Economic Implications of Harvest Time Effects on Switchgrass Moisture Content, Nutrient Concentration and Yield

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Introduction

- Switchgrass, a warm-season, herbaceous, perennial bunchgrass is native to the prairies of North America (Gibson et al., 2007)
- As an energy crop, advantages and disadvantages include:
  - ***Advantages***: drought tolerant, resist pests and disease, low establishment and maintenance costs (Rinehart, 2006; Gibson, 2007; Monti et al., 2009) and attendant potential for reduced net emissions of greenhouse gases (USEPA, 2010)
  - ***Disadvantage***: low bulk density and thereby logistical problems with transport and storage
- With a long harvest window, the opportunity exists to delay harvest
  - ***Advantages***: lesser nutrient replacement cost (Fig 1), in-field storage, natural dry down in standing crop, potential for single-pass harvest with attendant reduction in harvest energy and labor costs (Adler, 2006; Popp et al., 2015)
  - ***Disadvantage***: lower recoverable yield
- Cahill et al. (2014), among others, have evaluated the tradeoff associated with yield loss and nutrient cost savings associated with harvest delays, but evaluation of moisture content tradeoffs was not addressed. This issue can be modeled using ENCAP (Energy Crop Analysis and Planning), a spreadsheet based decision aid that analyzes yield and nutrient replacement cost tradeoffs while reporting moisture content across harvest window for locations shown in Figure 2

Objectives

- Determine economic impacts of alternative harvest dates in relation to moisture content, biomass yield and nutrient replacement cost of switchgrass
  - using data from a variety of field conditions as observed at experimental plots shown in Figure 2
  - highlight harvest cost differential between harvest options (Fig 3):
    - Multi-pass bale (**MPB**): 1st mow, 2nd bale and 3rd stage with twine
    - Multi-pass chop (**MPC**): 1st mow, 2nd rake and 3rd forage harvester with a pickup header
    - Single-pass chop (**SPC**): forage harvester with a cutting header

Data and Methods

- Using estimated yield curves – the relationship between yield and harvest date – we show differences between yield max (e.g. points **A** in Fig 1) and profit max (e.g. points **B** in Fig 1) by location and harvest year as estimated in ENCAP. Key baseline prices and costs are:
  - Switchgrass \$50/ton at side of field (baled) or chopped F.O.B. at storage safe moisture (<20% for MPB and MPC) and moisture at time of cutting for SPC
  - Nutrient costs of N = 0.62 \$/lb, P = 1.58 \$/lb and K = 0.60 \$/lb
  - Fuel = \$2.48/gal
  - Labor = \$9.50/hr
- Using default prices and performance parameters for equipment as available in ENCAP, breakeven cost of production including establishment and maintenance for 10 year useful lives of switchgrass across the MPB, MPC and SPC harvest options (Fig 4) are highlighted. All other costs are held constant.
  - Analyzed are labor and equipment cost tradeoffs across MPB, MPC and SPC by operation/equipment complement
  - SPC product is at moisture content of standing crop at time of harvest, MPC and MPB are field dried to <20% moisture for safe storage
  - Nutrient content in harvested biomass is also reported by harvest option
  - Profitability of MPC at the profit max harvest date is compared to SPC harvested when moisture content reaches 30% and 20% to show nutrient content and cost of production implications to answer our key question:

Is natural dry down in the standing crop worth waiting for when comparing harvest cost, nutrient content and energy savings against yield loss?

Figure 1. Comparison of Estimated Yield, Nutrient Removal, Partial Return and Moisture Content by Harvest Date by Location and Year.

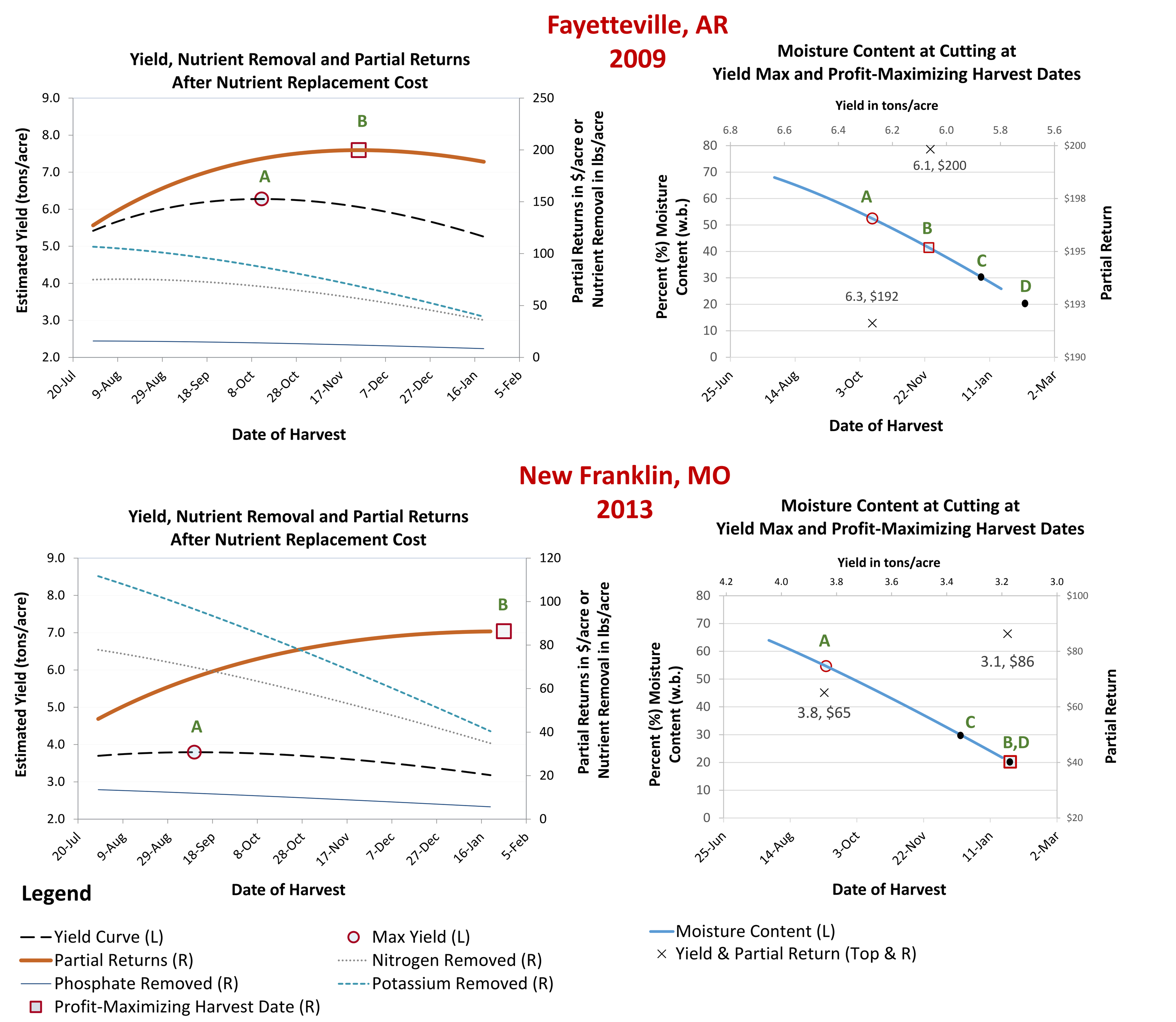


Figure 2. Map of Study Locations.

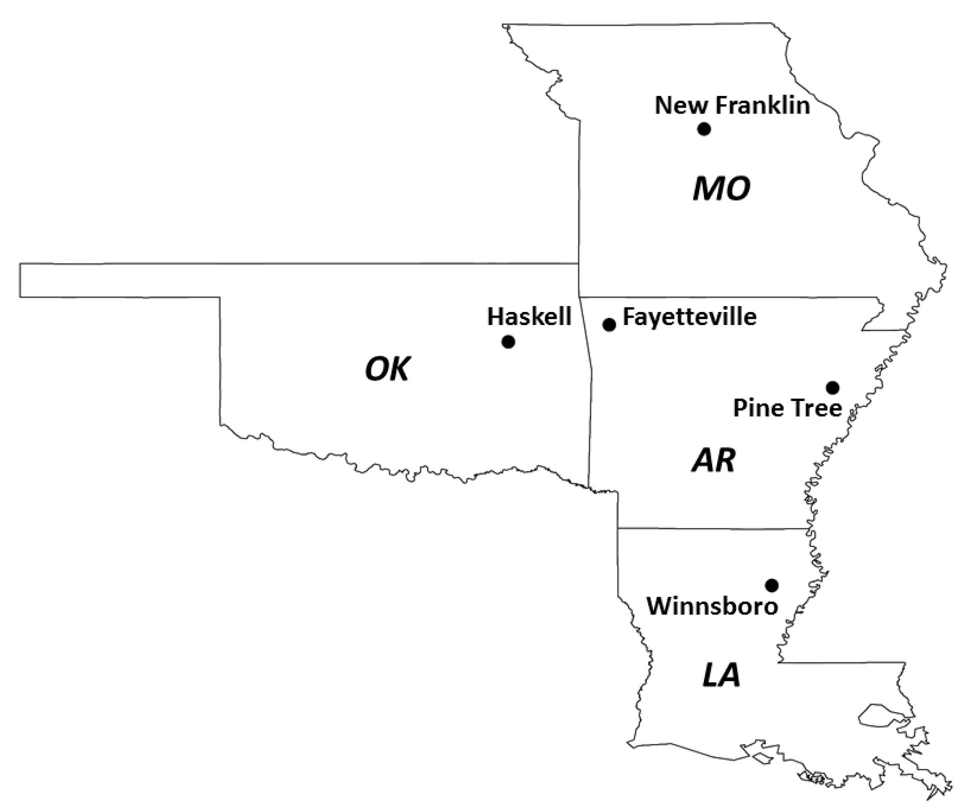
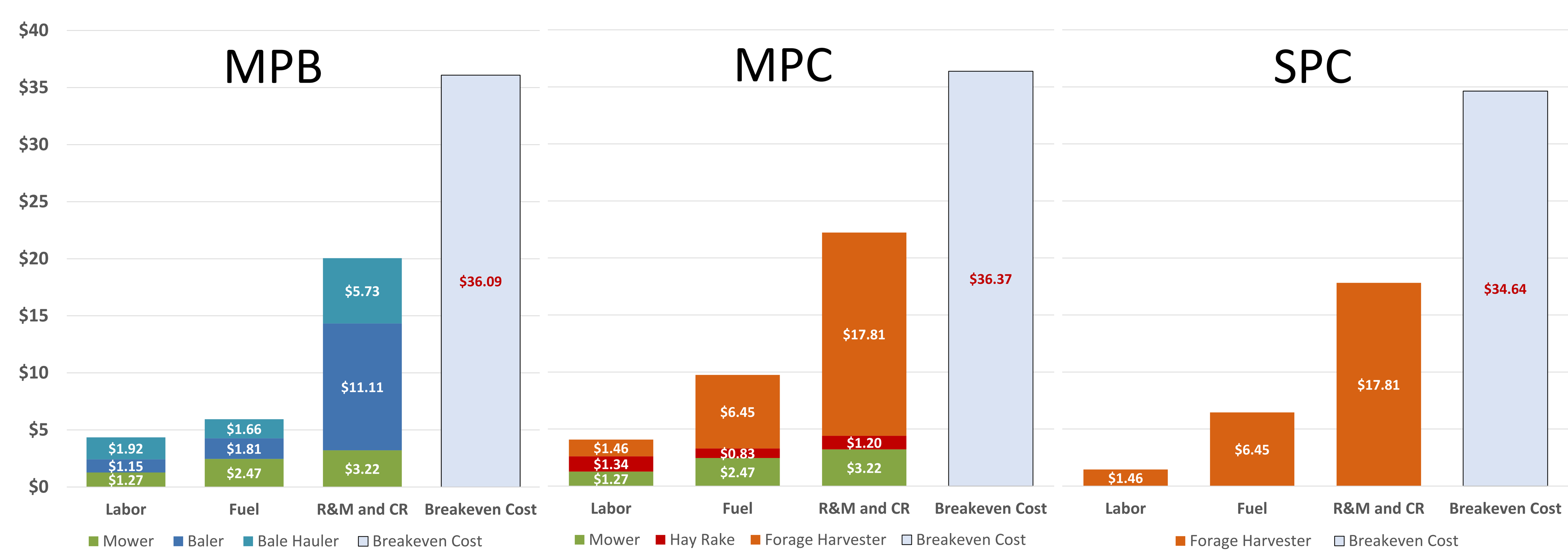


Figure 3. Harvest Equipment for MPB, MPC and SPC Options

Figure 4. Harvest Cost for MPB, MPC and SPC Options in \$/ton for 2009 at Fayetteville, AR with Harvest-Date Specific Fertilizer Replacement and Default Production Practices from ENCAP at a Yield of 6 dry ton/acre



Results

Is natural dry down in the standing crop worth waiting for when comparing harvest cost, nutrient content and energy savings against yield loss?

- At the Fayetteville, AR, location, across 4 years, profitability declines between point **B** (profit max) point **D** (moisture content reaches 20%), as yield loss was larger than energy and nutrient replacement cost savings (Fig 1)
- At the New Franklin, MO, location, across 2 years, profitability increases from **B** → **D**, as yield loss was minor and nutrient replacement cost declined rapidly with harvest date (Fig 1)
- Across four years, the Pine Tree, AR, location showed declines in profitability between profit-maximizing harvest date and 20% moisture content. Similarly, across two years, the Haskell, OK and Winnsboro, LA locations showed declines in profitability between profit-maximizing harvest date and 20% moisture content (see handout)
- Point **C**, where switchgrass harvest occurred at a 30% moisture level and required artificial drying using SPC, was rarely profitable after accounting for costs of drying the biomass to 20%
- Nutrient concentration changes with harvest date varied by location. This could be a struggle for biorefineries interested in consistent feedstock (see handout)
- Harvest cost differentials across harvest systems were minor when analyzed in relation to total specified expenses over the life of a switchgrass stand (Fig 4)

Implications

- Understanding the economic tradeoff between moisture content, yield and resultant harvesting technique enables producers and/or custom harvesters to decide whether or not to invest in cutter headers for their forage harvesters
- Changes in producer profit with delayed harvest provide information for optimal storage capacity needs by biorefineries as they coordinate harvest schedules
- The nutrient concentration information of the harvested biomass has processing cost ramifications that were not included in this analysis but are likely of interest to biorefineries

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Table 1. Comparison of Harvest Dates, Profitability, Harvest Cost, and Artificial Drying Expenses Using Different Harvesting Equipment by Location and Year with *ENV* × *DAY* Interactions.

Scenario[a]		Y_{max} **(A)**		π^* **(B)**				π_{mc30} **(C)**					π_{mc20} **(D)**			
Measure[b]		$YIELD_{max}$	DAY^*	$YIELD^*$	π^*	HC	MC	DAY_{30}	$YIELD_{30}$	π_{30}	HC_{30}	AD	DAY_{20}	$YIELD_{20}$	π_{20}	HC_{20}
Site[c]	**Year**	tons/acre		tons/acre	$/acre		% w.b.		tons/acre	$/acre				tons/acre	$/acre	
Fayetteville, AR	'09	6.3	11/25	6.1	170	29	43	1/2	5.6	156	28	10	1/28	5.1	159	26
	'10	6.5	11/26	6.3	177	30	40	12/27	5.9	163	30	10	1/23	5.5	168	28
	'11	6.5	11/26	6.3	174	30	41	12/29	5.8	160	30	10	1/25	5.4	164	27
	'12	6.2	11/25	6.0	169	29	41	12/28	5.6	156	29	10	1/23	5.2	160	26
Pine Tree, AR	'10	6.6	11/26	6.3	212	31	39	12/24	6.0	199	30	10	1/20	5.5	204	28
	'12	6.3	11/25	6.0	204	29	40	12/25	5.7	192	29	10	1/20	5.2	192	27
	'13	6.3	11/25	6.1	191	30	42	12/30	5.6	177	29	10	1/26	5.2	181	26
	'14	6.4	11/25	6.2	195	30	41	12/28	5.8	182	29	10	1/24	5.3	185	27
Haskell, OK	'10	7.6	11/28	7.3	228	34	36	12/16	7.1	213	36	12	1/12	6.7	221	34
	'11	7.5	11/28	7.3	225	34	36	12/18	7.0	209	36	12	1/15	6.6	217	33
Winnsboro, LA	'12	3.3	12/3	3.0	79	18	32	12/9	2.9	77	15	5	1/5	2.7	74	13
	'13	3.3	12/3	3.0	65	18	34	12/15	2.9	63	15	5	1/11	2.6	67	13
New Franklin, MO	'11	4.0	1/28	3.3	86	19	17	12/18	3.6	79	18	6	1/18	3.4	88	17
	'12	3.8	1/26	3.1	81	18	17	12/16	3.4	75	17	6	1/17	3.2	83	16
	'13	3.8	1/26	3.1	68	19	19	12/23	3.4	62	17	6	1/23	3.2	70	16

Notes:

[a] Scenarios are Y_{max} representing yield-maximizing conditions, π^* represents profit-maximizing conditions using a mower-conditioner followed by (fb) a twin-rake to combine the swath fb a forage harvester with pickup header, π_{mc30} involves a harvest operation when moisture content in the standing crop reaches 30% using only the forage harvester with a mower header fb artificial drying at the biorefinery and π_{mc20} is the same as π_{mc30} except that artificial drying expenses are avoided. The estimated date of maximum yield is October 12 for Fayetteville and Pine Tree, AR and Haskell, OK as the same yield curve was assumed for those locations. The maximum yield days for Winnsboro, LA and New Franklin, MO are September 30 and September 9, respectively.

[b] *DAY* is the harvest date, *YIELD* is the dry matter yield in tons/acre, π are partial returns in dollar ($) per acre, excluding fertilizer, operating interest, and returns to land at full yield potential (2nd harvest and beyond), *HC* are yield dependent harvest costs per acre and *AD* are artificial drying costs per acre. The performance measures are calculated at a switchgrass price and input costs described in Data and Methods.

Table 2. Comparison of Nutrient Concentrations (% d.b.) in Harvested Biomass Using Different Harvesting Equipment by Location and Year with *ENV* × *DAY* Interactions.

Scenario[a]		π^* **(B)**			π_{mc30} **(C)**			π_{mc20} **(D)**		
Measure[c]		*N*	*P*	*K*	*N*	*P*	*K*	*N*	*P*	*K*
Site[b]	**Year**									
Fayetteville, AR	'09	0.47	0.10	0.57	0.39	0.09	0.44	0.32	0.08	0.34
	'10	0.53	0.09	0.61	0.48	0.08	0.52	0.42	0.08	0.43
	'11	0.50	0.09	0.63	0.44	0.08	0.53	0.38	0.08	0.44
	'12	0.47	0.09	0.58	0.40	0.08	0.47	0.33	0.07	0.38
Pine Tree, AR	'10	0.27	0.06	0.24	0.21	0.05	0.13	0.13	0.04	0.01
	'12	0.20	0.06	0.19	0.12	0.05	0.07	0.03	0.04	0.00
	'13	0.32	0.07	0.36	0.23	0.06	0.24	0.15	0.05	0.11
	'14	0.32	0.07	0.37	0.24	0.06	0.25	0.16	0.05	0.13
Haskell, OK	'10	0.42	0.11	0.40	0.39	0.11	0.35	0.34	0.10	0.26
	'11	0.40	0.11	0.41	0.36	0.11	0.35	0.30	0.10	0.26
Winnsboro, LA	'12	0.42	0.06	0.08	0.40	0.05	0.03	0.27	0.03	0.00
	'13	0.66	0.08	0.43	0.62	0.08	0.35	0.52	0.06	0.13
New Franklin, MO	'11	0.38	0.07	0.37	0.51	0.09	0.60	0.41	0.07	0.43
	'12	0.30	0.06	0.26	0.45	0.09	0.51	0.33	0.07	0.32
	'13	0.53	0.09	0.60	0.64	0.10	0.78	0.54	0.09	0.62

Notes:

[a] Scenarios are Y_{max} representing yield-maximizing conditions, π^* represents profit-maximizing conditions using a mower-conditioner followed by (fb) a twin-rake to combine the swath fb a forage harvester with pickup header, π_{mc30} involves a harvest operation when moisture content in the standing crop reaches 30% using only the forage harvester with a mower header fb artificial drying at the biorefinery and π_{mc20} is the same as π_{mc30} except that artificial drying expenses are avoided.

[b] *N*, *P*, and *K* are nutrient concentrations expressed in percent weight of a nutrient/unit weight of dry yield of the biomass at time of harvest.