late July-early August	Late August-September	Late October-early November	November-December (Harvest)	
Year 1	C04		7/1/2010 (E2)		8/23/2010 (R1)	10/21/2010 (R5)		
	C06			7/27/2010 (E5)	9/23/2010 (R3)		11/18/2010 (S3)	
	C08				9/2/2010 (R3)	10/28/2010 (S1)	12/23/2010 (S5)	
	C12			7/26/2010 (E5)	9/23/2010 (R3)		11/18/2010 (S3)	
	C13				9/20/2010 (R2)		11/18/2010 (S3)	1/13/2011 (S5)
	C15				8/30/2010 (R0)	10/28/2010 (R3)	12/23/2010 (S5)	
	C16			8/10/2010 (R0)	10/7/2010 (R5)		12/2/2010 (S4)	
	C19		7/6/2010 (E2)		9/2/2010 (R3)	10/26/2010 (S1)		
	C27				9/2/2010 (R3)	10/28/2010 (S1)		
	C29				10/14/2010 (R5)		12/9/2010 (S5)	
	C33		7/19/2010 (E5)		9/16/2010 (R4)	11/11/2010 (S4)		
Year 2	C04	5/17/2011	6/28/2011	8/9/2011	9/21/2011	11/1/2011	11/28/2011	
	C06	5/20/2011	7/1/2011	8/9/2011	9/21/2011	11/1/2011	12/2/2011	
	C08	5/20/2011	6/28/2011	8/9/2011	9/19/2011	11/2/2011	12/5/2011	
	C12	5/16/2011	6/30/2011	8/12/2011	9/19/2011	11/1/2011	11/20/2011	
	C13	5/20/2011	7/1/2011	8/9/2011	9/21/2011	11/3/2011	11/22/2011	
	C15	5/17/2011	6/28/2011	8/9/2011	9/20/2011	11/3/2011	11/23/2011	
	C16	5/16/2011	6/30/2011	8/10/2011	9/21/2011	10/31/2011	11/20/2011	
	C19	5/19/2011	6/29/2011	8/12/2011	9/21/2011	11/1/2011	12/14/2011	
	C27	5/18/2011	6/27/2011	8/11/2011	9/21/2011	11/1/2011	11/22/2011	
	C29	5/19/2011	6/28/2011	8/8/2011	9/20/2011	11/2/2011	12/1/2011	
	C33	5/18/2011	6/28/2011	8/8/2011	9/21/2011	11/3/2011	12/2/2011	
Year 3	C04		6/29/2012		9/19/2012	11/1/2012		
	C06		6/29/2012		9/18/2012	11/1/2012		
	C08		6/27/2012		9/20/2012	11/4/2012		
	C12		6/25/2012		9/17/2012	10/30/2012		
	C13		6/25/2012		9/17/2012	11/7/2012		
	C15		6/28/2012		9/21/2012	10/30/2012		
	C16		6/27/2012		9/19/2012	10/31/2012		
	C19		6/26/2012		9/20/2012	10/30/2012		
	C27		6/26/2012		9/20/2012	10/31/2012		
	C29		6/29/2012		9/21/2012	11/1/2012		
	C33		6/28/2012		9/21/2012	10/30/2012		
	Day of Year:	136-140	176-182	220-234	259-264	301-311	324-348	
	Growth Stage 1:		E2-E5	E5-R0	R0-R5	R3-S4	S3-S5	S5
	Growth Stage2:	V2-V3	E3	R0-R3	R2-S1	R5-S4	S5	S5
	Growth Stage3:		E3-E5		S3-S5	S5		
	Growth Stage:	V2-V3	E2-E5	E5-R3	R0-S5	R3-S5	S3-S5	S5

Analysis

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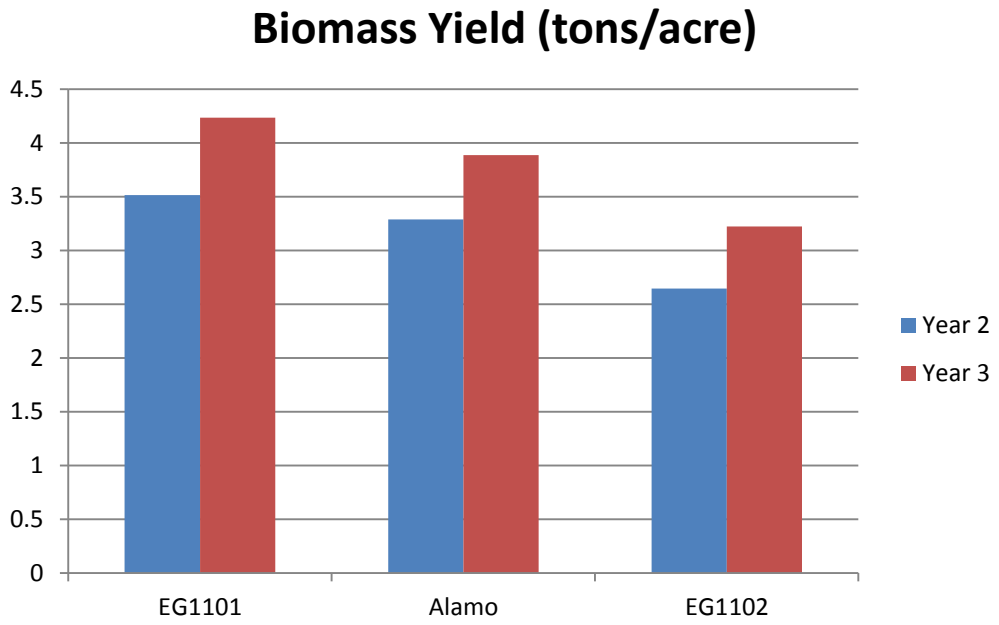
- Chemical composition – Ash, cellulose, hemicellulose, lignin, and extractives
- Structural – FTIR for crystallinity index
- Sugar release – hydrolyzability (xylose and glucose)
- Ethanol yield

- Additionally, soil samples were collected twice per year at each sampling point

Technical Results

- No significant differences in Year 2
- EG1102 significantly lower yield in Year 3
- Year 3 yield much lower than expected due to limited precipitation



Technical Results

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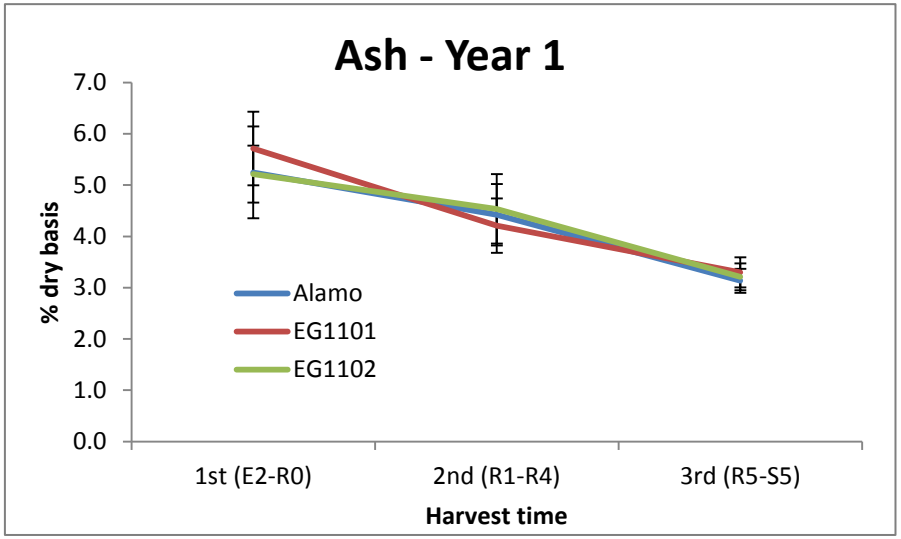
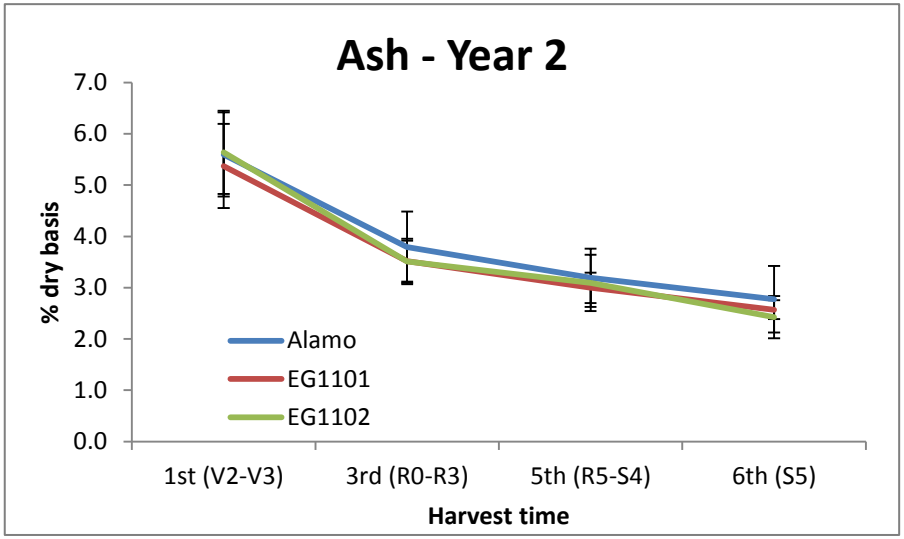
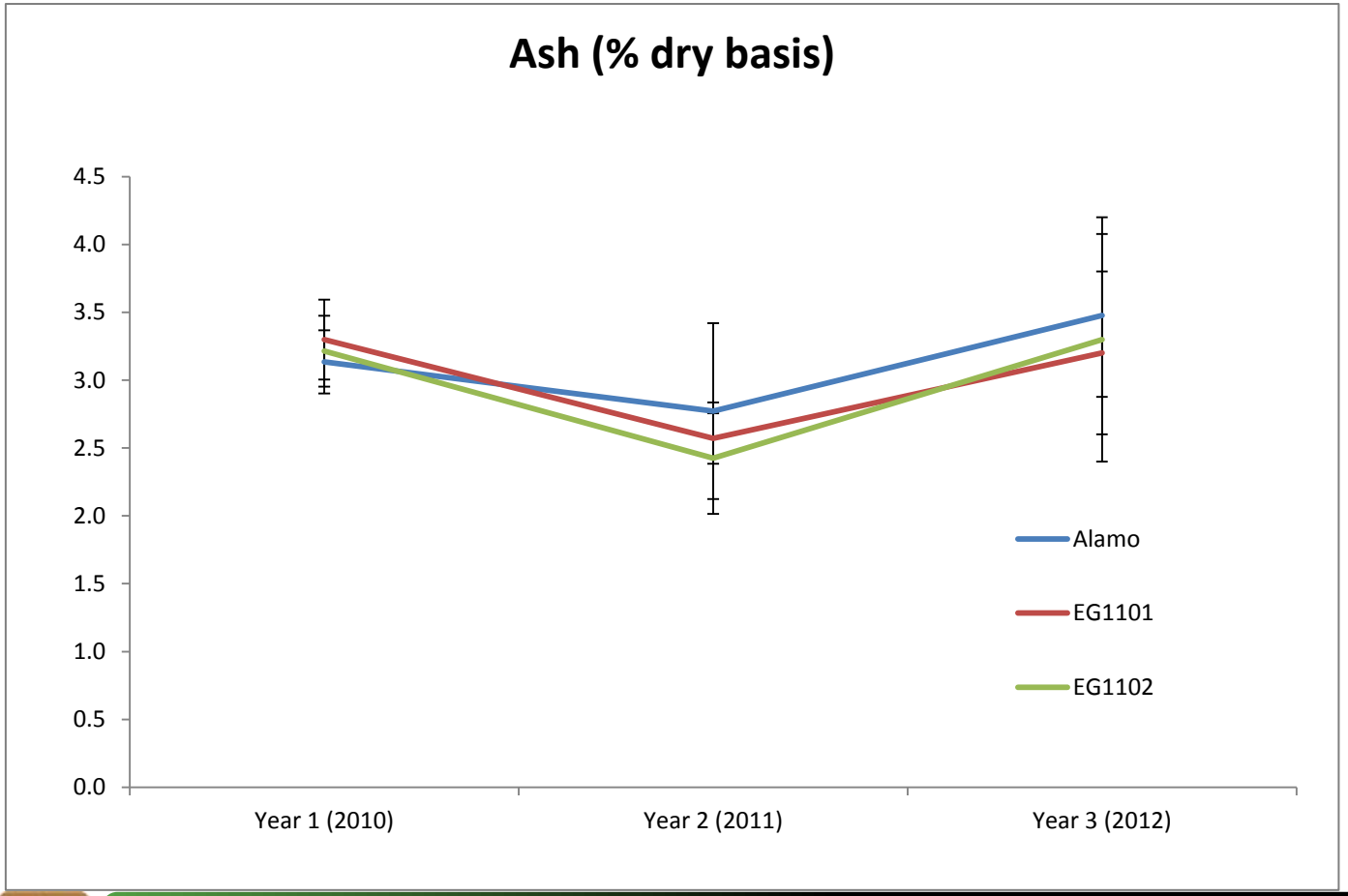
Trend of ash during growing season (3 farms)





Technical Results

Comparisons of three growth seasons
(at harvest for biorefinery use)



Technical Results

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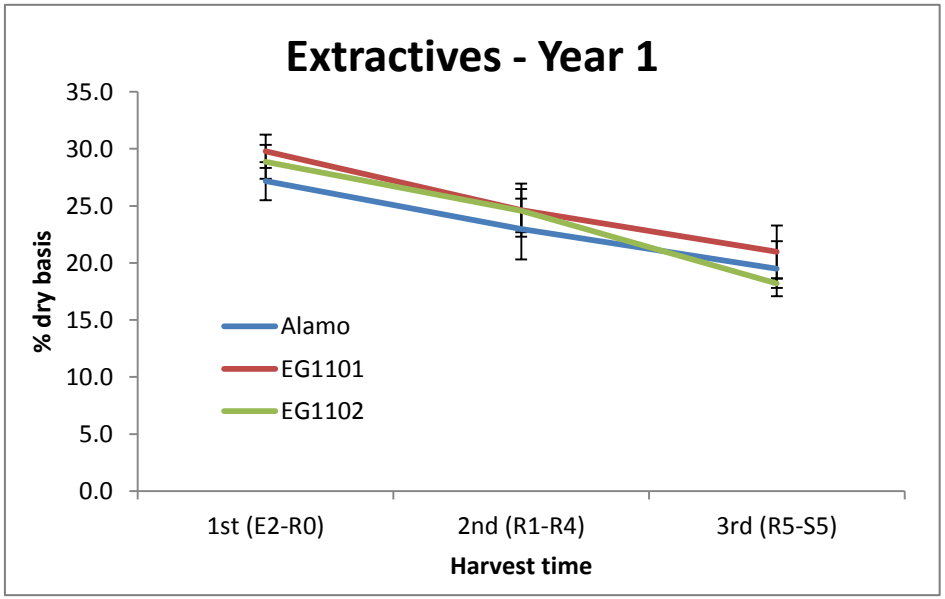
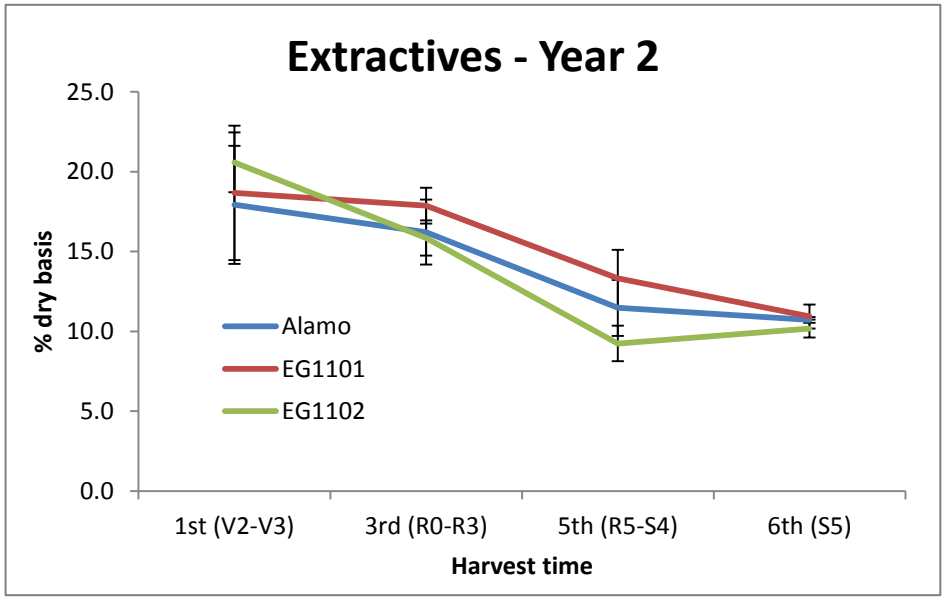
Trend of Extractives during growing season (3 farms)

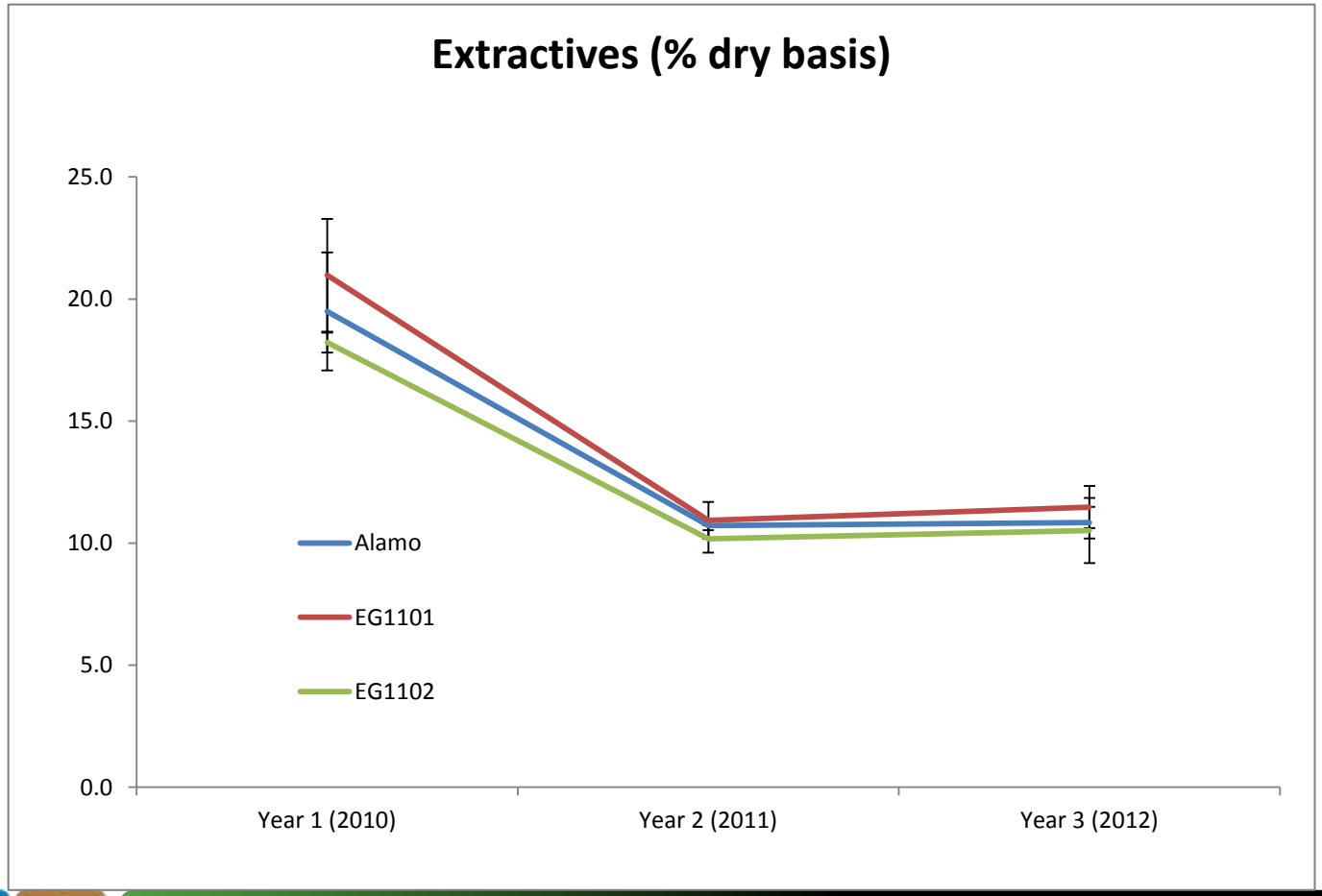




Technical Results

Center for Renewable Carbon

Comparisons of three growth seasons (at harvest for biorefinery use)



Technical Results

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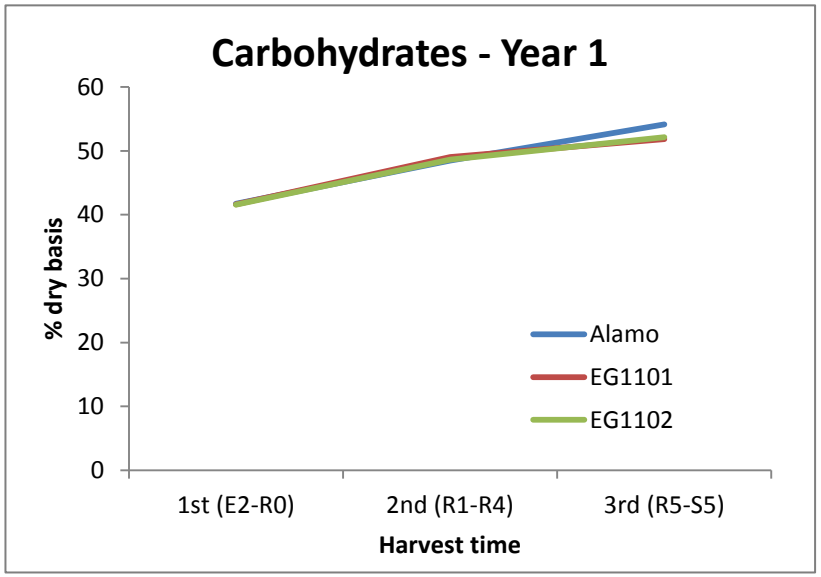
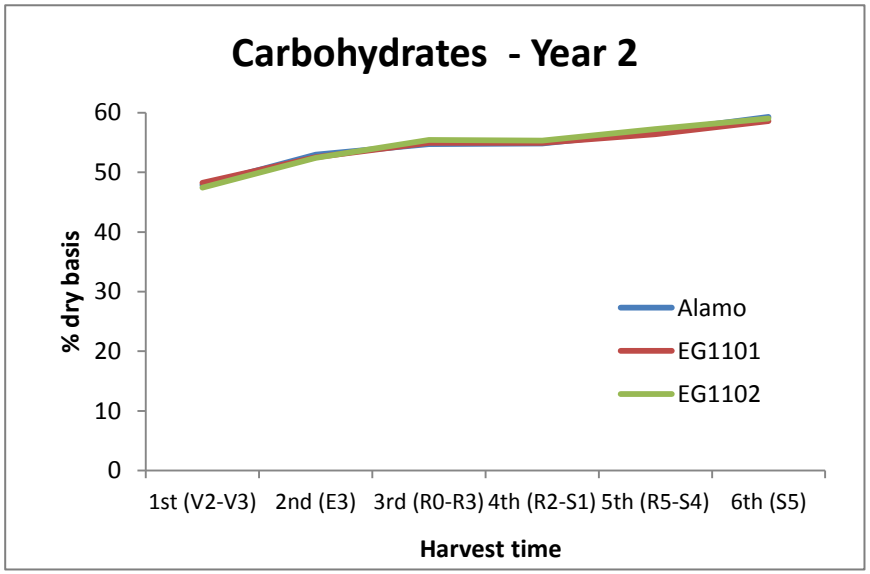
Trend of carbohydrates during growing season





Technical Results

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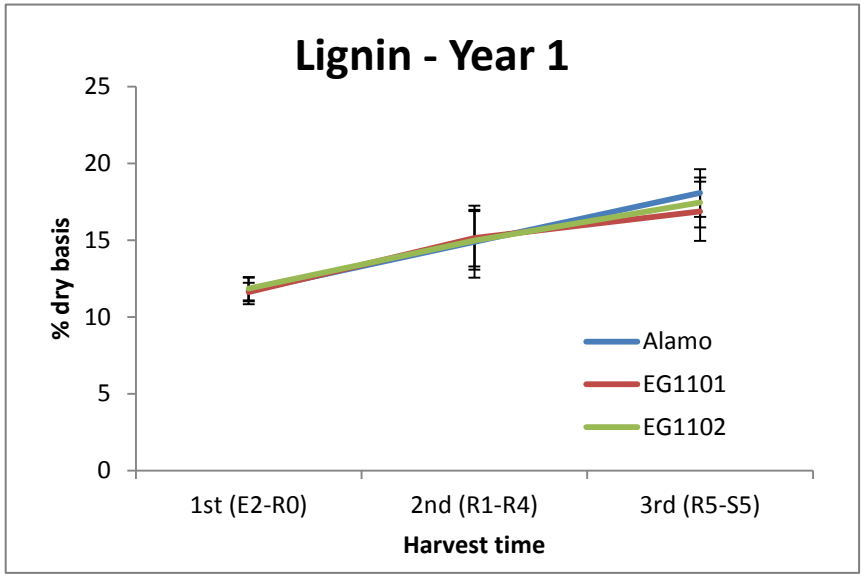
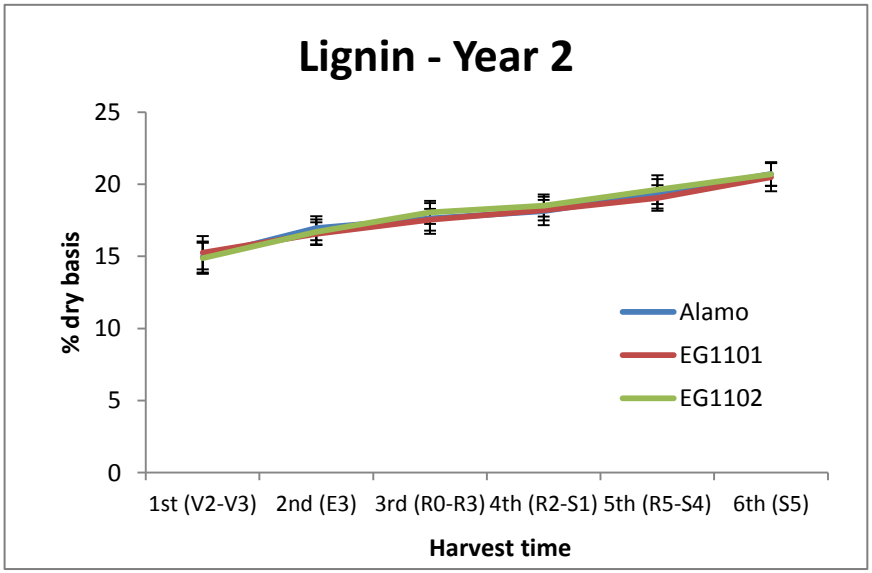
Trend of lignin during growing season





Technical Results

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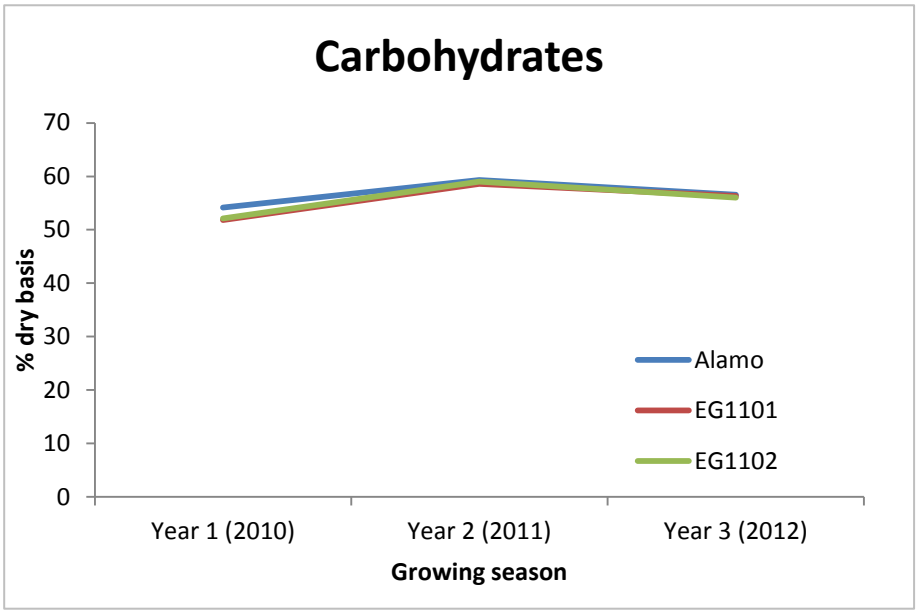
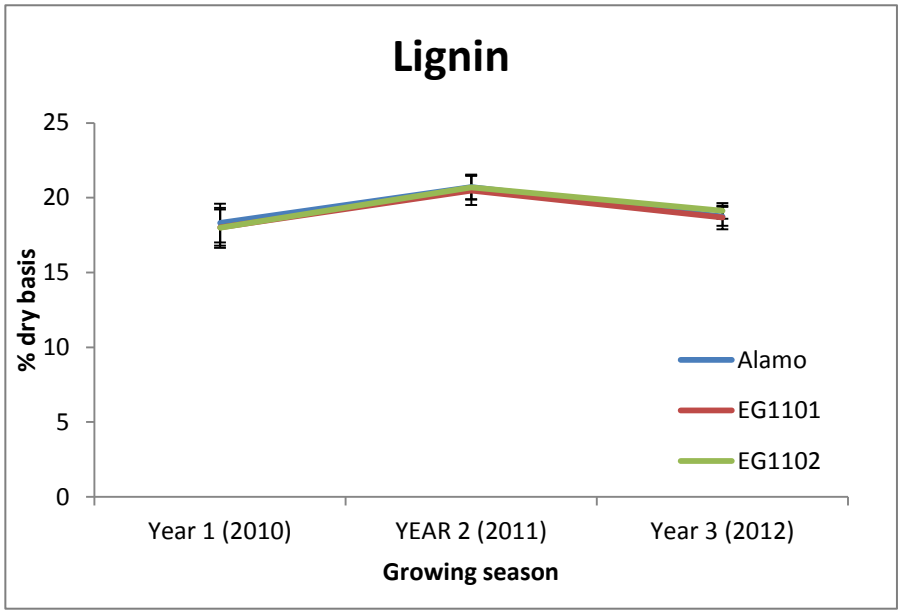
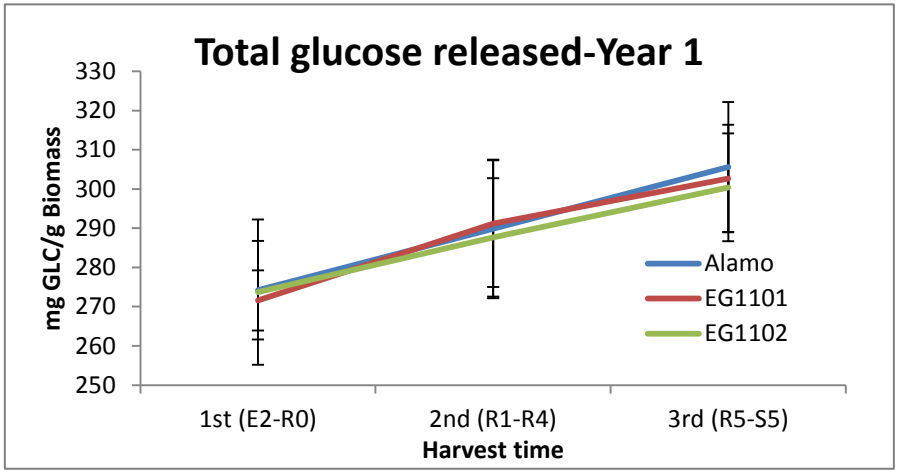
Yearly Structural Component Comparison (at harvest for biorefinery use)

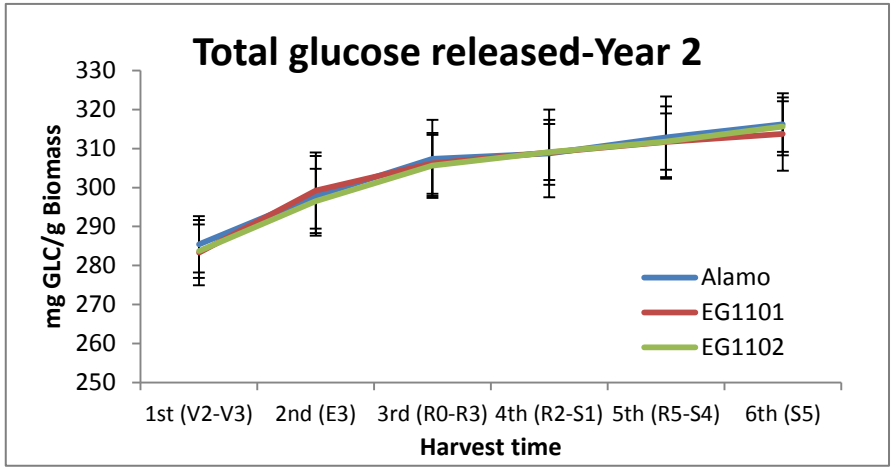




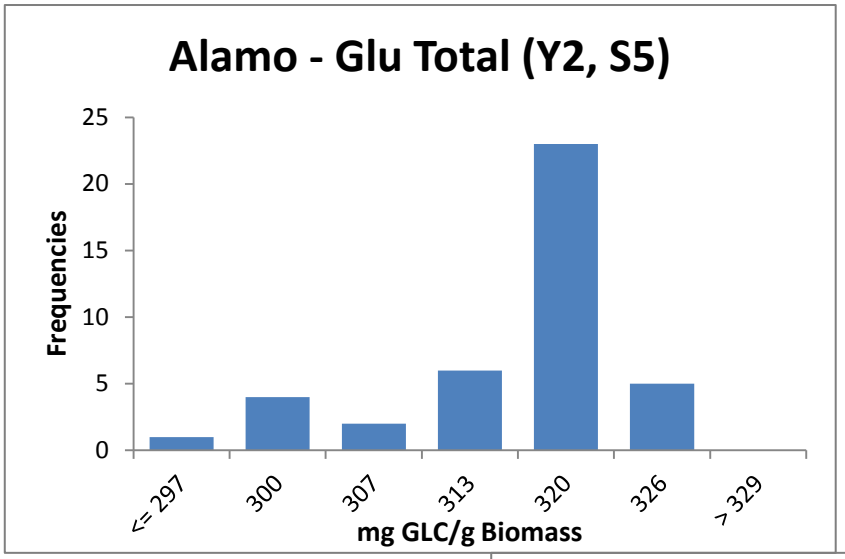
Technical Results

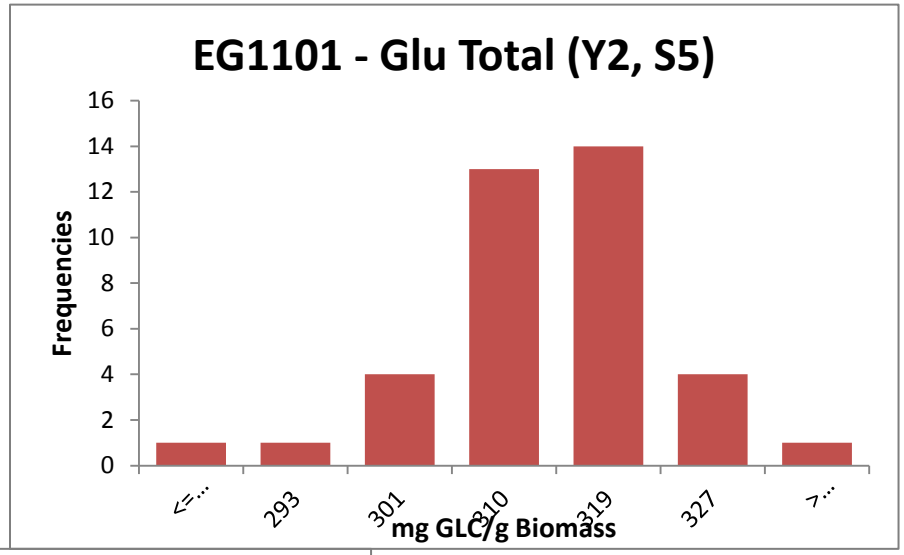
Hydrolyzability: total glucose released (after acidic pretreatment and saccharification)

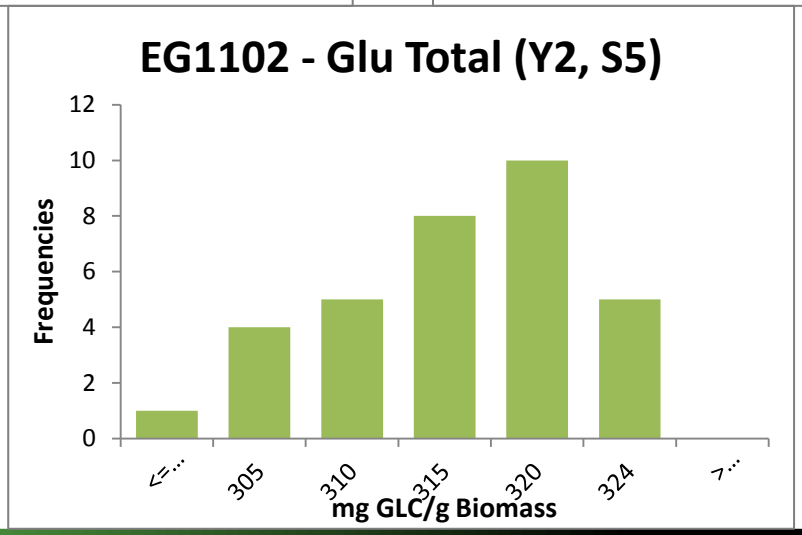




Glucose Released Variation Year 2







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1) To establish varietal trials and plots for demonstration of switchgrass production

2) To analyze chemical composition, structural form, and ethanol yield of the varieties sampled.

3) **To assess environmental and economic sustainability of the three different varieties of switchgrass.**

Environmental & Economic Data

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- Associated project collected data and performed LCA analysis (Green 2012)
- Work is underway to develop a model that relates yields and composition to management and soil attributes
- Economic analysis of varietal yield impacts being developed as well

Relevance

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- Project activities and goals directly address Bioenergy Technologies Office goals associated with feedstock supply and quality
  - Ft-C Crop Genetics – large scale demonstration of improved materials
  - Ft-G Feedstock Quality Monitoring – significant sampling and analysis across varieties, farms, and years
  - Ft-M Overall Integration – demonstrating scale-up of feedstock production and management
- Results of field demonstrations can be directly applied to bioenergy crop establishment and management systems throughout the industry
- Results of compositional and quality analysis will be applied in conversion technologies seeking to optimize harvest around plant growth stages and maturity

Critical Success Factors

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- Increased farmer knowledge of improved varieties and of switchgrass production in general
- Improved ability to make varietal selections and make large scale commercialization efforts more successful
- Improved knowledge base of feedstock characteristics and their performance in energy production
- Actual yield and performance data in a pilot scale cellulosic conversion process.

Future Work

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- Continued analysis of samples and results
  - Conduct 4th growing season sampling
  - Continue to validate and implement the NIR Model
  - Complete NIR analysis and ethanol yield analysis on later growing seasons
  - Complete modeling on yield/composition and management/soils relationships
- Continue development of additional NIR attributes (weed composition tools)
- Complete additional leveraged project relating structural characteristics to yield of the three varieties
- Complete final report and continue to develop publications from the results

Questions/Comments

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