TRANSITION TO A BIO ECONOMY

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# Expected Changes in Farm Landscape with the Introduction of a Biomass Market

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**Abstract**: This study examines how the introduction of dedicated energy crops—switchgrass and forage sorghum—may affect Arkansas' crop allocation decisions. The study captures crop production practices at the county or crop reporting district level. Results are in a static equilibrium framework and limited to a one-year ahead forecast. The model's predictive success was evaluated by comparing 2007 model results with no energy crop production to actual acreages harvested. Switchgrass entered land use at approximately $25 and $35/dry ton in 2007 and 2008, respectively. Higher 2008 commodity prices for traditional crops caused lower switchgrass acreage peaks compared to 2007. Further, at higher biomass price levels—$45 to $55/dry ton depending on year and whether or not land charges were applied—the annual energy crop, forage sorghum, surpassed switchgrass acreage primarily as a result of its higher yield. Since acreage supply response is quite elastic, biorefineries will be exposed to significant price risk, especially at higher biomass prices, when the annual energy crop exceeds perennial switchgrass in acreage. Finally, the study examined impacts of biomass production on resource use. Regardless of ownership scenario, in 2007 and 2008, a 13 and 10 percent reduction, respectively, in irrigation water per acre occurred when the price of switchgrass increases from $25 to $65. Labor and fuel use showed no such trends. This is a significant finding, given diminishing water resources for a large portion of the Arkansas crop producing region.

As second generation biofuel production becomes an increasing reality, it is anticipated that a percentage of traditional farmland will shift to the production of biomass in the form of dedicated energy crops. This study examines potential changes to Arkansas' farm crop allocation decisions by simulating to what extent crop, hay, and pasture land are affected by the introduction of two potential biomass crops—switchgrass and forage sorghum. Historical minimum and maximum harvested acres and yields, cooperative extension information on cost of production, and expected production cost information for biomass crops are used in a constrained optimization problem. Significant changes in fuel (and thereby irrigation cost), commodity, and fertilizer prices demonstrate how changes in production cost and revenue experienced from 2007 to 2008 may affect resource allocation decisions.

Modeling efforts of a similar type have been conducted at the national level (Walsh et al., 2003; English et al., 2006) to determine the potential supply and location of biomass crops. These efforts utilize regional cost of production information at the Agricultural Statistical District (ASD) level. A weakness of these national models is that county-level details regarding, for example, double cropping practices or technology-driven changes in production costs are overlooked. In contrast, this modeling effort uses expert opinion to determine costs of production on a county or crop reporting district level for the state of Arkansas. While most national models make broad assumptions and disaggregate down, this model incorporates county level detail and aggregates up. By surveying county level crop extension agents a more precise representation of

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the production nuances of each county can be captured. This modeling effort also differs from previous studies by including forage sorghum as a bioenergy crop and—for switchgrass—estimating the opportunity cost of missed crop production for the first year of switchgrass establishment. Switchgrass and forage sorghum were chosen as the alternative crops since i) they represent a continuum of low to high input in terms of irrigation water and fertilizer use; ii) they differ in yield potential and seasonal yield availability (a perennial cut late season with a significant stand establishment period required vs. an annual with as many as two cuttings); and iii) different modes of storage due to likely moisture content differences at time of harvest. These crops thus represent the expected spectrum of choices for producers interested in participating in either the short or long term production of biofuels.

One weakness of this modeling effort is the static equilibrium framework where results are limited to a one-year ahead forecast without detail on the dynamics of changes in land use. Switchgrass, for example, enters the solution at its prorated cost of production and yield as estimated for the eight to ten year useful life of the stand.

The objective of the paper is therefore to develop i) a 2007 land allocation baseline with and without land charges as a means to validate the model against actual acreage allocations as reported in 2007; ii) a 2008 land use baseline using fall 2007 costs of production and commodity futures prices; iii) estimation of biomass supply functions under varying output price scenarios; and iv) impacts of biomass production on resource use (labor, fuel, and irrigation water).

## 2. Data and Methods

Cost of production information, as reported by the cooperative extension service of the University of Arkansas, was entered into an EXCEL spreadsheet for all traditional crops of cotton, corn, rice, sorghum, soybeans, and wheat. These data are summarized in Table 1 and indicate average and range of costs for irrigated, non-irrigated and double cropped production across technology and soil type parameters (University of Arkansas Cooperative Extension Service, 2008). Fuel, labor, fertilizer, and irrigation water use were recorded both in terms of quantity and cost to allow for sensitivity analyses. Table 2 summarizes similar information for the expected cost of production of dedicated bioenergy crops using expert opinion.

Crop specific extension experts were also consulted on various production technology methods implemented within the nine crop reporting districts (CRD) as defined by the Arkansas Agricultural Statistics Service. That is, cotton extension experts were asked to assign percentages to each of the 28 possible cotton production methods in Arkansas within each CRD. This effort resulted in CRD-specific cost of production estimates. County level average 2004-2007 yields (USDA NASS, 2008) helped determine returns above total specified expenses for the 75 counties in Arkansas. This spatial differentiation on the basis of cost and yield was not possible for the dedicated energy crops – forage sorghum and switchgrass—as production methods are still somewhat new and county-specific yield data were not available.

**Table 1**. **Summary of average and range of per acre estimated total specified expenses for traditional crops of corn, cotton, grain sorghum, rice, soybean and wheat across reported production practices using input costs as of November, 2007, Arkansas**

| | | Corn | Cotton | | Grain Sorghum | | Rice | Soybean | | | Wheat |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Description | Units | Irr. | Irr. | Non-Irr. | Irr. | Non -Irr. | Irr. | Irr. | Dbl. Crop | Non-Irr. | Winter |
| Fertilizer (N-P-K-S-B) | | | | | | | | | | | |
| Urea (46-0-0) | lb | 215 | 218 | 174 | 293 | 239 | 329 | -- | -- | -- | 290 |
| Liq. Nitrogen (32-0-0) | lb | 405 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Amm. Nitrate (34-0-0) | lb | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| D. Phos. (18-46-0) | lb | -- | -- | -- | -- | -- | -- | -- | -- | -- | 150 |
| Phosphate (0-45-0) | lb | 163 | 130 | 130 | 130 | 109 | 98 | 80 | 70 | 80 | -- |
| Potash (0-0-60) | lb | 125 | 200 | 200 | 117 | 100 | 113 | 120 | 75 | 120 | -- |
| Sulfur (0-0-0-90) | lb | -- | 11 | 11 | -- | -- | -- | -- | -- | -- | -- |
| Boron (0-0-0-0-15) | lb | -- | 7 | 7 | -- | -- | -- | -- | -- | -- | -- |
| Irrigation | inch | 12 | 10 | 0 | 6 | 0 | 32 | 12 | 10 | 0 | 0 |
| Labor | | | | | | | | | | | |
| Operator | hrs | 0.72 | 1.11 | 1.58 | 0.59 | 0.55 | 0.92 | 0.54 | 0.49 | 0.39 | 0.40 |
| Hired | hrs | 0.39 | 0.68 | 0.66 | 0.19 | 0.10 | 0.58 | 0.31 | 0.26 | 0.11 | 0.09 |
| Fuel (incl. custom hire) | gal | 22.08 | 28.30 | 18.96 | 15.46 | 7.06 | 43.55 | 21.94 | 19.09 | 6.30 | 5.67 |
| Cost of Production | | | | | | | | | | | |
| Seed (incl.fees) | $ | 60.72 | 99.71 | 72.67 | 14.82 | 10.26 | 48.96 | 22.95 | 32.16 | 22.95 | 29.70 |
| Chemicals[1] | $ | 16.19 | 96.54 | 80.84 | 24.68 | 24.68 | 71.92 | 41.59 | 38.77 | 41.59 | 7.23 |
| Custom hire (no fuel) | $ | 10.52 | 55.56 | 51.01 | 16.67 | 16.67 | 45.08 | 24.91 | 26.09 | 24.91 | 24.41 |
| Repair & Maint. | $ | 14.23 | 25.71 | 23.22 | 11.20 | 7.14 | 17.48 | 11.78 | 11.25 | 6.25 | 6.09 |
| Ownership Charges[2] | $ | 71.48 | 133.1 | 104.6 | 72.40 | 31.35 | 80.04 | 70.15 | 70.91 | 26.79 | 25.61 |
| Operating Interest[3] | $ | 11.46 | 19.17 | 13.60 | 7.61 | 5.84 | 14.10 | 6.98 | 6.90 | 5.23 | 6.27 |
| Total Specified Exp.[4] | | | | | | | | | | | |
| Average | $ | 410.5 | 623.2 | 506.8 | 297.6 | 204.1 | 496.9 | 276.7 | 275.1 | 181.3 | 211.0 |
| Range (Max – Min) | $ | 80.35 | 135.3 | 9.33 | 62.99 | -- | 200.5 | 68.33 | 93.20 | 12.62 | 24.14 |
| # of Prod. Methods | | 7 | 28 | 3 | 3 | 1 | 8 | 8 | 10 | 2 | 4 |
| Land Charge[5] | $ | 69.23 | 92.31 | 64.17 | 80.77 | 64.17 | 115.38 | 92.31 | 40.83 | 52.50 | 40.83 |

Notes:

[1] Chemicals include herbicide, insecticide, fungicides, surfactants, adjuvants, harvest aides and growth regulators.

[2] Ownership charges include depreciation and capital costs but not housing, insurance and taxes.

[3] Operating interest (7%) is based on half of total specified expenses less ownership charges.

[4] A number of different crop production methods exist for each crop. Expert opinion was used to determine which of the reported methods was most relevant for each of the crop reporting districts.

[5] Land charges were based on reported charges for irrigated and non-irrigated acres as per Arkansas Agricultural Statistic Service (USDA NASS, 2008). These charges were further differentiated by crop using information from a focus group study conducted in 2001 (Hill, Popp and Manning, 2003).

**Table 2. Summary of per acre estimated total specified expenses for alternative crops of switchgrass and forage sorghum across expected production practices using input costs as of November, 2007, Arkansas**

| | | Switchgrass | | | Forage Sorghum | |
|---|---|---|---|---|---|---|
| Description | Units | Crop[1] | Hayland[2] | Pasture[2] | Irr. | Non-Irr. |
| Fertilizer (N - P - K - S) | | | | | | |
| Urea (46-0-0) | lb | -- | -- | -- | 300 | 220 |
| Ammonium Nitrate (34-0-0) | lb | 198[3] | 193[3] | 193[3] | -- | -- |
| Phosphate (0-45-0) | lb | 44[4] | 44[4] | 44[4] | 110 | 110 |
| Potash (0-0-60) | lb | 77[5] | 76[5] | 76[5] | 235 | 235 |
| Lime | ton | 0.10[6] | 0.13[6] | 0.13[6] | -- | -- |
| Irrigation | inch | 0 | 0 | 0 | 6 | 0 |
| Labor | | | | | | |
| Operator | hrs | 0.92 | 0.84 | 0.77 | 0.55 | 0.45 |
| Hired | hrs | 0.02 | 0.02 | 0.02 | 0.25 | 0.10 |
| Fuel (incl. custom hire) | gal | 5.08 | 4.68 | 4.33 | 12.81 | 5.80 |
| Cost of Production | | | | | | |
| Seed (incl. seed treatment & tech. fees) | $ | 8.40 | 10.50 | 10.50 | 22.53 | 15.17 |
| Chemicals[7] | $ | 4.29 | 3.80 | 3.80 | 25.71 | 25.71 |
| Custom hire (excl. fuel) | $ | 3.97 | 8.06 | 8.01 | 17.89 | 17.89 |
| Bale Wrap | $ | 10.68 | 9.89 | 8.93 | -- | -- |
| Repair & Maintenance | $ | 6.83 | 6.44 | 5.91 | 7.24 | 4.67 |
| Ownership Charges[8] | $ | 18.49 | 17.40 | 15.89 | 51.49 | 21.77 |
| Operating Interest[9] | $ | 3.22 | 3.45 | 3.35 | 8.33 | 6.41 |
| Total Specified Expenses[10] | $ | 104.80 | 109.94 | 105.73 | 297.69 | 211.28 |
| Land Charge[11] | $ | 56.00 | 35.00 | 25.00 | 80.77 | 64.17 |

Notes:

1,2 All costs and quantities are prorated over the useful life of 10 and 8 years, respectively, for establishing switchgrass on crop vs. hay or pasture land. For both establishment practices, 8 lb of pure live seed are applied per acre and cost of harvest is yield dependent. Note that chemical costs for establishment on hay or pasture land are based on the use of Atrazine, which is currently not licensed. Using alternatives would add an additional $3.99 prorated cost per acre.

3 Assumes 0 pounds per acre in the establishment year and 220 pounds per acre thereafter. The amounts differ between crop and hay land due to the difference in useful life.

4 Assumes approximately 20 lbs of phosphate fertilizer per acre per year. This amount is an estimate as current recommendations are to apply 40 lbs of fertilizer if soil P tests are medium +. Since P yield responses have been demonstrated to be insignificant (Parrish et al, 2003), we assume that the above fertilizer rate is adequate given Arkansas soils. Removal is also significantly affected by time of harvest.

5 Assumes approximately 45 lbs of potash fertilizer per acre per year. Again estimate is based on current recommendation to apply 80 lbs of potash fertilizer per acre per year based on soil tests. Same caveats as for P.

6 Assumes 1 ton per acre in the establishment year only.

7 Chemicals include herbicide, insecticide, fungicides, surfactants, adjuvants, harvest aides and growth regulators. Chemicals are only applied in year one for switchgrass and thus numbers represent prorated amounts.

8 Ownership charges include depreciation and capital costs but not housing, insurance and taxes.

9 Operating interest (7%) is based on half of total specified expenses less ownership charges.

10 Opportunity costs per acre for the establishment year are not included in total specified expenses and amount to $25 and $35 per acre for pasture and hay land prorated over 8 years and $52.21 per acre and $98.71 per acre for 2007 and 2008, respectively, on crop land prorated over 10 years.

11 State-wide average non-irrigated land charges are a conservative estimate for switchgrass on cropland. Forage sorghums are charged the same rate as grain sorghums due to similarities in production. Land charges for switchgrass on hay and pasture land reflect profitability of hay land and pasture land, respectively.

Historical harvested crop land information (including all crops, fruits, vegetables, hay land, and hay yield), pasture and irrigated acres were collected from agricultural census data for 1987, 1992, 1997 and 2002 (USDA Census of Agriculture). Conservation Reserve Program (CRP) acreage, as well as average county specific payments for 2007, were obtained from the USDA's Farm Service Agency (FSA, 2008). Annual harvested acres for the traditional crops were also available electronically by county from the Arkansas Agricultural Statistics Service from 1975 to 2007 (USDA NASS, 2008). Variation in pasture and hay land nutrient management systems (e.g. poultry litter or use of nitrogen fixing companion crops), number of harvests, grazing methods and operator rental arrangements proved too cumbersome to model. Hence pasture rental rates and hay land returns were set to reflect surrounding states' cash rental returns to pasture at $25/acre (USDA, 2008 Pasture Cash Rent) and hay land returns were set higher at $35/acre to reflect more productive land that could be harvested with conventional haying equipment. Since land rental arrangements vary significantly across Arkansas, cash rental rates by crop were used to differentiate between ownership (no land charges and thereby land allocation on the basis of relative profitability only) and cash rent only, where land allocation includes a proxy for ownership costs via cash rent. While neither extreme applies to Arkansas conditions, the two scenarios are expected to provide a reasonable range of estimates.

The net return ($NR$) of Arkansas crop, hay, and pasture land could then be maximized by choosing crop acres ($x$) on the basis of expected commodity prices ($p$), county relevant yield ($y$) and cost of production information ($c$) as follows:

$$\text{Maximize } NR = \sum_{i=1}^{75}\sum_{j=1}^{18}\left(p_j \cdot y_{ij} - c_{ij}\right)\cdot x_{ij} \tag{1}$$

Subject to:

$xmin_{ij} \leq x_{ij} \leq xmax_{ij}$

$irrmin_i \leq \sum irr_{ij} \leq irrmax_i$

$iacresmin_i \leq \sum x_{ij} \leq iacresmax_i$ for irrigated crops only

$acresmin_i \leq \sum x_{ij} \leq acresmax_i$ for all crops except pasture and CRP

where $i$ denotes each of the 75 counties of production and $j$ denotes the 18 land management choices. *Xmin* and *xmax* are historically reported county acreage minima and maxima over the harvest years 2000 through 2007 for each crop (USDA NASS, 2008). The model was also run using historical minima and maxima reaching back to 1975 when cotton acreage was very small in Arkansas. The model predicted large acreage shifts from cotton to biomass. This was considered unrealistic given Arkansas' investment in cotton gins and specialized harvesting equipment. Energy crops had zero minima. Switchgrass on crop land was limited to a maximum of 10% of total harvested land to reflect an expected farmer adoption lag for a new crop. Switchgrass on hay and pasture land was limited to a maximum of 10% of the sum of hay and pasture land so as not to encroach on current livestock production. Cattle and calf numbers for the census years corresponding to hay and pasture land numbers were used to determine average acreage per head of livestock. The January 1, 2008, inventory numbers were subsequently multiplied by the average acreage per head to determine how much hay and pasture land were required to maintain the current herd of cattle. In the most restricted county, Faulkner, the minimum was 90% of the maximum and hence the 10% of maximum constraint. Because forage sorghum is similar in production technology to grain sorghum, it was not curtailed, except to historically reported maximum irrigated county crop acres (*iacresmax*) and harvested county crop land (*acresmax*) for irrigated and non-irrigated production, respectively. *Irrmin* and *irrmax* restricted the amount of water *(irr)* that can be used across crops and county. Restrictions were based on initial base model runs primarily for purposes of analyzing a hypothetical restriction of water use to sustainable levels (not reported here). *Iacresmin* and *iacresmax* are the 1987 to 2007 census-based reported irrigated acres that reflect technological, socioeconomic, and capital barriers to irrigation, again at the county level. *Acresmin* and *acresmax* are total harvested acres at the county level, as collected by the Census, and were amended by adding 10% of county CRP enrollments to the maximum harvested acre totals to reflect the potential for added acres from land coming out of CRP and the typical ten year enrollment horizon of CRP acreage. Note that winter wheat was considered as part of harvested acres even though this crop is usually entertained in double crop rotations with soybean, corn, or sorghum crops.

Crop price information ($p_j$) was based on the July futures prices as of December of the previous year and no commodity price program support with the exception of wheat where May futures prices as of September of the previous year were used to reflect different planting times (Great Pacific Trading Company, 2008). Basis expectations, defined as the local cash price less the nearby futures contract to account for time, location, and quality differences, were set to zero for all crops and prices were adjusted for hauling, drying and commodity board check off charges as appropriate (Table 3).

Switchgrass and forage sorghum prices were then modified over a range of $25 to $65 per dry ton (dt) to estimate the supply response functions under various input cost scenarios (2007 vs 2008). With the recent rise in fertilizer prices, local startup companies interested in collecting rice and wheat straw were bidding $40 to $50 to encourage farmer participation at the time of this writing. The range of prices chosen reflects the authors' best guess as to prices biorefineries may be willing to entertain to obtain adequate biomass supply. A discount of $5 per dt relative to baled switchgrass stored at the side of the field was applied to forage sorghum as it was assumed to be sold standing in the field for forage chopping and direct hauling to the processing facility where it would be artificially dried. This discount is an estimate given a lack of accurate available cost information on relative harvest, storage, packaging, drying, transport and processing costs for switchgrass and forage sorghum. Per acre yields ($y_{ij}$) are county averages for most crops. Because double cropped soybean yields are only reported at the CRD level for Arkansas and not separated by irrigation management, this crop was assumed to be exclusively irrigated within minimum and maximum county acreage restrictions prorated on the basis of irrigated full season soybean county acreage information. For Arkansas grain sorghum, NASS does not separate yields by irrigated management, so county extension agents were asked to provide a breakdown of irrigated vs. non-irrigated production by CRD. A yield increase (decrease) of 17.5 bushels from the overall average was then applied to irrigated (non-irrigated) grain sorghum based on 2000-2007 NASS data for the state of Kansas where yield differences are tracked (NASS, 2007). Per acre cost of production estimates ($c_{ij}$) were developed as reported above, and depending on the model run, estimates either included or excluded cash rent.

**Table 3. Summary of 2007 and 2008 commodity price, yield, and input cost information**
**Commodity Prices and Yields**

| Commodity | Unit | Futures Prices[1] 2007 | Futures Prices[1] 2008 | Custom Hauling[2] / Drying[3] and Checkoff / Other[4] | 2007 baseline average yield[5] (2004-2007) | Production Method / Region |
|---|---|---|---|---|---|---|
| Corn | bu | $4.00 | $4.25 | $0.35 | 151.5 | Irrigated |
| Wheat | bu | $4.60 | $7.00 | $0.16 | 51.9 | Irrigated |
| Beans | bu | $7.10 | $11.00 | $0.186 (2007)<br>$0.205 (2008) | 40.6<br>26.8<br>32.7 | Irrigated<br>Non-irrigated<br>Double cropped |
| Rice | lb | $0.11 | $0.14 | $0.01 | 6,896.3 | Irrigated |
| Cotton | lb | $0.58 | $0.67 | -$0.04 | 1,099.7<br>888.8 | Irrigated<br>Non-irrigated |
| Grain Sorghum | bu | $3.80 | $4.04 | $0.16 | 105.2<br>70.0 | Irrigated<br>Non-irrigated |
| CRP | acre | $52.00 | | | | State average |
| Forage Sorghum | dt | | | | 9.75<br>6.50 | Irrigated<br>Non-irrigated |
| Switchgrass | dt | | | | 5.20<br>4.56<br>4.13 | Cropland<br>Hay<br>Pasture |

**Input Prices**

| | Units | 2007 | 2008 |
|---|---|---|---|
| Fertilizer (N - P - K - S) | | | |
| Urea (46-0-0) | lb | 0.18 | 0.20 |
| Liquid Nitrogen (32-0-0) | lb | 0.12 | 0.15 |
| Ammonium Nitrate (34-0-0) | lb | 0.12 | 0.15 |
| Diammonium Phosphate (18-46-0) | lb | 0.14 | 0.24 |
| Phosphate (0-45-0) | lb | 0.14 | 0.22 |
| Potash (0-0-60) | lb | 0.13 | 0.14 |
| Sulfur (0-0-0-90) | lb | 0.23 | 0.20 |
| Boron (0-0-0-0-15) | lb | 0.53 | 0.40 |
| Lime | ton | 33.00 | 33.00 |
| Labor | | | |
| Operator | hrs | 9.45 | 9.45 |
| Hired | hrs | 8.19 | 8.19 |
| Fuel | gal | 2.20 | 2.33 |
| Operating Interest | % | 7.75 | 7.00 |

Notes:
1. Futures prices were for the July contract month as of December of the previous year except for wheat where May futures prices as of September were used to reflect a different planting period (GPTC, 2008).
2. Custom hauling charges amounted to $0.15 per bushel for all commodities except cotton.
3. Drying charges were $0.19 per bushel on corn and $0.30 per bushel on rice.
4. Commodity check off was ½% of price on soybean, $0.01 per bushel on grain sorghum, corn, cotton and wheat and $0.0135 per bushel on rice. Cotton ginning returns of $0.05 per lb were added for cotton.
5. Average yields are for the 2007 baseline scenario without alternative energy crops using per acre county average yields reported by NASS for 2004 through 2007. Forage sorghum yields did not vary by county due to lack of information. Switchgrass yields are prorated and a result of 0, 4 and 6 dt/acre in years 1, 2 and 3 through 10 on crop land, 0, 3.5 and 5.5 dt/acre in years 1, 2 and 3 through 8 on hay land, and 0, 3 and 5 dt/acre in years 1, 2 and 3 through 8 on pasture land.

All model runs were estimated in a linear programming context using the Premium Solver Plus software add-in to EXCEL (Frontline, 2008) as the model required in excess of 3,000 adjustable variables to maximize NR subject to an even larger number of constraints, as described in Equation 1. The 2007 baseline was executed using zero prices for alternative energy crops to see how accurately the model would predict observed total harvested land allocations in 2007 on the basis of 2006 input cost and 2007 commodity price expectations. The baseline results were also used to provide an estimate of per acre opportunity costs that would be incurred in the year of establishment for switchgrass, a crop that does not yield to its full potential until year three with zero saleable product in year one. This opportunity cost ($o_i$) was added to the prorated net returns above total specified expenses for switchgrass ($nr$) as follows:

$$nr_{i,switchgrass} = \left( \sum_{n=1}^{k^t} [((p \cdot y_n^t) - c_n^t)/(1+r)^n] \right) - o_i / k^t \quad (2)$$

where $n$ is the production year in the useful life ($k^t$) of switchgrass with useful life varying by land type ($t$ – crop, hay, or pasture land), $p$ is the price per dt of switchgrass, $y_n{}^t$ and $c_n{}^t$ are the production year-dependent yield and cost of production by land type, $r$ is the capital recovery rate (6%) and $o_i$ are the average county net return estimates to pasture, hay, or conventional crops observed in the base run with switchgrass and forage sorghum prices set to zero.

To conduct the sensitivity analyses surrounding commodity and input costs, the 2007 baseline was updated to 2008 by using fall of 2007 commodity price expectations and input costs as shown in Table 3.

**3. Results**

Comparing the 2007 baseline prediction (2007 Base—no rent and 2007 Base—with rent) to actual acreage of harvested crop land suggested that the model was slightly conservative in crop production (-2.4% and -7.1%) for the entire state (Table 4). The largest prediction errors amongst land use choices varied depending on whether or not land charges were included. Perhaps the profitability of hay land was set too low and/or zero basis assumptions were optimistic for rice and wheat. Nonetheless, the range of baseline expectations with and without land charges was deemed sufficiently representative to allow for the estimation of biomass supply functions and sensitivity analyses on crop and input prices.

The bottom four rows of Table 4 show acreage allocation changes due to changes in commodity and input prices between 2007 and 2008. A brief review and comparison of the futures prices of 2007 and 2008 (Table 3) explains the baseline acreage increases primarily in soybeans and wheat as their prices relative to other commodities experienced greater increases (Table 4).

Adding switchgrass production at \$5 increments in switchgrass price to the above model runs resulted in significant changes in acreage allocations. In the no-rent scenarios for 2007 and 2008, switchgrass entered the crop mix at relatively low switchgrass prices ($P_s$) of \$25 and \$35, respectively. In 2007 switchgrass acreage peaked at or near \$40 (no rent—483 thousand acres) and \$45 (with rent—674 thousand acres). Given higher commodity prices in 2008, biomass acreage decreased with switchgrass acreage peaking at or near \$45 (no rent—368 thousand acres) and \$50 (with rent—374 thousand acres).

**Table 4. 2007 and 2008 baseline crop acreage allocation in thousands of acres—predicted vs. actual and year to year changes**

| Description | Corn | Cotton | Soybean | Rice | Wheat | Grain Sorghum | Hay-land | Pasture | Total (Excl. Pasture |
|---|---|---|---|---|---|---|---|---|---|
| 2007 Actual Harvested Acres | 590.0 | 850.0 | 2,790.0 | 1,325.0 | 700.0 | 215.0 | 1,580.0 | 1,977.1 | 8,031.0 |
| | | | | | | | | | |
| 2007 Base – no rent | 543.7 | 868.9 | 2,532.5 | 1,464.4 | 801.3 | 216.5 | 1,409.8 | 2,036.8 | 7,837.0 |
| % deviation from actual | -7.8% | 2.2% | -9.2% | 10.5% | 14.5% | 0.7% | -10.8% | 3.0% | -2.4% |
| 2007 Base – with rent | 543.2 | 732.7 | 2,480.3 | 1,459.2 | 607.9 | 204.3 | 1,434.8 | 2,036.8 | 7,462.4 |
| % deviation from actual | -7.9% | -13.8% | -11.1% | 10.1% | -13.2% | 5.0% | 9.2% | 3.0% | -7.1% |
| | | | | | | | | | |
| 2008 Base – no rent | 321.7 | 805.7 | 2,778.1 | 1,550.9 | 1,009.8 | 70.4 | 1,340.9 | 2,036.8 | 7,877.4 |
| % change from 2007 | -40.8% | -7.3% | 9.7% | 5.9% | 26.0% | -67.5% | -4.9% | 0.0% | 0.5% |
| 2008 Base – with rent | 329.2 | 756.6 | 2,686.9 | 1,547.1 | 1,029.4 | 108.1 | 1,383.1 | 2,036.8 | 7,840.4 |
| % change from 2007 | -39.4% | 3.3% | 8.3% | 6.0% | 69.3% | -47.1% | -3.6% | 0.0% | 5.1% |

**Table 5. Profit per acre of switchgrass and forage sorghum under different pricing levels and production methods with and without land charges**

| | | Switchgrass Price[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Land Use | $25 | $30 | $35 | $40 | $45 | $50 | $55 | $60 | $65 |
| | | ----------------------------- Profit Per Acre[2] ----------------------------- | | | | | | | | |
| 2007 | Switchgrass on Crop Land | -$13 | $7 | $26 | $46 | $65 | $85 | $104 | $124 | $143 |
| | with rent | -$66 | -$46 | -$27 | -$7 | $12 | $32 | $51 | $70 | $90 |
| | Switchgrass on Hay Land | -$24 | -$6 | $12 | $30 | $48 | $66 | $84 | $102 | $120 |
| | Switchgrass on Pasture | -$28 | -$11 | $5 | $21 | $38 | $54 | $70 | $86 | $103 |
| | Non-irrigated Forage Sorghum | -$63 | -$31 | $2 | $34 | $67 | $99 | $132 | $164 | $197 |
| | with rent | -$127 | -$95 | -$62 | -$30 | $3 | $35 | $68 | $100 | $133 |
| | Irrigated Forage Sorghum | -$82 | -$33 | $16 | $64 | $113 | $162 | $211 | $259 | $308 |
| | with rent | -$163 | -$114 | -$65 | -$17 | $32 | $81 | $130 | $178 | $227 |
| 2008 | Switchgrass on Crop Land | -$26 | -$6 | $13 | $32 | $52 | $71 | $91 | $110 | $130 |
| | with rent | -$84 | -$64 | -$45 | -$25 | -$6 | $14 | $33 | $53 | $72 |
| | Switchgrass on Hay Land | -$33 | -$15 | $3 | $21 | $39 | $57 | $75 | $93 | $111 |
| | Switchgrass on Pasture | -$36 | -$20 | -$4 | $12 | $29 | $45 | $61 | $77 | $94 |
| | Non-irrigated Forage Sorghum | -$81 | -$49 | -$16 | $16 | $49 | $81 | $114 | $146 | $179 |
| | with rent | -$151 | -$119 | -$86 | -$54 | -$21 | $11 | $44 | $76 | $109 |
| | Irrigated Forage Sorghum | -$103 | -$54 | -$5 | $44 | $92 | $141 | $190 | $239 | $287 |
| | with rent | -$187 | -$138 | -$90 | -$41 | $8 | $57 | $105 | $154 | $203 |

Notes:

[1] Note that forage sorghum was priced at a constant 5 per dry ton less than switchgrass for all switchgrass price levels and that average yields for switchgrass on crop, hay and pasture land, non-irrigated and irrigated forage sorghum were 5.2, 4.56, 4.125, 6.5 and 9.75 dry tons per acre, respectively.

[2] Profit per acre figures include opportunity cost for the year of establishment for switchgrass and amounted to 3.13, 4.38, 5.22 and 9.88 per acre on hay, pasture, 2007crop and 2008 crop land, respectively. Forage sorghum is not expected to be grown on pasture land. Non-irrigated forage sorghum as well as other non-irrigated crops of grain sorghum, soybean, wheat and cotton can be established on hayland with the cost of preparing a seedbed allocated to the haying enterprise.

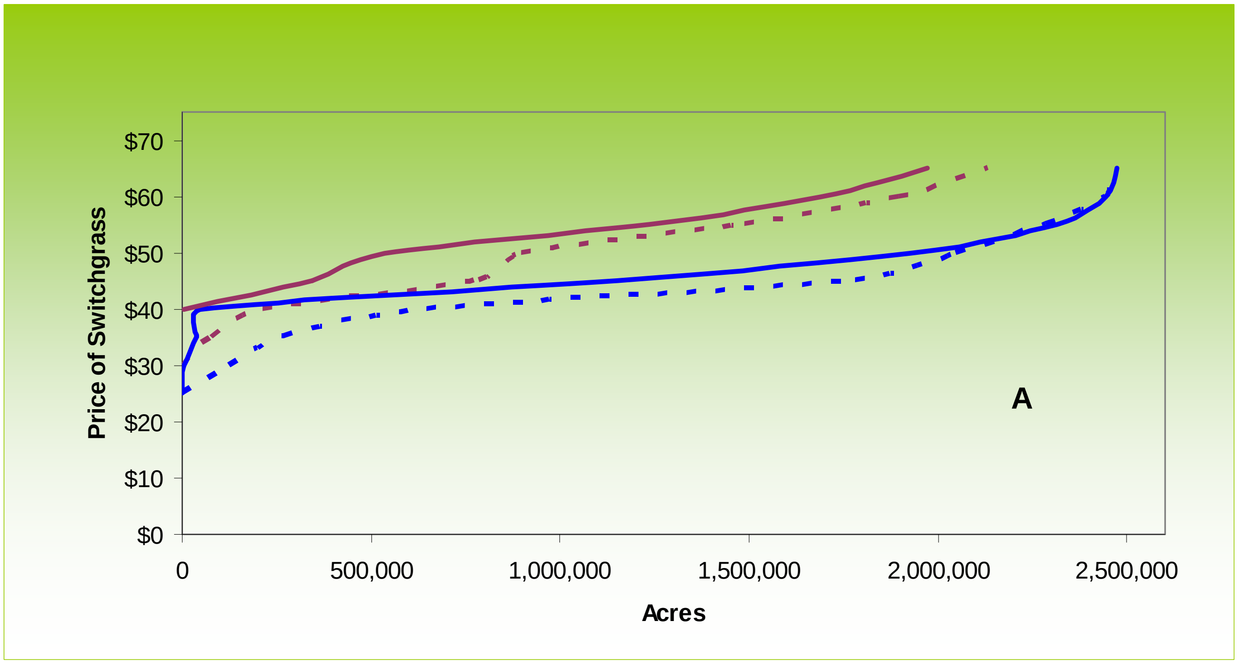
In 2007, forage sorghum surpassed switchgrass acreage at $P_s$ near \$50 (with rent) and \$45 (no rent) with that price threshold increasing to \$55 for 2008 (with rent) and remaining at \$45 (no rent). This is likely a function of forage sorghum's profitability, relative to switchgrass (Table 5). Given forage sorghum's yield advantage over switchgrass, its profitability increased by approximately \$30 and \$50 per \$5 increase in $P_s$ in 2007 and 2008, respectively (Table 5). Hence, forage sorghum reaches acreage in excess of 2.2 million at the high end of $P_s$ in 2007 (regardless of land charges).

At relatively low biomass prices, marginal soybean, wheat, grain sorghum and hay land are replaced to provide the initial increases in biomass acreage (namely, switchgrass acreage). At higher biomass prices, however, the profitability of annually grown forage sorghum drives large increases in production, allowing forage sorghum to surpass even rice in acreage totals and rise to the number two crop behind soybeans in 2007 and 2008 albeit at the high end of biomass prices.

The top panel in Figure 1 shows the above mentioned biomass acreage response for 2007 and 2008 with and without land charges. As expected, higher commodity prices for traditional crops in 2008, compared to 2007, shift the supply function of biomass to the left. Similarly, the inclusion of land charges raises the threshold price level for significant production of biomass, given the increased opportunity cost of growing switchgrass. Given the modeling framework presented here, biorefineries interested in a given level of production (drawing a vertical line through the graph at some desired output level) to fill the needs of their plant will likely experience relatively large changes in the price they need to pay for biomass either from year to year or whether land charges are included. The vertical gap between supply functions shown for 2007 and 2008 in the bottom panel of Figure 1 is approximately \$10 per ton when comparing supply responses with or without rent. Also, for production levels between ¼ and 2 million acres, the supply response to \$1 changes in $P_s$ is approaching 120,000 and 80,000 acres in 2007 and 2008, respectively. This suggests that biorefineries are exposed to a significant amount of price risk especially at higher biomass prices when producers are expected to and can readily switch in and out of annual forage sorghum production.

With the introduction of any new alternative cropping decision, tracking the change in input use is imperative. A major finding in this study is that estimated irrigation water use per acre declines as alternative biofuel crops take on a larger role. Regardless of land charges, both in 2007 and 2008, a 13% and 10% reduction in water usage per acre occurred as $P_s$ increased from \$25 to \$65, respectively (Table 6). Average irrigation water savings of 0.73 ac-inch per acre or 3.83% per \$10 increase in $P_s$ (between \$35 and \$65) can be expected across 2007 and 2008 commodity and input price conditions. Given diminishing water resources in the Arkansas Delta, these findings are significant for maintaining profitable crop production with anticipated irrigation restrictions.

**Figure 1**. Estimated Combined Switchgrass and Forage Sorghum Acreage (A) and Production (B) with Changes in Input and Output Prices as well as Land Charges.



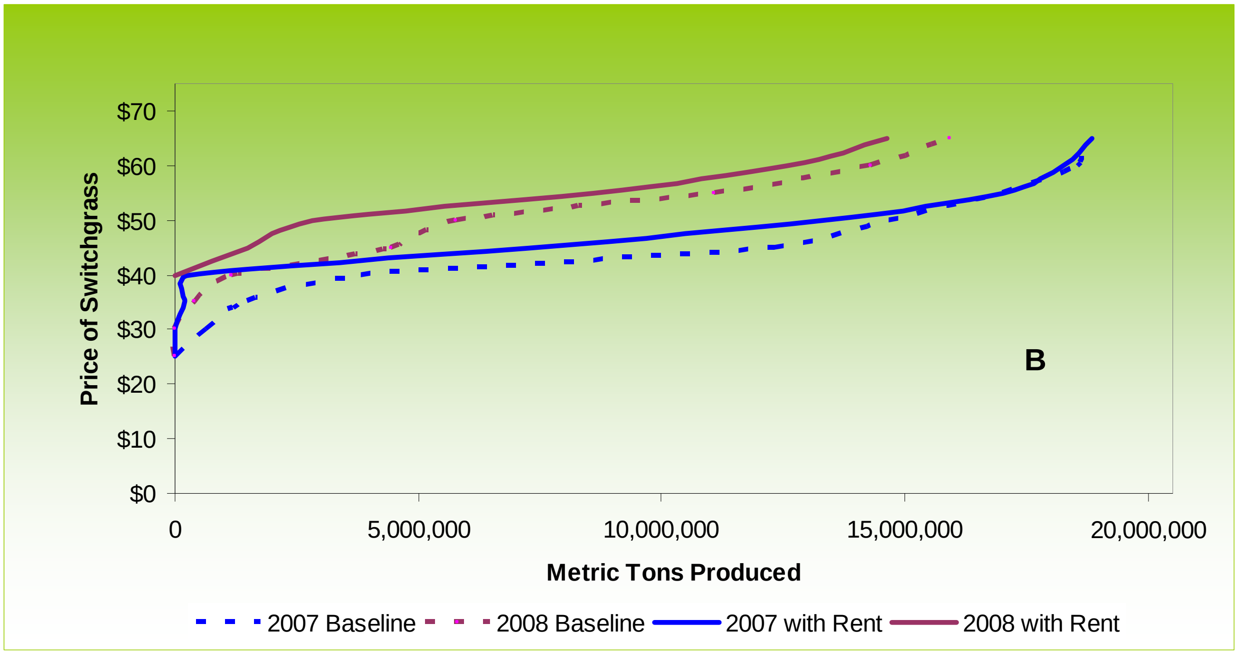



**Table 6**. **Resource use with biomass crop activity, 2007 and 2008, Arkansas**

| Year | Land Charge | | Price of Switchgrass[1] | | | | |
|---|---|---|---|---|---|---|---|
| | | | $25 | $35 | $45 | $55 | $65 |
| 2007 | Yes | Fuel Use[2] (000s gal) | 148,015 | 147,994 | 151,791 | 148,913 | 147,863 |
| | | Fuel Use/ac | 19.83 | 19.83 | 18.98 | 18.62 | 18.48 |
| | | Irrigation (000s ac-inch) | 83,950 | 83,950 | 83,957 | 79,052 | 78,101 |
| | | Irrigation (ac-inch/ac) | 18.74 | 18.74 | 17.82 | 16.51 | 16.31 |
| | | Labor Use[2] (000s hrs) | 6,703 | 6,719 | 7,302 | 7,354 | 7,257 |
| | | Labor/ac | 0.90 | 0.90 | 0.91 | 0.92 | 0.91 |
| | No | Fuel Use[2] (000s gal) | 151,981 | 152,721 | 155,850 | 151,178 | 148,089 |
| | | Fuel Use/ac | 19.39 | 19.09 | 19.48 | 18.90 | 18.51 |
| | | Irrigation (000s ac-inch) | 84,420 | 84,436 | 84,302 | 80,777 | 78,284 |
| | | Irrigation (ac-inch/ac) | 18.74 | 18.72 | 17.76 | 16.87 | 16.35 |
| | | Labor Use[2] (000s hrs) | 7,077 | 7,232 | 7,608 | 7,359 | 7,268 |
| | | Labor/ac | 0.90 | 0.90 | 0.95 | 0.92 | 0.91 |
| 2008 | Yes | Fuel Use[2] (000s gal) | 149,750 | 149,747 | 151,295 | 153,330 | 153,709 |
| | | Fuel Use/ac | 19.10 | 19.10 | 19.29 | 19.17 | 19.22 |
| | | Irrigation (000s ac-inch) | 84,229 | 84,229 | 84,245 | 84,220 | 83,890 |
| | | Irrigation (ac-inch/ac) | 19.50 | 19.50 | 19.48 | 18.41 | 17.52 |
| | | Labor Use[2] (000s hrs) | 6,795 | 6,796 | 7,074 | 7,295 | 7,374 |
| | | Labor/ac | 0.87 | 0.87 | 0.90 | 0.91 | 0.92 |
| | No | Fuel Use[2] (000s gal) | 151,075 | 151,463 | 154,849 | 153,731 | 154,692 |
| | | Fuel Use/ac | 19.18 | 19.04 | 19.36 | 19.22 | 19.34 |
| | | Irrigation (000s ac-inch) | 84,489 | 84,489 | 84,473 | 84,209 | 84,147 |
| | | Irrigation (ac-inch/ac) | 19.58 | 19.58 | 19.59 | 18.01 | 17.58 |
| | | Labor Use[2] (000s hrs) | 6,903 | 6,975 | 7,418 | 7,300 | 7,392 |
| | | Labor/ac | 0.88 | 0.88 | 0.93 | 0.91 | 0.92 |

Notes:
1 Note that forage sorghum was priced at a constant $5 per dry ton less than switchgrass for all switchgrass price levels.
2 Fuel and labor use exclude hay, pasture and CRP land due to lack of data. Forage sorghum harvest is also not included.

Per acre fuel and labor use fluctuated up and down as $P_s$ increased. 2007 results demonstrated a moderate reduction (2%) in per acre fuel usage as $P_s$ increased from $25 to $65, but with higher commodity prices in 2008, fuel usage per acre remained nearly constant. Labor use in both 2007 and 2008 was also relatively stable per acre (+/- 4% deviation from average across price scenarios) with some increases in total hours observed primarily at the mid price range of $P_s$. A caveat for these findings is that fuel and labor use on hay, pasture and CRP land could not be tracked and forage sorghum harvest is not modeled as the crop is sold standing in the field.

## 4. Summary and Conclusions

A model for Arkansas crop, hay, and pasture land allocation was developed to estimate potential acreage allocation decisions with varying assumptions on land charges as biomass crops such as forage sorghum and switchgrass are anticipated to provide a portion of the feedstock for second generation biofuels. Given acreage restrictions based on historical minimum and maximum acres of traditional crops for each county in Arkansas, the model results suggest that significant acreage of both switchgrass, at low biomass prices, and forage sorghum, at higher biomass prices, enter land use allocations, even with high commodity prices for traditional crops. Predictions of exact acreage and location will remain a challenge, however, as supply response is deemed quite elastic at switchgrass prices above $35 per dry ton. Of significant importance to Arkansas producers, facing declines in aquifer water supply, is the decline in per acre irrigation water use with the adoption of biomass crops.

Shortcomings of the model are its static nature, as well as the need for a best guess on price differentials among biomass crops given uncertainty in desired end product characteristics, harvest, storage, preprocessing, and transportation costs. Inclusion of crop residue from conventional crops would also add to providing a clearer picture of spatial biomass supply. Finally, because of the lack of spatial yield histories on forage sorghum and switchgrass, the above results are subject to considerable error on yield potential. Additional errors are possible as differences in harvest and storage technology could lead to significant differences in yield losses between time of harvest and biorefinery processing.

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