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Irrigation Restriction and Biomass Market Interactions: The Case of the Alluvial Aquifer

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The U.S. Geological Survey has determined that irrigation in Arkansas' Delta is unsustainable. This study examines how irrigation restrictions would affect county net returns to crop production. It also considers the effect of planting less water-intensive bioenergy crops—switchgrass and forage sorghum—in the event biofuel markets become a reality. Results suggest that sustainable irrigation restrictions without bioenergy crops would decrease producer returns by 28% in the region. Introducing these alternative crops would both reduce groundwater use and may restore state producer returns, albeit with significant spatial income redistribution to crop production throughout the state.

Key Words: biomass crops, ground water irrigation, spatial income redistribution, sustainability

JEL Classifications: Q24, Q25, Q32, Q42, O13

In 2004, the Arkansas Natural Resources Commission (ANRC) estimated groundwater withdrawals in Arkansas at 6.5 billion gallons per day, a 70% increase from the amount used in 1985 and over twelve times that of 1945 (ANRC, 2007). Today's irrigation level is unsustainable in the sense that water use exceeds recharge. To reach sustainable pumping levels, the United States Geological Survey's (USGS) 2006 estimates indicated that certain counties in the Arkansas Delta will need to reduce irrigation pumping rates by as much as 67% from their 2004 usage (USGS, 2008). This is significant since approximately 63% of the state's total water supply is sourced from groundwater, and further, 95% of that comes from the Alluvial aquifer in the Delta region of Arkansas (USGS, 2008).

With water supplies declining in parts of the Alluvial aquifer, water-intensive agricultural production and associated processing industries are at risk in the near future. Other potential adverse effects are land subsidence, saline water encroachment, increased cost to well users and reduced base flow to streams and wetlands. Exacerbating this issue is the drilling of over 10,000 new wells in the Alluvial aquifer since 1997 (ANRC, 2007), which is likely a result of yield enhancement and yield risk reductions associated with irrigation.

This study examines how Arkansas' farm crop allocation in the Arkansas Delta might change if i) irrigation in the Alluvial aquifer was constrained to more sustainable levels; and ii) a hypothetical market existed for less water-intensive bioenergy crops. Though not yet a reality, commercial-scale biofuel production has potential in Arkansas. In contrast to the heavily irrigated crops currently produced in the Delta region of Arkansas, biofuel production

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from feedstocks such as switchgrass and forage sorghum would require little to no irrigation (McLaughlin and Kszos, 2005; Parrish and Fike, 2005). In the case of forage sorghum, irrigation to enhance yields is an option at irrigation rates significantly below those required for rice (one-sixth) and one-half the rates required for corn, cotton or soybeans. Further, because these feedstocks are dedicated energy crops, fewer byproduct marketing implications need to be considered (e.g., distiller dried grains, a protein rich feed, are a byproduct of corn to ethanol processing; glycerin, used mainly in pharmaceutical applications, and soybean meal are by- and coproducts of soybean-based biodiesel). Therefore, the potential for the introduction of switchgrass and forage sorghum as "dedicated" bioenergy crops—dedicated in the sense that these crops are targeted for fuel production with lesser byproduct marketing and/or dispersal issues than listed for corn to ethanol or soybean-based biodiesel—and their impact on irrigation water use and statewide agricultural net returns need investigation.

First, a static equilibrium, constrained optimization model was developed to determine the most profitable crop allocations for the state of Arkansas (Popp, Nalley, and Vickery, 2008). It differs from Dicks et al.'s (2009) approach in the sense that the model is not iteratively resolved with price reactions to crop allocation decisions as in the POLYSIS framework. However, our static model tracks fuel, labor, fertilizer, and irrigation water use on a crop and production technology specific basis for all crops, including switchgrass and forage sorghum on a county by county basis. Hence, the model can be constrained to model various irrigation water use and/or other resource restrictions.

County specific irrigation data and sustainable pumping rates in acre inches were obtained from the USGS (USGS, 2008). The model considers crop-specific and county totals of historical minimum and maximum non-irrigated and irrigated harvested acres along with county yield averages (USDA NASS, 2008). University of Arkansas Cooperative Extension Service's (UACES) estimated cost of crop production (UACES, 2008), specific to production practices most commonly used in each of the 75 counties, were used when possible. The use of county data is essential for analysis of spatial implications of irrigation water use restrictions as well as biomass production effects. Results should i) aid the development of irrigation policies such as irrigation taxes or permits; ii) provide information about investments in irrigation projects to enhance irrigation efficiency and/or supplies; and iii) inform about changes in cropping decisions or land use in the case of scarce water resources.

The Study Region

The Mississippi River Valley alluvial aquifer ("the Alluvial aquifer") encompasses parts of Arkansas, Missouri, Louisiana, and Tennessee. For purposes of this study, the term Alluvial aquifer refers to the portion of the Mississippi River Valley aquifer within Arkansas. Long-term water-level data collected over a 25-year period indicate an average water level decline of 3.8 inches per year in the Alluvial aquifer over a 24 year period (USGS, 2008). In some Delta counties such as Cross, Lonoke, and Jackson, the water level decline is as much as 11.3, 9.6, and 8.2 inches per year, respectively. Thus, some of the state's largest agricultural crop-producing counties are experiencing unsustainable long-term ground-water withdrawals.

Simulated studies (Ackerman, 1989; Mahon and Poynter, 1993) estimate the recharge rate for the Alluvial aquifer to be between 0.8 to 1.4 inches a year. Therefore specific areas within the state of Arkansas are currently experiencing ground-water withdrawals of such magnitude that they are deemed unsustainable in the sense that ground-water levels are consistently falling, resulting in greater pumping costs, ground water becoming sporadically unavailable and/or ground water quality becoming poorer. Unlike more complex dynamic mathematical programming approaches used for determining optimal irrigation strategies of a limited resource (Almas, Arden Colette, and Adusumilli, 2008; Howitt, 1995; Reca et al., 2001; Sethi, Sudhindra, and Manoj, 2006), we utilize USGS-modeled sustainable irrigation water use estimates to constrain the crop modeling decisions. In other words, the idea is not to determine optimal irrigation application rates, which would require more extensive modeling, but merely to measure the impact of curtailing irrigation. As such we follow mathematical programming approaches used by Dicks et al. (2009), Doye, Popp, and West (2008), and Kenkel and Bunt (2008).

Figure 1 illustrates the degree to which water use needs to be curtailed to be sustainable on the basis of 1997 water use—the latest available reports by USGS at the time of this writing. That is, for example, Arkansas county needed to curtail 1997 water use to 57% of the 1997 irrigation level such that ground water levels would no longer decline in Arkansas county. Arkansas, Lonoke, Lee, Poinsett, and St. Francis counties would all need to reduce their pumping rates by over 40% to maintain ground-water levels. Arkansas is the largest rice producer in the United States, and these counties alone consisted of 28% of Arkansas' total rice acreage, the state's most profitable crop, in 2007. This presents a problem for sustainability given the profitability of rice combined with the intensive amount of water needed for its production. Nearly all of Arkansas' corn, rice, and irrigated cotton acres withdraw water from the Alluvial aquifer. In 2007 and 2008, especially, this issue was exacerbated by increases in corn and rice prices resulting in heightened production and concomitant water use. Several options exist to curtail irrigation use to a sustainable rate: cap-and-trade a fixed quantity of water, taxation, irrigation permits, subsidization of less-irrigation intensive crops, or man-made irrigation alternatives such as combinations of on-farm reservoirs and river water diversion as proposed in the Grand Prairie Area Demonstration Project (Hill et al., 2006).

Data and Methods

A state model that tracks crop profitability and resource use was necessary to model producer behavior on a county by county basis. This required cost of production information, fuel, labor, fertilizer, and irrigation water use as reported by UACES, both in terms of quantity and cost to allow for sensitivity analyses. Since as many as 28 different budgets exist for each of the main commodities of rice, corn, cotton, wheat, and soybean, crop specific extension experts were consulted to determine which of the reported production methods were most prevalent in each of the nine crop reporting districts (CRD) as defined by the Arkansas Agricultural Statistics Service. That is, rice extension experts were asked to determine which of the eight possible rice production methods in Arkansas were most frequently used within each CRD. This effort resulted in CRD-specific cost of production and resource use estimates. County average yields from 2004–2007 yields (USDA NASS, 2008) helped determine returns above total specified expenses that in turn were used to model producer crop acreage allocation decisions for all 75 counties in Arkansas. Note that 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. Tables 1 and 2 highlight biomass yield and cost of production information used. Yield and expected irrigation requirement information was based on state expert opinion.[1]

The model also incorporates corn stover as a potential biomass crop by using an average corn harvest index of 0.43 (Cox and Cherney, 2001; Wilts et al., 2004; Graham et al., 2007) to obtain yield-dependent above ground biomass estimates for stover. It is assumed that 50% of the above ground biomass is removed to sustain organic matter. Using a stalk shredder, rake, round baler, and staging equipment at a cost of \$11.90 per dry ton with an additional \$14.04 per dry ton to replace 22.29 lbs of Nitrogen, 4.38 lbs of Phosphorus, and 19.92 lbs of Potassium per dry ton of stover harvested resulted in a total cost estimate of \$25.94 per dry ton of corn stover. Unlike, Petrolia (2008), we assumed complete farmer participation where the producer begins to collect corn stover only when revenue exceeds costs by \$5 per dry ton. Other crop residues were not modeled due to excessive wear and tear on equipment in the case of high

[1] The other 73 crop cost of production estimates used in the model are available from the authors upon request. State experts were Drs. C. West and J. Kelley, both with the Department of Crop, Soil and Environmental Sciences, University of Arkansas.

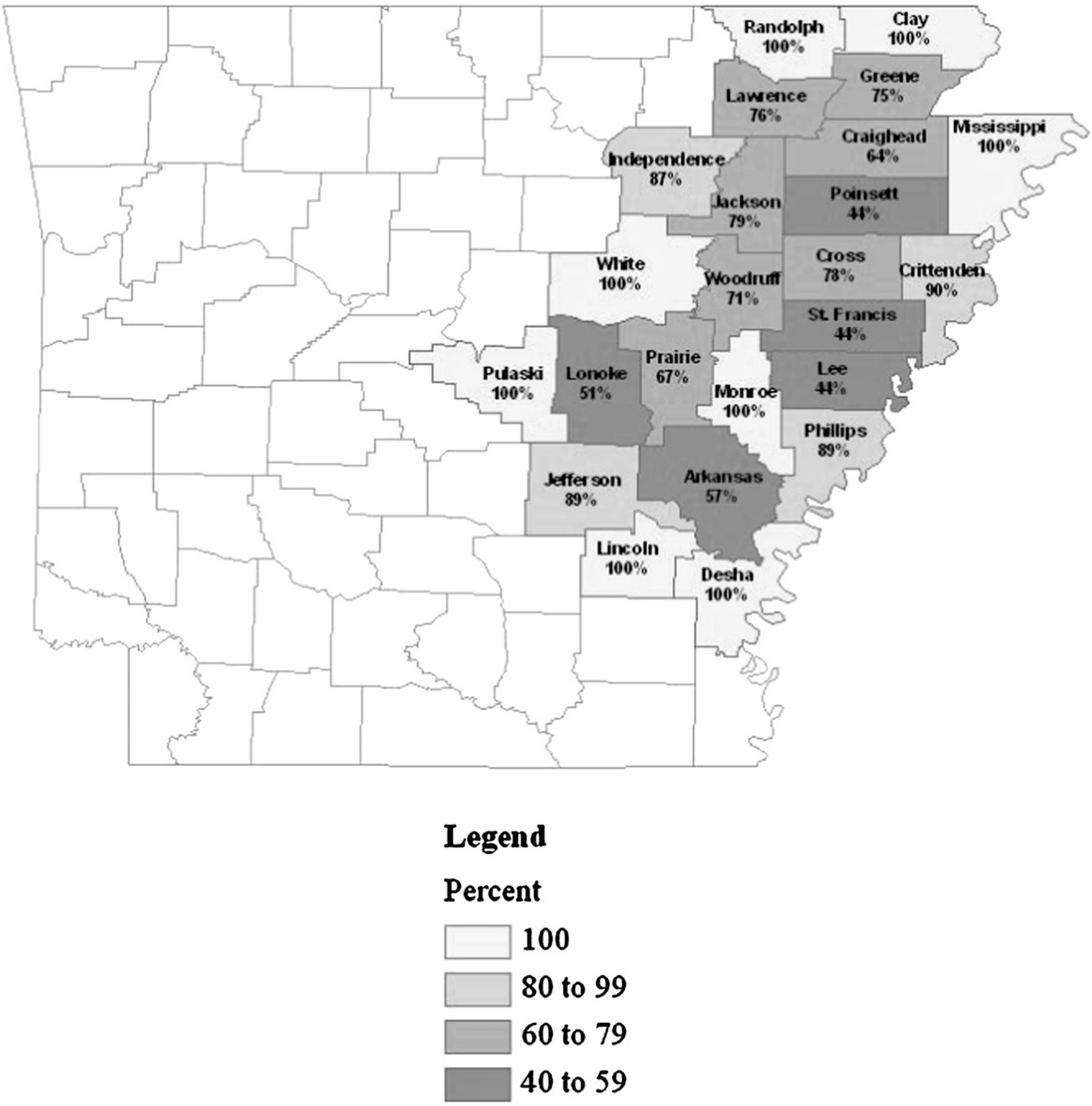

Figure 1. Sustainable Irrigation Water Use as a Percentage of Estimated 2007 Water Use for Crop Producing Counties Affected by Alluvial Aquifer Depletion in Arkansas (numbers are adapted from USGS (2008))

silica content in rice straw and economically insufficient yield in the case of winter wheat, cotton, soybean, and grain sorghum.

The model is also constrained by historical land use decisions to reflect technological, socioeconomic, and capital investment barriers. Hence, 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 CRP payments for 2007, were obtained from the USDA's Farm Service Agency state office. Annual harvested acres for the traditional crops were 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 (e.g., use of poultry litter, commercial fertilizer, or nitrogen fixing

Table 1. Baled Switchgrass Stored at Field Side Including Storage and Grinding Losses. Estimated Cost of Production on Crop Land, Arkansas, 2007[a]

Description	Total Cost ($)	Prorated Present Value of Total Cost Over Useful Life of Stand at 6% ($)
Establishment Year		
Field Preparation[b]	78.53	7.85
Pre-Plant Weed Control[c]	11.98	1.20
Planting[d]	100.08	10.01
Post-Plant Weed Control[e]	41.16	4.12
Operating Interest[f]	17.54	1.75
Total Specified Expenses	249.29	
Foregone Profit[g]	52.21	5.22
Replant Charge[h]	15.51	1.55
Year 2		
Fertilizer[i]	60.39	38.75
Harvest[j]	51.89	4.90
Operating Interest[k]	3.63	0.34
Total Specified Expenses	115.91	
Years 3+		
Fertilizer[i]	60.39	38.75
Harvest[j]	75.44	41.69
Operating Interest[k]	4.21	2.33
Total Specified Expenses	140.04	
Storage & Grinding Losses[l]	16.18	10.34
Total Specified Expenses—PV over useful Life[m]		$120.59
Useful Life of Stand		10 yrs
Dry Matter Yield—Year 2		4 tons
Dry Matter Yield—Year 3+		6 tons
Prorated Dry Matter Yield—Net of Losses		4.78 tons/acre
Profit—PV over Useful Life[n]		($19.82)

[a] Please contact authors for cost of production details not included below. All fertilizer and herbicide applications are hired.

[b] Field preparation occurs in September and includes one pass with a disk to incorporate 1 ton of lime, 167 lb of phosphate (0-45-0) and 83 lb of potash (0-0-60) fertilizers. For switchgrass established on hay land and pasture, field preparation occurs in spring and includes two passes with a disk and one burn down herbicide application at 4 lb a.i. per acre of glyphosate (Roundup). Costs for the latter are not shown.

[c] This includes one herbicide application of 1 lb a.i. glyphosate (Roundup) in March by air (not needed in spring-planted grass).

[d] Included are one pass with a cultipacker and 8 lb of pure live seed applied using a no-till drill for accurate depth control. Operations occur in April. For spring-planted switchgrass, fertilizer is applied in spring at the same rates as fall-seeded switchgrass.

[e] Aerial herbicide application of 0.33 lb a.i. quinclorac (Paramount) and 0.5 oz a.i. imazapyr (Ally or Cimaron) per acre in May.

[f] Operating interest at an annual rate of 7.75 percent is charged on all expenses except capital recovery on owned equipment for 1 ½ years on fall-planted switchgrass and one year on spring-planted switchgrass given the lack of harvest in the establishment year.

[g] Since no crop harvest is expected in the establishment year, opportunity cost of foregone profit is added to costs. As an example, the model based state average profitability per acre on crop, pasture, and hay land is used above. Note that these foregone profits varied by county from $35 to $117 per acre using 2007 crop model results.

[h] Replanting charges include the fraction of total specified expenses and foregone profits for the establishment year on acreage that did not establish. We assume replanting of 5% on crop land, 15% and 25% on hay and pasture land, respectively.

[i] The fertilizer program to replace nutrients is 89 lbs of phosphate (0-45-0), 133 lb of potash (0-0-60) and 220 lb of ammonium nitrate (34-0-0) for year 2 and onward. Nutrient replacement is not scaled to yield.

[j] Harvest is performed using a mower conditioner, hay rake, large round baler (#1,275 dry matter or #1,500 as is 15% moisture) using bale wrap and an automatic bale mover for staging without tarp or storage pad preparation. Note that cost per acre increased with yield beyond year 2.

[k] Operating interest is again applied to operating expense except for only half year given sale of product.

[l] Storage losses of 5% and eventual grinding losses of 3% are charged to this enterprise to make final product comparable in particle size to forage chopped forage sorghum.

[m] This represents the average, discounted per acre cost adjusted for yield and cost differences across the useful life of the stand. Dividing these discounted total specified expenses by the prorated dry matter yield results in a discounted breakeven price of $25.21 per dry ton. This is substantially lower than the nominal price of $35.59 needed to cover production costs. Note also that the breakeven price would vary by county as state average foregone profits during the establishment year are used in this example.

[n] This is the net present value of revenue less total specified expenses assuming a nominal price of $35 per dry ton of switchgrass stored at the side of the field for eventual grinding to a particle size of 1” or less.

Table 2. Dryland and Irrigated Forage Sorghum. Estimated In Field Costs of Production Using Forage Chopper, Arkansas, 2007[a]

	Cost of Production ($)	
Operating Input	Dryland Forage Sorghum[b]	Irrigated Forage Sorghum[c]
Fall Field Preparation[d]	13.63	13.63
Seedbed Preparation & Planting[e]	67.13	76.33
Fertilizer[f]	98.07	112.17
Post-Plant Field Work[g]	8.50	57.53
Harvest[h]	43.65	51.81
Operating Interest[i]	7.52	9.61
Total Specified Expenses	238.50	321.07

[a] Please contact authors for cost of production details not included below.
[b] Expected yield is approximately 10 harvested tons per acre at 35 percent moisture or 6.5 dry tons per acre. Assumed are no yield losses as forage harvester blows material into a silage truck for transport to a drying and processing facility. Breakeven price is $36.69 per dry ton.
[c] Expected yield is approximately 15 harvested tons per acre at 35 percent moisture or 9.75 dry tons per acre. Assumed are no yield losses as above. Breakeven price is $32.93 per dry ton.
[d] Fields are cultivated using a disk harrow and chisel plow in November of the previous year.
[e] Seedbed preparation is accomplished using a field cultivator for incorporation of fertilizer, and equipment to prepare beds for planting in 30" rows. Treated seed is applied at 8 and 12 lbs per acre for dryland and irrigated production, respectively. Also included are preplant herbicide applications of 2 pts of Atrazine and 1.5 pts of Dual II Magnum per acre.
[f] Both dryland and irrigated forage sorghum receive 100 lb of urea (46-0-0), 110 lb of phosphate (0-45-0) and 230 lb of potash (0-0-60) fertilizers. Post plant sidedressed urea is applied at 120 and 200 lb for dryland and irrigated production, respectively. All fertilizer is custom applied.
[g] Two pts of Atrazine are applied in May regardless of irrigation practice. Two three acre-inch applications using furrow irrigation are applied in June on irrigated crop to avoid drought stress.
[h] Crop is mowed using a modified mower conditioner, hay rake and self propelled forage harvester. Harvest costs are scaled to yield as equipment field speeds would slow with higher yield.
[i] Operating interest is charged on total specified cost less capital recovery on owned equipment and charged for ½ year.

companion crops), number and method of harvests, grazing differences, and operator rental arrangement proved too cumbersome to model. Hence hay land returns and pasture rental rates were set to $35/acre for productive land that can be harvested with hay equipment and $25/acre—the average of surrounding states' cash rental returns to pasture (USDA Pasture Cash Rent, 2008). This assumption is limiting but not for the case of irrigation analyses as pasture and hay land are non-irrigated.

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:

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

Subject to:

$xmin_{ij} \le xij \le xmaxij$

$iacresmin_i \le \sum xi_j \le iacresmax_i$—for irrigated crops only

$\sum irr_{ij} \le irrmax_i$—$irrmax_i$ was limiting after the base run

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

where *i* denotes each of the 75 counties of production and *j* denotes the 18 land management or crop choices. *Xmin* and *xmax* are historically reported county harvested acre minima and maxima over the harvest years 2000 through 2007 for each crop (USDA NASS, 2008).[2] Energy crops had zero acreage 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, perennial crop. Switchgrass on hay and pasture land was limited to a maximum of 10%

[2] The model was also run using historical minima and maxima reaching back to 1975 when cotton acreage was limited 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.

of the sum of hay and pasture land so as not to encroach on current livestock production.[3] Because forage sorghum is similar in production technology to grain sorghum, it was not curtailed, except to historically reported maximum irrigated total county crop acres (*iacresmax*) and total harvested county crop land (*acresmax*) for irrigated and non-irrigated production, respectively. *Iacresmin* and *iacresmax* are the 1987 to 2002 census based reported irrigated acres that reflect technological, socioeconomic, and capital barriers to irrigation, again at the county level. *Irrmax* represents the amount of water used in the 2007 base model run without water restrictions and is the constraint that was modified to enforce eventual sustainable water use restrictions on a county basis by tracking acre-inch use across crops, irr_{ij}. *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 part of harvested acres even though this crop can be 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 (Great Pacific Trading Company, 2008).[4] Basis expectations were set to zero for all crops and prices were adjusted for hauling, drying, and commodity board check off charges as appropriate. (See Table 3 for commodity price, yield, and input cost information.) Switchgrass and forage sorghum prices were then modified over a range of \$25 to \$55 per dry ton (dt) to estimate to what degree these crops enter land allocations. A discount of \$5/dt relative to baled switchgrass stored at the side of the field was applied to forage sorghum to reflect differences in: i) hauling and drying charges (field chopped forage sorghum would have lower bulk density, lead to more water transport and need to be dried in comparison to switchgrass); ii) material processing (switchgrass needs to be reduced in particle size with 3% grinding losses whereas forage sorghum is expected to be process-ready as the material is chopped to particle size less than 1″); iii) year round availability (baled switchgrass is storable and incurs storage losses (5%) whereas forage chopped sorghum needs to be processed over a relatively short time horizon—the assumption in this model). Because particle size reduction is expected to be expensive for switchgrass and since no staging costs are required for forage sorghum it is the authors' estimate that chopped forage sorghum would become available at a lower cost to biorefineries, and we model it at a \$5 per dry ton discount to switchgrass. This remains an estimate given a lack of accurate available cost information on relative harvest, storage, packaging, drying, transport, and processing costs for forage sorghum relative to switchgrass.

Yields (y_{ij}) reflect the per acre county averages for most crops. Since Arkansas NASS does not differentiate irrigated and nonirrigated double cropped soybeans and sorghum acreage, minor modifications, as described by Popp, Nalley, and Vickery (2008), were made to double cropped soybean maximum and minimum acreage restrictions and grain sorghum yield differences between irrigated and non-irrigated production. Per acre cost of production estimates (c_{ij}) were developed as reported above.

The initial 2007 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 its full potential until year three. Production in the establishment year is expected to be sufficiently small that it would only

[3] 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 was required to maintain the current herd of cattle. In the most restricted county, Faulkner, the minimum was 90% of the maximum.

[4] Wheat prices were based on the May futures prices as of September of the previous year (Great Pacific Trading Company, 2008).

Table 3. Summary of 2007 Commodity Price, Yield, and Input Cost Information

Commodity Prices and Yields					
Commodity	Unit	Futures Prices[a]	Custom Hauling[b]/Drying[c] and Checkoff/Other[d]	2007 Baseline Average Yield[e] (2004–2007)	Production Method/Region
Corn	bu	$4.00	$0.35	151.5	Irrigated
Wheat	bu	$4.60	$0.16	51.9	Irrigated
Beans	bu	$7.10	$0.186	40.6	Irrigated
				26.8	Non-irrigated
				32.7	Double cropped
Rice	lb	$0.11	$0.01	6,896.3	Irrigated
Cotton	lb	$0.58	-$0.04	1,099.7	Irrigated
				888.8	Non-irrigated
Grain Sorghum	bu	$3.80	$0.16	105.2	Irrigated
				70.0	Non-irrigated
CRP	acre	$52.00			State average
Forage Sorghum	dt			9.75	Irrigated
				6.50	Non-irrigated
Switchgrass	dt			4.78	Cropland
				4.20	Hay
				3.80	Pasture

Input Prices		
Description	Units	2007($/unit)
Fertilizer (N - P - K - S)		
Urea (46-0-0)	lb	0.18
Liquid Nitrogen (32-0-0)	lb	0.12
Ammonium Nitrate (34-0-0)	lb	0.12
Diammonium Phosphate (18-46-0)	lb	0.14
Phosphate (0-45-0)	lb	0.14
Potash (0-0-60)	lb	0.13
Sulfur (0-0-0-90)	lb	0.23
Boron (0-0-0-0-15)	lb	0.53
Lime	ton	33.00
Labor		
Operator	hrs	9.45
Hired	hrs	8.19
Fuel	gal	2.20
Operating Interest	%	7.75

[a] 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).
[b] Custom hauling charges amounted to $0.15 per bushel for all commodities except cotton.
[c] Drying charges were $0.19 per bushel on corn and $0.30 per bushel on rice.
[d] Commodity check off was 0.5% 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.
[e] 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. Biomass yields are reported in dry tonnage per acre. 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. The switchgrass yields are further adjusted by accounting for storage and harvest losses of 8% with switchgrass staged off-field and stored for a period of up to 6 months. Forage sorghum is field chopped using forage harvesters. Yield estimates are based on expert opinion and cited references.

cover cost of harvest, or alternatively would be left in field to ensure better root development and therefore better yields for the life of the stand. Different modeling assumptions exist, however (see Khanna, Dhungana, and Clifton-Brown, 2008; Popp, 2007; Garland, 2007). Given this lack of yield in the establishment year, foregone profits to alternative crop choices (o_i) were subtracted from the discounted, prorated net returns above total specified expenses for switchgrass (*nr*) as follows:

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

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. Further, the data in Table 1 was adjusted for switchgrass grown on hay and pasture land by increasing the replant charge to 15 and 25% compared to 5% on crop land and reducing the useful life and yields over the stand lives for hay and pasture based switchgrass as noted in the note to Table 3.

Sensitivity Analyses

First, a 2007 baseline scenario was estimated using the linear programming software Premium Solver Plus, an add-in to Excel (Frontline Solver, 2008) to maximize *NR* as described in Equation (1). The 2007 baseline was developed using zero prices for alternative energy crops to see how accurately the model would predict actual land allocations in 2007 on the basis of cooperative extension input cost estimates and 2007 commodity price expectations.[5] This baseline estimate was unconstrained in the sense that farmers could pump as much water as needed to maximize profit per acre while staying within historical irrigated acre limits.

In subsequent model runs, each county was constrained to their respective sustainable water use based on the information from Figure 1. That is, actual 1997 crop acres were used in the model to determine irrigation water use per county and subsequently multiplied by the percentages in Figure 1 to determine fully sustainable acre inch use ($irrmax_i$) for each county. This iteration was run to determine changes in crop allocation and overall profitability implications of an irrigation sustainability restriction. A second set of model runs was performed to estimate the results of a less restrictive, 50% sustainability scenario with irrigation restrictions halfway between the unrestricted and sustainable water use rates. For example, to meet sustainable water use, Arkansas county needed to cut water use by 43%. The less restrictive assumption cut that reduction in half to 21.5%. Essentially, the second iteration provided a scenario of doubling the current life expectancy of the aquifer.[6] Practically speaking, this may be a more realistic option for producers to implement since it requires a lesser reduction in pumping. The scenario may also be more realistic than the full sustainability scenario in the sense that farmers are adopting more irrigation efficient production technologies, tail water recovery systems, and on-farm water storage to capture and store above ground water resources (Hill et al., 2006). Profitability and acreage distribution among crops were compared to the baseline to see how/if they diverge. When the fully sustainable iterations were run, the model in Equation (1) was rerun with the modification of the $irrmax_i$ constraint to:

$$\sum irr_{ij} \leq iacreinchsustain_i, \tag{3}$$

[5] The model's predictive power was within 10% for corn, cotton, grain sorghum, hay land, pasture land, rice, and soybean, and within 15% of the actual 2007 wheat acreage (Popp, Nalley, and Vickery, 2008).

[6] This is a rough approximation, due to the non linearity of pumping rates and cones of depressions within the aquifer. Therefore this "doubling" term is simply an estimate.

where $iacreinchsustain_i$ were county specific sustainable water use rates in acre inches pumped. For the second iteration where the target is to double the life of the aquifer, the constraint (3) was relaxed as follows:

$$\sum irr_{ij} \leq iacreinchedoubl_i, \tag{4}$$

where

$$iacreinchedoubl_i = irrmax_i - ½\,(irrmax_i - iacreinchsustain_i). \tag{5}$$

A final set of model iterations was performed to introduce the impact of the two alternative crops (switchgrass and forage sorghum) at varying prices to see how/if they entered production in Arkansas under the full sustainability and doubling of aquifer life scenarios. Since both of the alternative crops are less water intensive than most traditional crops they should become more attractive to farmers given water use restrictions.

One of the goals of this study was to see what market price levels for switchgrass and forage sorghum would be needed to restore profits to state levels observed under the unrestricted irrigation assumption. Alternatively, what would the market price of switchgrass have to be so that the state would be indifferent when forced to cut irrigation to varying degrees of sustainability?

Results

Table 4 highlights the results from each of the model iterations. The unrestricted baseline scenario indicated total net returns to land and management of $526 million for the 24 counties in Arkansas who have pumping access to the Alluvial aquifer. These returns are gross revenue net of total specified expenses of seed, fertilizer, chemicals, fuel, custom work, repair and maintenance, operating interest, and equipment ownership charges excluding property taxes and insurance. These counties represented 80% of Arkansas' agricultural net returns as modeled in this analysis. The Alluvial counties in the unrestricted base model also represented 91% of Arkansas' irrigated production and included 1.682, 1.381, 0.509, and 0.441 million acres of irrigated soybean, rice, cotton, and corn, respectively. By constraining the model to sustainable pumping levels the Alluvial region's net returns declined to $377 million (a 28% reduction) with significant reductions in irrigated crops and slight increases in hay and non-irrigated crops (especially winter wheat production, Table 4). Large rice producing counties like Poinsett, Arkansas, and Cross would experience rice acreage reductions of 57%, 42%, and 35%, respectively. Figure 2 shows the reduction of irrigated rice, soybean, cotton, and corn acreage on a county level basis when the aquifer is constrained to sustainable pumping levels. These numbers represent significant acreage reductions that affect not only the producers but also the rice, soybean, and cotton processing industries located in the region. The model estimates suggest that ensuring the survival of the Alluvial aquifer would result in an approximate 32% reduction in annual acre-inches pumped for the Alluvial region at a cost of $149 million in annual net returns to producers, *ceteris paribus*.

Table 4 also illustrates the results when the irrigation is restricted to a lesser than fully sustainable level to "double" the life of the aquifer. As mentioned earlier this constraint may be more realistic given expected resistance to major irrigation restrictions and implementation of ground water saving technologies. Under this scenario, the Alluvial region's net returns decline to $448 million (a 15% decrease). This represent a $71 million dollar increase in net returns compared to the sustainable pumping constraint for the Alluvial region. Figure 3 shows the changes in acreage for rice, irrigated soybean, irrigated cotton, and corn. This constraint would result in an approximate 15% reduction in acre-inches pumped for the Alluvial region at a cost of $78 million in net returns to producers, *ceteris paribus*.

Figure 4 summarizes graphically dry matter production of biomass from the different sources as irrigation water becomes more restricted (panel A to C). By introducing the alternative biomass crops which are less water intensive, the hypothetical biomass price required to return the state's net returns to "pre-irrigation restriction" levels was determined with the assumption that commodity prices for

Table 4. Crop Acreage Reallocations Under Varying Sustainability Scenarios and Alternative Biomass Prices, 2007, Alluvial Aquifer Counties of Arkansas

		Crops[a]															
		Corn	Cotton		Soybean		Rice	Wheat	Grain Sorghum		Switchgrass & Forage Sorghum						
Scenario		Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Irr.	Non-Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Hay	Pasture	Total Irr. Acres	Total Acre-Inches Used[b]	Total Net Returns[c]
2007 Base ($P_S^d = 0$)		441	280	509	614	1,682	1,381	688	105	100	—	—	218	359	4,114	78	526
% of State[e]		*81*	*99*	*87*	*84*	*93*	*94*	*86*	*96*	*93*	—	—	*15*	*18*	*91*	*93*	*80*
50% Sustain		267	280	458	781	1,565	1,146	880	129	63	—	—	231	359	3,499	66	448
100% Sustain		198	284	397	884	1,248	908	897	129	61	—	—	232	359	2,812	53	377
P_S^d	Sustain																
25	50%	267	280	458	781	1,565	1,146	880	129	63	—	—	231	359	3,499	66	448
	100%	198	284	397	884	1,248	908	897	129	61	—	—	232	359	2,812	53	377
35	50%	269	280	458	780	1,565	1,146	880	129	58	1	—	231	359	3,496	66	454
	100%	202	284	397	860	1,248	908	897	129	52	51	—	232	359	2,808	53	382
45	50%	271	280	458	634	1,565	1,140	737	127	50	545	41	231	359	3,525	66	473
	100%	205	284	397	677	1,248	905	778	128	44	1,162	18	232	359	2,818	53	412
55	50%	265	135	447	593	1,565	1,123	139	33	25	1,491	159	140	323	3,583	66	557
	100%	193	135	389	593	1,248	895	139	33	21	2,198	130	140	323	2,877	52	538

[a] Crop, Hay, Pasture, and Total Irrigated Acre columns are in thousands of acres. Irrigated soybean includes full season and double cropped soybean.

[b] Total Acre Inches Used are crop production related statewide usage figures presented in millions.

[c] Returns to land and management after total specified expenses of seed, fertilizer, chemicals, fuel, custom work, repair and maintenance, operating interest, and equipment ownership charges excluding property taxes and insurance. Counties affected by the Alluvial aquifer include Arkansas, Clay, Craighead, Crittenden, Cross, Desha, Greene, Independence, Jackson, Jefferson, Lawrence, Lee, Lincoln, Lonoke, Monroe, Mississippi, Poinsett, Phillips, Prairie, Pulaski, St. Francis, Randolph, White, and Woodruff. Numbers are expressed in millions of 2007 U.S. dollars.

[d] Price of switchgrass per dry ton. Forage sorghum price is discounted by $5 per dry ton to reflect expected difference in processing and harvest costs.

[e] Percentages in italics represent the 24 counties affected by the aquifer relative to information for the entire state of Arkansas.

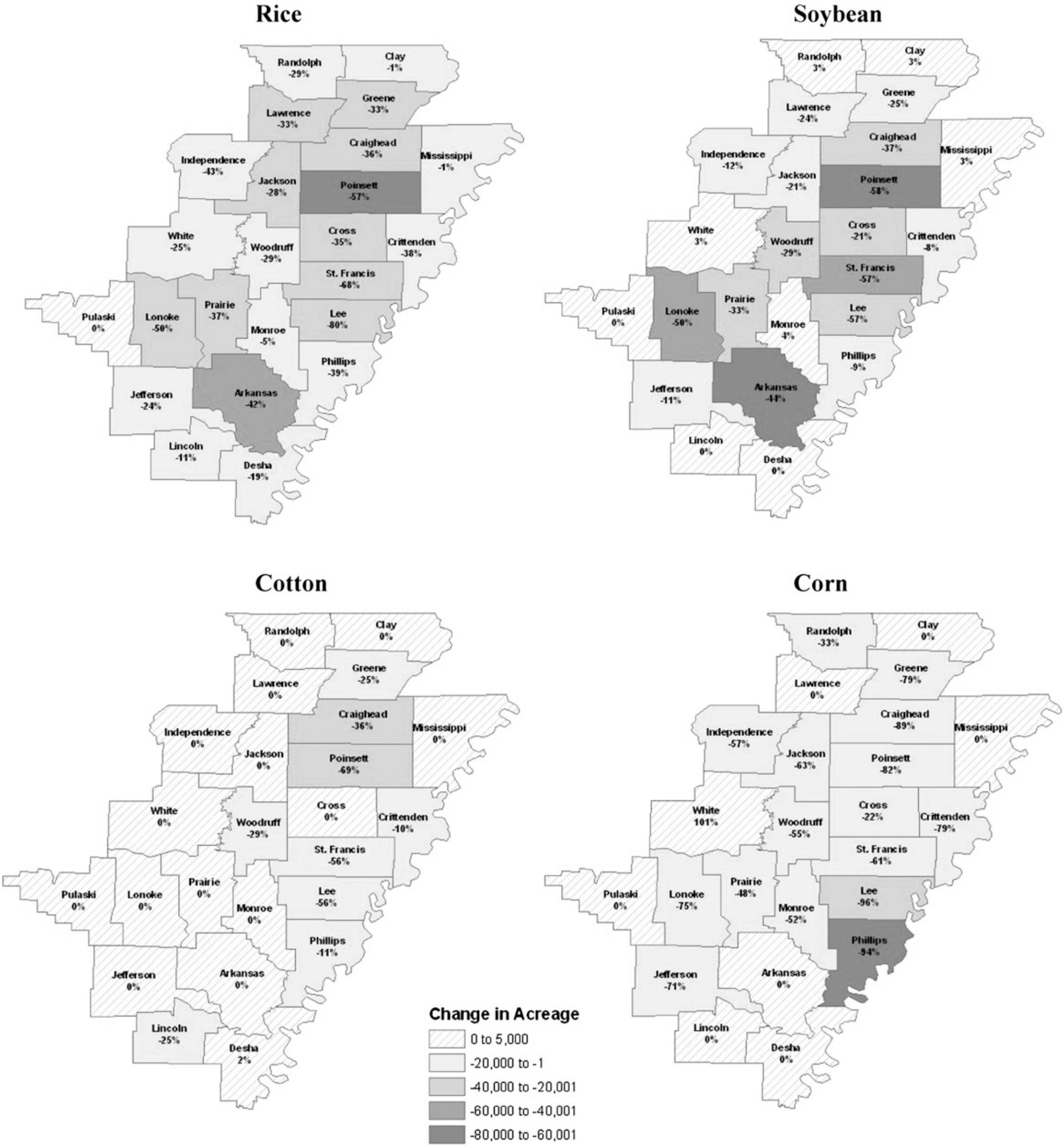

Figure 2. Estimated Reduction in Rice (top left), Irrigated Soybean (top right), Irrigated Cotton (bottom left), and Corn (bottom right) Acreage with Full Sustainable Water Use Restrictions under 2007 Crop Producing Conditions in the Alluvial Aquifer Region of Arkansas

food, feed, and fiber would not change and, simultaneously, that demand for alternative crops would establish at those price levels. The lower half of Table 4 shows what happens to land use as switchgrass price increases from \$25/dry ton to \$55/dry ton. At a switchgrass price of \$35 a dry ton under the full sustainability scenario, the model indicates that there would be 51,000 acres of non-irrigated biomass crops. At \$45 a ton under the same scenario those numbers increase to 1,162,000 and 18,000 acres for non-irrigated biomass and irrigated forage sorghum, respectively. As a reference point actual rice acreage in 2007 was 1.4 million acres for the state. Surprisingly, acreage of non-irrigated biomass crops

Figure 3. Estimated Reduction in Rice (top left), Irrigated Soybean (top right), Irrigated Cotton (bottom left), and Corn (bottom right) Acreage with Water Use Restrictions Implemented to Double the Life of the Alluvial Aquifer under 2007 Crop Producing Conditions in the Alluvial Aquifer Region of Arkansas

under the $45 a ton and full sustainability scenario would make it the second largest crop behind soybean in the region when compared to the 2007 model results without a biomass market. Under the full sustainability level and at the $45 a ton for switchgrass and corn stover ($40 per ton for forage sorghum), the Alluvial region's net returns to producers decreased by 22% from its original unconstrained level. That is, with the introduction of alternative crops, the Alluvial region can sustain the Alluvial aquifer and reduce net returns by a lesser 22% compared to 28% without the alternative crops.

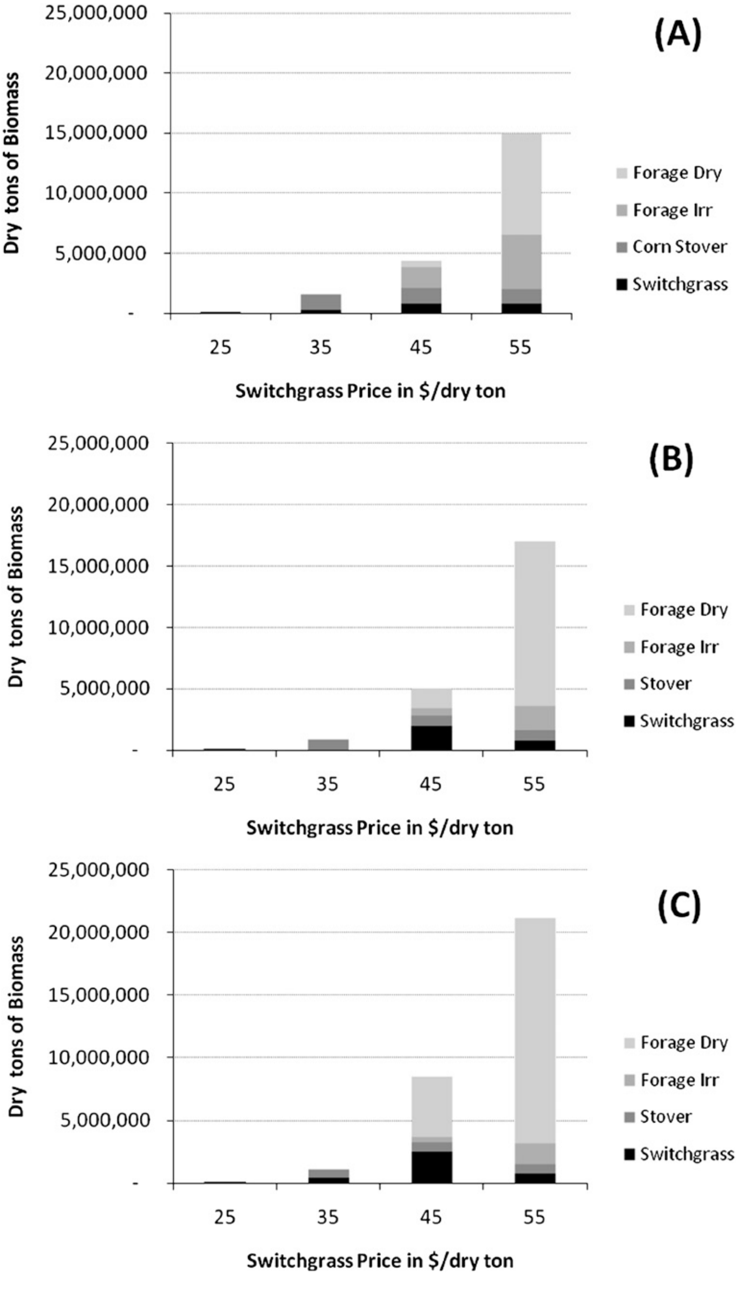

Figure 4. Statewide Biomass Supply Response Estimates Given Static Crop Price Conditions in Arkansas 2007 without Irrigation Restrictions (A), with 50% Irrigation Restriction (B) and under Sustainable Irrigation (C)

Producers in counties outside the Alluvial region, however, would gain net returns as $45 biomass returns a profit. In fact, to achieve the level of initial, unconstrained *state* agricultural net returns as specified in this model, switchgrass market prices would need to be $50.01 and $52.19 for the full and 50% sustainability levels, respectively (Table 5). At $50.01 per dry ton, using Wallace et al.'s (2005) assumptions of 78.3 gallons of ethanol per dry ton of biomass and non-feedstock conversion costs of $1.46 per gallon of ethanol, the breakeven cost

Table 5. Summary of Income Effects by Irrigation Restriction and Biomass Price Effects

Biomass Price	Net Returns in Millions of $ $0.00			$50.01	$52.19	Irrigation Restriction Effects		Biomass Compensation Effect	
Scenarios[a] Counties/CRD[b]	Base Line (1)	50% Sustain (2)	100% Sustain (3)	50% Sustain (4)	100% Sustain (5)	(2) vs (1)	(3) vs (1)	(4) vs (2)	(5) vs (3)
CRD 1	21	21	21	23	25	0%	0%	11%	18%
CRD 2	17	17	17	19	20	0%	0%	10%	17%
Clay	30	30	30	33	33	0%	−1%	11%	12%
Craighead	34	27	22	30	29	−21%	−36%	11%	32%
Greene	20	14	13	18	18	−27%	−37%	22%	42%
Independence	5	5	4	6	6	−16%	−21%	27%	40%
Jackson	18	14	11	18	19	−23%	−38%	30%	70%
Lawrence	20	16	14	19	19	−22%	−30%	18%	34%
Mississippi	38	38	38	41	42	0%	−1%	6%	9%
Poinsett	38	28	18	33	30	−25%	−52%	15%	66%
Randolph	13	11	10	13	13	−19%	−22%	16%	21%
White	8	8	7	11	12	0%	−7%	39%	62%
CRD 3	225	191	168	220	220	−15%	−25%	15%	31%
CRD 4	22	22	22	25	27	0%	0%	16%	24%
CRD 5	13	13	13	16	18	0%	0%	21%	31%
Arkansas	43	41	30	42	37	−5%	−31%	2%	24%
Crittenden	17	14	13	15	15	−20%	−22%	7%	15%
Cross	26	23	18	26	24	−10%	−29%	12%	34%
Lee	21	12	9	14	15	−44%	−57%	17%	70%
Lonoke	26	21	15	24	23	−18%	−41%	12%	53%
Monroe	16	16	13	19	16	−3%	−21%	17%	26%
Phillips	28	22	16	26	22	−22%	−42%	15%	32%
Prairie	26	23	18	25	23	−11%	−31%	5%	27%
Saint Francis	18	14	11	15	16	−23%	−43%	7%	55%
Woodruff	12	10	8	12	13	−13%	−31%	20%	61%
CRD 6	234	197	152	216	205	−16%	−35%	10%	35%
CRD 7	18	18	18	22	24	0%	0%	21%	31%
CRD 8	5	5	5	7	8	0%	0%	34%	48%
Desha	28	27	27	30	31	−1%	−3%	10%	15%
Jefferson	23	18	15	21	21	−21%	−34%	17%	35%
Lincoln	13	12	12	13	14	−7%	−8%	9%	13%
CRD 9	100	94	90	107	109	−7%	−10%	14%	21%
Alluvial Counties	526	448	377	505	495	−15%	−28%	13%	31%
State Total	657	579	507	657	657	−12%	−23%	13%	29%

[a] Scenarios are the baseline without biomass crops and no irrigation restrictions (1), irrigation restrictions to double/sustain the life of the aquifer (2)/(3). Scenarios (4) and (5) remove irrigation restriction impacts on state returns with biomass price.
[b] CRD stands for crop reporting district as reported by National Agricultural Statistics Service for Arkansas. County detail for CRDs 1, 2, 4, 5, 7, 8 and part of 9 are excluded as the irrigation restriction effects were zero.

per gallon without co-product credit and transportation charges would be $2.10 per gallon of ethanol from biomass (a price that can compete at approximately $101 per barrel of crude oil (Roberts, 2008)) at a state wide volume of 1.06 billion gallons of ethanol production (compared to U.S.-wide gasoline consumption of 140 billion gallon in 2004).

While the above indicates that state net returns can be hypothetically returned to pre-irrigation restriction levels as long as biofuel markets develop to the extent shown above, there are significant spatial income redistribution effects as portrayed in Table 5. As expected, irrigation restrictions do not affect returns in counties with sustainable pumping practices. The income ramifications of the restrictions in the Alluvial aquifer counties, however, range from 1% to as much as a 57% decreases in county net returns. However, these Alluvial aquifer counties, on average, are 13 and 31% better off with biomass markets than without, under doubling the aquifer life and full sustainability scenarios, respectively, *after* irrigation restrictions have been imposed *and* biomass prices rise to the levels needed to return state net returns to pre-irrigation restriction levels.

This indicates that the introduction of these crops may mitigate some of the adverse effects of irrigation water use restrictions on producer returns. There are, however, both counties that win and lose with these scenarios, as indicated in Table 5. Also not taken into account are the financial ramifications of reduced milling and processing of traditional crops as well as added processing of biomass crops on communities in the Delta.

Conclusions

Concerns over the decreasing water level in the Alluvial aquifer in Arkansas have led many to question the future of the water-intensive rice industry in the Arkansas Delta. This study set out to examine how profit maximizing cropping decisions would change at a county level if producers were constrained to irrigation levels that would sustain the Alluvial aquifer indefinitely. This is a timely and an important topic since the Alluvial region in Arkansas represents approximately 80% of crop returns to land use of Arkansas. This study also estimated the income and crop allocation effects of the introduction of biomass crops given the recent emphasis of national policy on energy independence. Both switchgrass and forage sorghum can be grown successfully under non-irrigated conditions with corn stover production a function of irrigated corn production.

The model iterations examined two irrigation restriction scenarios for the Alluvial aquifer: i) sustainable water use and ii) approximate doubling of the groundwater's useful life. The model also estimated the acreage allocation of two biomass energy crops that are less water-intensive than traditional crops and would thus be more attractive under an irrigation restriction policy. Estimates suggested that if producers are constrained to sustainable levels without the introduction of alternative crops, the Alluvial region's producer net returns would decrease by 28% ($149 million) not counting ancillary effects on rice processing and cotton ginning industries. If producers are constrained to levels that double the life of the aquifer, producer net returns would decrease by 15% ($78 million).

Further, results indicated that the hypothetical introduction of alternative, less water-intensive crops can meet policy objectives of securing a more energy independent and sustainable future while simultaneously reducing irrigation requirements. When switchgrass was introduced at $25 dollars per dry ton, only a small amount of acreage enters production and not in the Alluvial region. However, under the sustainable aquifer scenario, when the hypothetical market price for switchgrass is $45 a ton, nearly 1.2 million acres of biomass crops are grown using non-irrigated production. At these production levels, the Alluvial region's producer net returns were $412 million, a 22% reduction compared to the 2007 baseline. At switchgrass price levels slightly higher than $50 per dry ton, irrigation sustainability could be achieved without losses to state returns. Additionally, if the goal is to double the life of the aquifer and alternative crops entered at the state breakeven price level of $50.01 per dry ton, regional net returns would decline by only 4%.

A hypothetical scenario of returning state producer net returns to levels prior to irrigation restrictions suggested significant wealth redistribution effects—Alluvial region producers lose net returns to groundwater irrigation and non-Alluvial region counties gain as biomass production is a relatively profitable land use choice. Nonetheless, biomass markets would lessen the financial loss for Alluvial region producers facing eventual declines in irrigation water supply. This study suggests that the examination of less water-intensive crops that could provide the biomass for the second generation of biofuels, a processing industry that could also potentially absorb possible losses associated with reduced rice milling or cotton ginning, needs further investigation. Not accounted for in this study and also subject to further research would be the effects of biomass crops on traditional food, feed, and fiber crop prices as well as the effect of spatial biomass yield differences, potential crop rotation effects of forage sorghum, and corn residue collection effects. Also, the study is based on sustainable water use calculated using USGS's 1997 report. Since crop producers have not been restricted to use less water since then, it is expected that groundwater levels have declined further and sustainable groundwater use would be lower. Offsetting this effect are investments in groundwater saving technologies and above ground water collection efforts. Also, relative commodity prices can change and would impact results.

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