Economic Analysis of the Conditions for Which Farmers will Supply Biomass Feedstocks for Energy Production

by
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Executive Summary

This study developed a farm-level model to evaluate contract biomass feedstock production under risk for a northwest Tennessee 2,400 acre grain farm. A quadratic programming model incorporating farm labor and land quality constraints, biomass yield variability, crop and energy price variability, alternative contractual arrangements, and risk aversion was developed for the analysis. The four potential types of contracts analyzed in this study that could be used to encourage biomass production offer different levels of biomass price, yield, and production cost risk sharing between the farm and the processor. The spot market contract (SPOT) based on the yearly energy equivalent value with gasoline assumes that all of the output price, yield, and production cost risk from biomass production is incurred by the farmer. With the standard marketing contract (STANDARD), a portion of the price risk on expected production is shifted from the producer to the processor. All of the price risk is shifted from the farmer to the processor with an acreage contract (ACREAGE) that pays a specified price for all production produced on the contracted acreage. However, the ACREAGE contract does not provide any protection against yield risk and production cost risk. On the other hand, the gross revenue contract (REVENUE) provides the greatest potential risk benefits to the farmer because all of the biomass price and yield risk is assumed by the processor. In addition, a contract provision for switchgrass that provides a financial incentive to reduce production cost risk by covering part of the materials cost of establishing the switchgrass stand was also modeled.

The important findings from this research were as follows. First, under the spot market price contract scenario, the net revenues from biomass crops were not high enough to induce biomass production on the representative farm. Results indicate that a price above the energy equivalent price would be needed to encourage biomass production on the representative farm. Biomass prices under the SPOT contract scenario averaged $29.44/dt (standard deviation of $9.34/dt) for wheat straw, $29.44/dt (standard deviation of $15.50/dt) for corn stover, and $34.77/dt (standard deviation of $7.43/dt) for switchgrass.

Second, the ACREAGE and REVENUE contracts were more effective at inducing maximum farm biomass production at lower contract prices than the STANDARD contract for a risk neutral decision maker (Figure 1 on page iv). Under the assumption of risk neutrality, the same amount of biomass was supplied by the representative farm under the REVENUE contract as under the ACREAGE contract. Expected biomass crop net revenues were identical for both contract structures. Most of the biomass supplied by the representative farm under the STANDARD, ACREAGE, and REVENUE contracts was from switchgrass. In addition, some corn stover was produced but no wheat straw was supplied for ethanol production by the representative farm.

Third, because the REVENUE contract reduced biomass crop net revenue variability relative to the ACREAGE contract, the REVENUE contract provided more risk benefits to the representative farm under the assumption of risk aversion (Figure 2 on page v). In addition, because of the greater price and yield protection offered with the REVENUE contract, swtichgrass production was generally induced at lower contract prices than with the STANDARD contract. Fourth, results of this study suggest that a planting incentive to offset part of the cost of establishing switchgrass may be effective at inducing biomass larger production at lower contract prices. The incentive may provide a method for the processor to reduce average per ton cost of material at the plant gate for perennial biomass crops such as switchgrass.

Finally, as more of the farm crop area was planted into biomass crop at higher contract prices, the greater the annual variation in biomass supplied to the processing plant. Thus, for a processor, there may be a relationship between the annual variation in biomass material supplied and the cost of biomass materials. A higher contract price may induce more production on an individual farm. This could result in fewer farms in a more concentrated geographic area being needed to supply the plant. The biomass materials transportation cost may be lower but the biomass storage cost incurred to ensure a steady supply of feedstock to the plant may be higher with the increased variability of annual biomass production with higher contract prices.
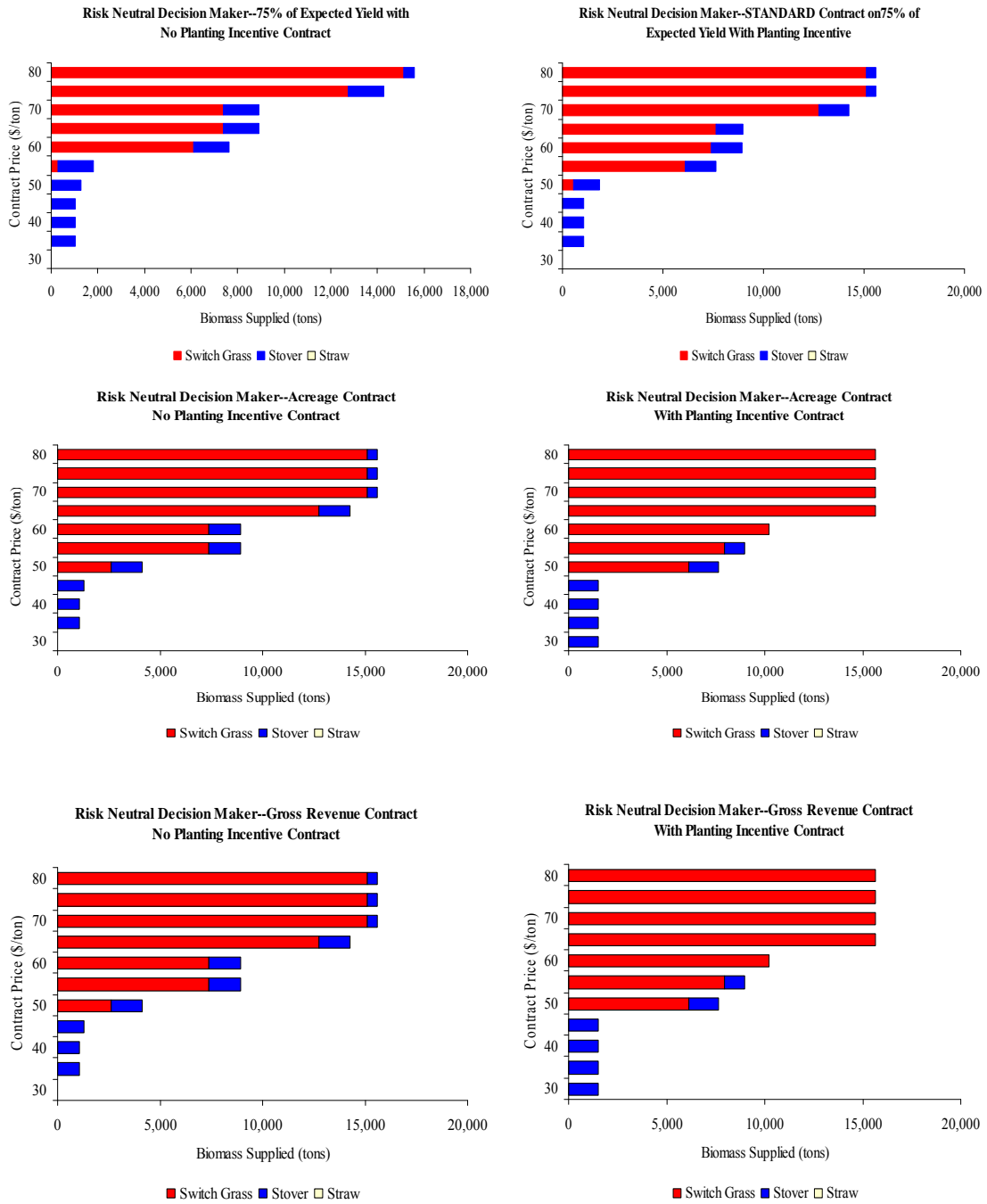
Figure 1. Representative Farm Biomass Supplied at Different Contract Prices for the STANDARD, ACREAGE, and REVENUE Contract Scenarios Assuming a Risk Neutral Decision Maker.
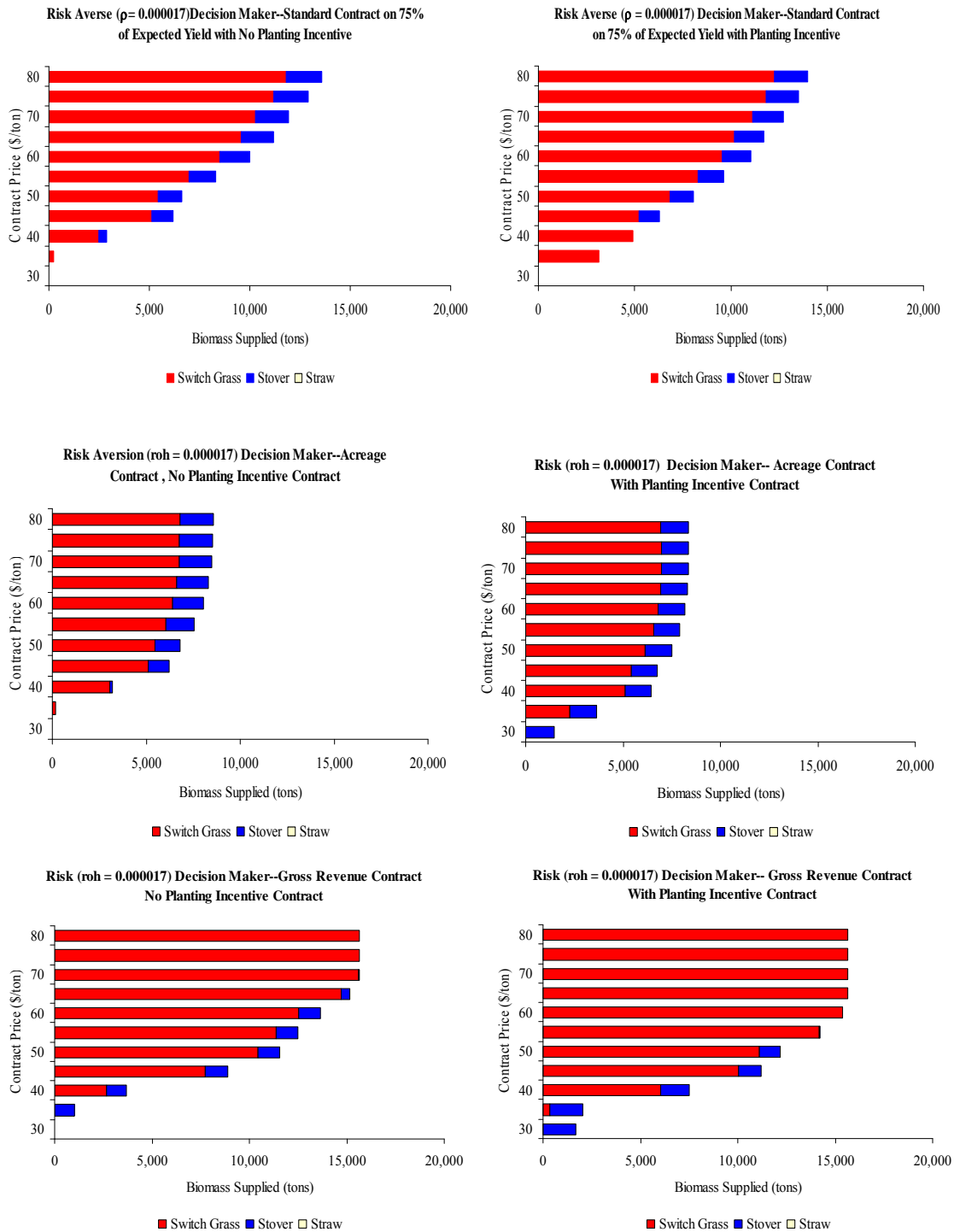
Figure 2. Representative Farm Biomass Supplied at Different Contract Prices for the STANDARD, ACREAGE, and REVENUE Contract Scenarios Assuming a Risk Averse Decision Maker (90 percent Risk Significance Level).

Introduction

Farmers, agribusiness, policymakers, and others are interested in the potential for on-farm production of biomass for energy production (English et al, 2006). Numerous studies have estimated the cost of producing energy crops in the U.S including: Cundiff (1996), Downing (1996), Duffy (2001), Graham (1995), Johnson (1990), Lindsey (1998), Vaughan (1989) and Walsh (1998). De La Torre Urgarte, et al. (2003) determined the potential impact that a biomass industry would have on the nation's agricultural sector. Other studies evaluated the potential for bioenergy and bioproduct markets in the U.S. under a variety of market and policy scenarios. Duffield, (1998), Evans (1997), FAPRI (2001), Raneses (1996), Urbanchuk (2001), and USDA-OCE (2002) among others, examined the use of traditional agricultural crops (starch from corn grain, soybean oil) as feedstocks for bioenergy and bioproducts. Bernow (2002), DiPardo (2001), English (2004 a,b), Haq (2001), and McCarl (2000) evaluated the use of cellulose feedstocks (including crop residues and energy crops) as bioenergy and bioproduct feedstocks. Except for English et al. (1992), most of the studies were conducted at a county, state, regional, or national level. For the most part, the aforementioned studies did not focused on the farm level issues that would be involved with the production of bioenergy crops including potential incentives through contracts that might be needed to induce biomass production on farms.

Compared to other agricultural commodities, transportation costs from grower to processor for biomass feedstocks will be relatively high, due to their bulkiness and low energy densities. This transportation cost factor will likely result in a more locally-grown market situation for biomass feedstock. Thus, the development of biobased industries, at least initially, will hinge on the local availability of sufficient, cost competitive biomass feedstocks. Given the high cost of constructing a production facility, the processor likely will have an interest in providing production contracts or other incentives to induce farmers to supply sufficient feedstocks to keep the plant operating at capacity. There may also be opportunities for farmer cooperative-based vertical ownership of the bioenergy processing plant for the local market.

Farmers face a wide variety of risks such as unforeseen changes in crop yields and prices and other important economic variables caused by weather, pests, etc. Risks that affects income variability influences farmers' production and marketing choices. Income variations affect a farmer's ability to meet fixed financial obligations such as debt repayment on land and equipment and family living expenses. Certain energy crops may have the potential to provide risk management benefits to farmers if a market for biomass crops develops in the United States. For example, switchgrass is a perennial prairie grass that is native to the United States and is known for its hardiness and rapid growth and is tolerant of poor soils, flooding and drought. Switchgrass may also require less annual purchased inputs than other crops such as corn or wheat. Thus, switchgrass production may have the potential to reduce production risk reduction when included in a farm's portfolio of crop enterprises. However, income variability also results from institutional, legal, and contractual arrangements that may occur between biobased processing plants and farmers.

Contracting of production has become increasingly important in United States agriculture, making up about 39 percent of the value of production in 2003 (McDonald et al., 2005). The two types of contracts most often used in agriculture are production contracts and marketing contracts (MacDonald and Korb, 2006). With a production contract, the contractor typically retains ownership of the commodity being produced with the farmer providing services to the contractor. Farmers often have a limited degree of autonomy with production contracts. Marketing contracts focus on the commodity as it is delivered to the contractor, rather than the services provided by the farmer. The contract typically specifies the quantity and quality of the commodity to be delivered to specific location at either a predetermined price or using a method for determining price. Marketing contracts can be used to limit a farmer's exposure to price risks and may specify price premiums to be paid for production that has certain quality attributes. However, farmers may gain utility or satisfaction from non-contract production because of the independence that it offers (Key, 2005). Thus, farmers who value independence may need to be compensated by a bioenergy processing plant to give up the satisfaction that comes from independent production.

A number of factors may influence farmers' willingness to supply biomass feedstocks such as corn stover, wheat straw, and/or switchgrass to a local processing facility. For example, how do biomass crops such as switchgrass compare to traditional crops with respect to costs of production, yields, price potential in terms of its energy equivalent to gasoline or coal, net returns, and risk (variability of net returns) under different management practices, weather conditions, energy market conditions, government policies, and contract pricing arrangements provided by the processing plant? Supplying biomass feedstocks will require changes in the way farmers manage their operations. The ability of farmers to respond to the market will be constrained by on-farm economic, structural, and resource constraints (e.g., time constraints, equipment constraints, land ownership, debt structure, farm size, production activities (i.e., crop, livestock), soil type and topography, farm program participation, etc.). For example, who would pay for investment in perennial crop establishment, harvest equipment, and storage for the biomass? Would the farm have enough labor resources to grow and harvest the crop? Farmers who must bear all of the feedstock price, production risks, and financial risks may not be willing to supply biomass or be willing to supply limited amounts of biomass at all to a processing facility. The willingness of farmers to provide biomass feedstocks will be a function of biomass feedstock profits, variability of profits, and correlation of profits relative to traditional crop profits. These factors will vary with respect to the contractual incentives that may be offered by the processing facility. Thus, an understanding of the factors that will affect farmer decisions to supply biomass feedstocks is essential.

A biomass-based energy industry may have a very different set of price and production risks than for coal and oil industries. Weather may have a very large impact on the quantity and quality of crop biomass materials produced in the United States. Severe droughts are not uncommon in the United States and can cover large geographic areas. What happens if there is a production shortfall in a drought year for a contract that specifies a minimum quantity and quality to be delivered as is common with other agricultural marketing and production based contracts in the United States (McDonald et al., 2004)? Will the farmer be financially responsible for making up the difference by paying a penalty or be forced to purchase tonnage at the current market price to fulfill the contract? Alternatively, what happens in a very wet year when production may be in excess of processor plant needs and harvest and storage may be difficult? How will these disparate production risks be shared between the processor and the farmer? Another potential risk with on-farm biomass production is the potential for more soil erosion and runoff with certain crops such as corn stover (English et al., 2007). Soil losses could have a negative impact on soil quality, environmental quality, yields, and profitability for farmers over time if not enough residue is left on the soil surface to biomass harvesting due to the removal of biomass that would normally be left on the soil surface or incorporated into the soil.

Currently, research about the potential risks and risk management benefits of on-farm biomass production is lacking. In addition, analysis of the impacts of alternative biomass contract structures on risk and farmer williness to supply biomass is also limited. Larson et al. (2005) evaluated the risk management benefits of a marketing contract with a penalty for production underage or excess production is sold at the spot market price based on the energy equivalent value as a substitute for gasoline on farmer willingness to supply switchgrass, corn stover, or wheat straw. However, the Larson et al (2005) study did not evaluate other potential contract alternatives such as acreage contracts (Paulson and Babcock, 2007), gross revenue contracts (Garland, 2007), or other financial incentives that could be used to induce on-farm biomass production for a processor. Thus, the objective of this research is to evaluate the ability and willingness of farmers to provide biomass feedstocks given their on-farm situation and potential contractual arrangements with user facilities. The specific farm situation evaluated in the present analysis was for a grain and oilseed farm operation in west Tennessee.

Methods and Data

Description of the West Tennessee Representative Farm

A farm-level risk programming model for a representative grain farm in Weakley and Obion Counties in northwest Tennessee was developed for the analysis. A panel of northwest Tennessee farmers, with assistance from University of Tennessee Extension personnel, used consensus building methods to describe the farm size and crop enterprise characteristics of a typical farm in northwest Tennessee (Tiller, 2001). The 2,400 acre farm produces corn, soybeans, and wheat.

The specific crop rotations for the farm were derived from the USDA-NRCS soil survey database (USDA-NRCS, 2005). The crop enterprises and rotations assumed for the representative farm were continuous corn, continuous soybeans, continuous winter wheat, a soybean-corn rotation, a soybean-corn-corn rotation and a soybeans-wheat double-crop enterprise. In addition, the farm was assumed to bale straw for sale on a portion of its wheat area.

The 2,400-acre farm was assumed to have three major soil types common to northwest Tennessee: Collins (0% slope with no fragipan), Memphis (1% slope with 42" depth to fragipan), and Loring (3% slope with 30" depth to fragipan). In general, the Collins and Memphis soils are the most productive and the Loring soil is the least productive. The representative farm was assumed to have 1,200 acres of Collins soils, 528 acres of Loring soils, and 672 acres of Memphis soils. The area of the farm in each soil type was determined using data from the USDA-NRCS soil survey database (USDA-NRCS, 2005). The major tillage practice in northwest Tennessee is no tillage and was used to simulate yields and estimate production costs for all crop activities on the farm (Tennessee Department of Agriculture, 2004).

Biomass Contract Scenarios

The representative farm was assumed to have the opportunity to provide biomass feedstocks to a local single-user facility that produces ethanol. The farm was assumed to be able to produce three energy crop production alternatives: corn stover, wheat straw and switchgrass. Thus, the representative farm had the choice between producing corn grain only or corn grain and corn stover. Similarly, the representative farm could produce wheat grain only or wheat grain and wheat straw for sale to individual, wholesalers, and retailers or wheat straw for ethanol production. The number of gallons of ethanol assumed to be produced per dry ton (dt) of biomass was assumed to be 69.2 gallons for wheat straw, 72 gallons for corn stover, and 76 gallons for switchgrass (Wang, Saricks, and Santini, 1999). Contract prices for corn stover and wheat straw were adjusted downward by 5 percent and 9 percent, respectively, from the contract price for switchgrass to reflect the lower gallons per dt produced.

The potential biomass contracting alternatives modeled for the west Tennessee representative crop farm were: 1) a spot market contract (SPOT) where biomass is priced yearly on its current energy equivalent value as a substitute for gasoline at the processing plant gate, 2) a standard marketing contract (STANDARD) with a penalty for production underage or excess production is sold at the spot market price (Musser, Mapp, and Barry, 1984; Paulson and Babcock, 2007), 3) an acreage contract (ACREAGE) which provides a guaranteed annual price on the actual biomass produced in each year on the contracted biomass acreage (Paulson and Babcock, 2007), and 4) a gross revenue contract (REVENUE) which provides a guaranteed annual gross revenue per acre from biomass based on a guaranteed contract price times expected yield per acre over the life of the contract (Garland, 2007).

The four potential types of contracts that could be used to encourage biomass production offer different levels of biomass price, yield, and production cost risk sharing between the representative farm and the processor. The SPOT contract assumes that all of the output price, yield, and production cost risk from biomass production is borne by the farmer. With the STANDARD contract, a portion of the price risk on expected production is shifted from the producer to the processor. All of the price risk is shifted from the farmer to the processor with an ACRAGE contract but the farmer still incurs all of the yield and production cost risk. On the other hand, the gross revenue contract provides the greatest potential risk benefits to the farmer because all of the biomass price and yield risk is assumed by the processor. In addition, a contract provision for switchgrass that provides a financial incentive to reduce production cost risk by covering the materials cost of establishing the switch grass stand was also modeled. The gross revenue contract and the planting incentive are two potential switchgrass production incentives that are being consider for contract production for the cellulosic ethanol pilot plant being constructed for

Tennessee Biofuels Initiative (Garland, 2007). The time period for each of the four types of contracts modeled was assumed to be 5 years (Garland, 2007).

Farm-Level Risk Programming Model
 As with traditional crops, the production of biomass crops such as switchgrass is risky for farmers because of uncertainty about production costs, output prices, yields, and profitability. Thus, a mean-variance framework was used to evaluate the risk and return tradeoffs of biomass production in a whole farm setting under different contract arrangements. It was assumed that the objective of the farm decision maker is to maximize expected utility and that the risk and return tradeoff can be adequately represented using the mean and variance of farm net revenues.

Objective Function.
 The objective function specification for the farm-level quadratic programming model is:

(1) $$\text{Maximize } CE = \overline{\text{WFNR}} - \lambda \sigma^2_{\text{WFNR}},$$

where CE is the certainty equivalent, $\overline{\text{WFNR}}$ is expected whole-farm net revenue (returns to land, management, and risk), λ is the Pratt-Arrow absolute risk aversion coefficient, and σ^2_{WFNR} is the variance of whole-farm net revenues. Expected whole-farm net revenue is defined as:

(2) $$\overline{\text{WFNR}} = \sum_i \sum_s \overline{\text{CNR}}_{i,s} \times A_s,$$

where $\overline{\text{CNR}}$ is expected net revenue (\$/acre) for crop activity i on soil type s and A is the area (acres) devoted too crop activity i on soil type s. The variance of whole-farm net revenues, σ^2_{WFNR}, is:

(3) $$\sigma^2_{\text{WFNR}} = \sum_s \sum_i A_s^2 \times \sigma^2_{i,s} + 2 \sum_{s=} \sum_t \sum_{i=} \sum_j A_s \times A_t \times \sigma_{i,s} \sigma_{j,s} \times \rho_{ij},$$

where σ^2 is the variance of net revenue for crop activity i on soil type s and ρ is the correlation coefficient between two crop activities.

Resource Constraints.
 The three constraints specified in the model were for soil type, labor, and available field days for wheat straw and corn stover harvest. Total land was restricted to 2,400 acres and land for each soil type was restricted to 1,200 acres of Collins soils, 528 acres of Loring soils, and 672 acres of Memphis soils. Six bimonthly labor periods were specified in the model. Labor requirements by period were from crop budgets by Gerloff (2007a; 2007b). Labor availability by period was for a family of four (Johnson, 1991). Total family labor availability by period was 510 hours for January-February, 510 hours for March-April, 675 hours for May-June, 705 hours for July-August, 585 hours for September-October, and 585 hours for November-December. In addition to family labor, it was assumed that the farm could hire an additional 2,000 hours of labor per year at \$8.50/hour (Gerloff, 2007a). Hired labor was assumed to have an efficiency of 90% in the model to account for the extra management time for the farm operator (Musser, Mapp, and Barry, 1984). The number of suitable days available to harvest corn stover and wheat straw after grain harvest was constrained to 21-10 hour days. For the soybean-wheat double crop, the available days to harvest straw between the wheat grain harvest and the planting of the soybean crop was assumed to be 10-10 hour days.

4

Crop Net Revenue Equations and Definitions

A 99-year distribution of net revenues for each the crop activity was simulated for use in the quadratic programming model to determine risk-efficient farm plans under the alternative contracting scenarios. The variables treated as random in the simulation of net revenues were crop prices, crop yields, nitrogen fertilizer price, diesel fuel price, and selected biomass harvest and transportation costs as a function of harvested yield. Nitrogen fertilizer and diesel fuel are the two largest annual operating expenses incurred by farmers in west Tennessee that are subject to year-to-year variation and were included as random variables along with output prices and crop yields.

<u>Corn, Soybean, and Wheat Enterprises</u>

Annual net revenues for the non-energy crop enterprises (corn, soybean, wheat, wheat grain and straw, soybean-corn rotation, soybean-wheat double crop grain, and soybean-wheat double-crop grain and wheat straw) were simulated using the following budget equation:

$$(4) \qquad \mathrm{CNR}_{i,s,n} = \sum_h P_{h,n} \times Y_{h,s,n} - \mathrm{RNF}_n \times \mathrm{NF}_h - \mathrm{RDF}_n \times \mathrm{DF}_h - \mathrm{VC}_h - \mathrm{FC}_h.$$

where h is an index for crop h in crop activity i being produced annually on an acre of land (single-crop or double-crop enterprise), s is soil type, n is crop year, P is crop price ($/bu), Y is crop yield (bu/acre), RNF is nitrogen fertilizer price ($/lb), NF is nitrogen fertilizer applied (lb/acre), RDF is diesel fuel price ($/gal), DF is diesel fuel (gal/acre), VC is the other variable operating costs of production ($/acre) that do not vary in the simulation of crop net revenues, and FC is the fixed ownership costs of production ($/acre).

<u>Switchgrass Crop Enterprises</u>

The equations to calculate net revenues for switchgrass production under the four potential contracting mechanisms described previously are:

      1.   Switchgrass spot market contract (SGSNR):

$$(5) \qquad \begin{aligned} \mathrm{SGSNR}_{s,n,z} = {} & \mathrm{SGSP}_n \times \mathrm{SGY}_{s,n} - \mathrm{BTC} \times \mathrm{SGY}_{s,n} - \mathrm{RNF}_n \times \mathrm{SGNF} \\ & - \mathrm{RDF}_n \times \mathrm{SGDF} - \mathrm{SGVC} - \mathrm{SGFC}_z, \end{aligned}$$

where SGSP is yearly switchgrass spot market price based on its energy value as a substitute for gasoline in the production of ethanol ($/dt), SGY is switchgrass yield (dt/acre), BTC is the cost of transporting the biomass from the edge of the field to the conversion facility ($/dt), SGNF is the nitrogen fertilization rate for switchgrass (lb/acre), SGDF is diesel fuel used in the production of switchgrass (gal/acre), SGVC is the other variable costs for switchgrass that do not vary in the simulation ($/acre), and SGFC is the fixed costs for producing switchgrass including prorated establishment expenses under planting incentive z (z=0, no planting incentive; z=1, with planting incentive).

      2.   Switchgrass standard marketing contract (SGMNR):

$$(6) \qquad \begin{aligned} \mathrm{SGMNR}_{s,n,z} = {} & (\mathrm{SGCP} - \mathrm{BTC}) \times \mathrm{CP} \times \mathrm{ESGY}_s + (\mathrm{SGSP}_n - \mathrm{BTC}) \times (\mathrm{SGY}_{s,n} - \mathrm{ESGY}_s) \\ & - \mathrm{RNF}_n \times \mathrm{SGNF} - \mathrm{RDF}_n \times \mathrm{SGDF} - \mathrm{SGVC} - \mathrm{SGFC}_z, \end{aligned}$$

where SGCP is the contract price for switchgrass ($/dt) and CP is the proportion between 0 and 1 of expected switchgrass yield, ESGY (dt/acre), that is contracted to be delivered to the user-facility. The other variable definitions are the same as for Equation (5). Equation (6) assumes that the user-facility will

buy all of the biomass produced by the farm but also provides for a penalty if there is a shortfall in promised production. For example a farmer could contract 50% of expected biomass production. If the biomass yield exceeds the contract level, the gross revenue is the sum of receipts from the contracted biomass yield times the contracted price plus the yield above the contracted yield times the spot market price. In years when realized yields are below the contracted level, the farmer does not have enough biomass to satisfy the contract. The farmer pays a penalty to the biomass user for the shortfall that is equal to the difference between the actual yield and the contracted yield times the spot market price.

3.   Switchgrass acreage contract (SGANR):

$$
\begin{aligned}
SGANR_{s,n,z} = {} & SGCP \times SGY_{s,n} - BTC \times SGY_{s,n} - RNF_n \times SGNF \\
& - RDF_n \times SGDF - SGVC - SGFC_z,
\end{aligned}
$$

(7)

where the variable definitions are the same as for Equations (5) and (6). Equation (7) assumes that all production is purchased at the contract price specified by processor.

4.   Switchgrass gross revenue contract (SGRNR):

$$
\begin{aligned}
SGRNR_{s,n,z} = {} & SGCP \times ESGY_{s,n} - BTC \times SGY_{s,n} - RNF_n \times SGNF \\
& - RDF_n \times SGDF - SGVC - SGFC_z,
\end{aligned}
$$

(8)

where the variable definitions are the same as for Equations (5) and (6). Under the gross revenue contract, the processor assumes all of the biomass price and yield risk. The producer still incurs all of the production cost risk. The three sources of production costs risk modeled are nitrogen fertilizer cost, diesel fuel cost, and transportation cost based on tonnage produced. With the guaranteed gross revenue provision, there is potential for shirking on the part of the producer with respect to the production and delivery of switch grass to the processor. For the purpose of this analysis, it was assumed that provisions were written into all of the contract scenarios as necessary to prevent shirking on the part of the producer.

Corn Grain and Stover Enterprises

The equations used to simulate corn grain and stover net revenues under the four potential bioenergy contract types are:

1.   Corn grain and stover spot market contract (CGSSNR):

$$
\begin{aligned}
CGSSNR_{s,n} = {} & CGP_n \times CGY_{s,n} + CSCP_n \times CSY_{s,n} - BTC \times CSY_{s,n} \\
& - RNF_n \times CGSNF - RDF_n \times CGSDF - CGSVC - CGSFC,
\end{aligned}
$$

(9)

2. Corn grain and stover standard marketing contract (CGSMNR):

$$
\begin{aligned}
\text{CGSMNR}_{s,n,z} = {} & \text{CGP}_n \times \text{CGY}_{s,n} + (\text{CSCP} - \text{BTC}) \times \text{CP} \times \text{ECSY}_{s\backslash} \\
& + (\text{CSSP}_n - \text{BTC}) \times (\text{CSY}_{s,n} - \text{ECSY}_s) - \text{RNF}_n \times \text{CGSNF} \\
& - \text{RDF}_n \times \text{CGSDF} - \text{CGSVC} - \text{CGSFC},
\end{aligned}
$$
(10)

3. Corn grain and stover acreage contract (CGSANR):

$$
\begin{aligned}
\text{CGSANR}_{s,n,z} = {} & \text{CGP}_n \times \text{CGY}_{s,n} + \text{CSCP} \times \text{CSY}_{s,n} - \text{BTC} \times \text{CSY}_{s,n} \\
& - \text{RNF}_n \times \text{CGSNF} - \text{RDF}_n \times \text{CGSDF} - \text{CGSVC} - \text{CGSFC},
\end{aligned}
$$
(11)

4. Corn stover gross revenue contract (CGSRNR):

$$
\begin{aligned}
\text{CGSRNR}_{s,n} = {} & \text{CGP}_n \times \text{CGY}_{s,n} + \text{CSCP} \times \text{ECSY}_{s,n} - \text{BTC} \times \text{CSY}_{s,n} \\
& - \text{RNF}_n \times \text{CSNF} - \text{RDF}_n \times \text{CGSDF} - \text{CGSVC} - \text{CGSFC},
\end{aligned}
$$
(12)

where CGP is corn grain price ($/bu), CGY is corn grain yield (bu/acre), CSP is corn stover spot market price based on its energy value as a substitute for gasoline in the production of ethanol ($/dt), CSY is corn stover yield (dt/acre), BTC is the cost of transporting the biomass from the edge of the field to the conversion facility ($/dt), CGSNF is the nitrogen fertilization rate for the corn grain and stover enterprise (lb/acre), CGSDF is diesel fuel used in the production of corn grain and stover (gal/acre), CGSVC is the other variable costs for corn grain and stover that do not vary in the simulation ($/acre), and CGSFC is the fixed costs for producing corn grain and stover. Equations (9), (10), (11), and (12) were used to calculate net revenues for the continuous corn enterprise and for the corn crop in the years that corn is produced in a rotation with soybeans.

Wheat Grain and Straw Enterprise

The equations used to simulate continuous wheat grain and straw net revenues under the four potential biomass contract types are:

1. Wheat grain and straw spot market contract (WGSSNR):

$$
\begin{aligned}
\text{WGSSNR}_{s,n} = {} & \text{WGP}_n \times \text{WGY}_{s,n} + \text{WSCP}_n \times \text{WSY}_{s,n} - \text{BTC} \times \text{WSY}_{s,n} \\
& - \text{RNF}_n \times \text{WGSNF} - \text{RDF}_n \times \text{WGSDF} - \text{WGSVC} - \text{WGSFC},
\end{aligned}
$$
(13)

2. Wheat grain and straw standard marketing contract (WGSMNR):

$$
\begin{aligned}
\text{WGSMNR}_{s,n,z} = {} & \text{WGP}_n \times \text{WGY}_{s,n} + (\text{WSCP} - \text{BTC}) \times \text{CP} \times \text{EWSY}_{s\backslash} \\
& + (\text{CSSP}_n - \text{BTC}) \times (\text{WSY}_{s,n} - \text{EWSY}_s) - \text{RNF}_n \times \text{WGSNF} \\
& - \text{RDF}_n \times \text{WGSDF} - \text{WGSVC} - \text{WGSFC},
\end{aligned}
$$
(14)

3. Wheat grain and straw acreage contract (WGSANR):

$$(15) \quad \begin{aligned} WGSANR_{s,n,z} = {} & WGP_n \times WGY_{s,n} + WSCP \times WSY_{s,n} - BTC \times WSY_{s,n} \\ & - RNF_n \times WGSNF - RDF_n \times WGSDF - WGSVC - WGSFC, \end{aligned}$$

4.   Wheat grain and straw revenue contract (CGSRNR):

$$(16) \quad \begin{aligned} WGSRNR_{s,n} = {} & WGP_n \times CGY_{s,n} + WSCP \times EWSY_{s,n} - BTC \times WSY_{s,n} \\ & - RNF_n \times WSNF - RDF_n \times WGSDF - WGSVC - WGSFC, \end{aligned}$$

where WGP is corn grain price ($/bu), WGY is wheat grain yield (bu/acre), WSP is wheat straw spot market price based on its energy value as a substitute for gasoline in the production of ethanol ($/dt), WSY is wheat straw yield (dt/acre), BTC is the cost of transporting the biomass from the edge of the field to the conversion facility ($/dt), WGSNF is the nitrogen fertilization rate for the wheat grain and straw enterprise (lb/acre), WGSDF is diesel fuel used in the production of wheat grain and straw (gal/acre), WGSVC is the other variable costs for wheat grain and straw that do not vary in the simulation ($/acre), and WGSFC is the fixed costs for producing wheat grain and straw.

Soybean-Wheat Double-Crop Grain and Straw Enterprise

The equations used to simulate continuous soybean-wheat doublecrop grain and straw net revenues under the four potential biomass contract types are:

1.   Soybean-wheat double-crop grain and straw spot market contract (SWGSSNR):

$$(17) \quad \begin{aligned} SWGSSNR_{s,n} = {} & SGP_n \times SGY_{s,n} + WGP_n \times WGY_{s,n} + WSCP_n \times WSY_{s,n} \\ & - BTC \times WSY_{s,n} - RNF_n \times SWGSNF - RDF_n \times SWGSDF \\ & - SWGSVC - SWGSFC, \end{aligned}$$

2.   Soybean-wheat double-crop grain and straw standard marketing contract

(SWGSMNR):

$$(18) \quad \begin{aligned} SWGSMNR_{s,n,z} = {} & SGP_n \times SGY_{s,n} + WGP_n \times WGY_{s,n} \\ & + (WSCP - BTC) \times CP \times EWSY_s \\ & + (CSSP_n - BTC) \times (WSY_{s,n} - EWSY_s) \\ & - RNF_n \times SWGSNF - RDF_n \times SWGSDF \\ & - SWGSVC - SWGSFC, \end{aligned}$$

3.   Soybean-wheat double-crop grain and straw acreage contract (SWGSANR):

$$(19) \quad \begin{aligned} SWGSANR_{s,n,z} = {} & SGP_n \times SGY_{s,n} + WGP_n \times WGY_{s,n} + WSCP \times WSY_{s,n} \\ & - BTC \times WSY_{s,n} - RNF_n \times SWGSNF - RDF_n \times SWGSDF \\ & - SWGSVC - SWGSFC, \end{aligned}$$

4.   Soybean-wheat double-crop grain and straw revenue contract (CGSRNR):

$$(20) \quad \begin{aligned} WGSRNR_{s,n} = {} & WGP_n \times CGY_{s,n} + WSCP \times EWSY_{s,n} - BTC \times WSY_{s,n} \\ & - RNF_n \times WSNF - RDF_n \times WGSDF - WGSVC - WGSFC, \end{aligned}$$

where SGP is corn grain price ($/bu), SGY is wheat grain yield (bu/acre), WGP is corn grain price ($/bu), WGY is wheat grain yield (bu/acre), WSP is wheat straw spot market price based on its energy value as a substitute for gasoline in the production of ethanol ($/dt), WSY is wheat straw yield (dt/acre), BTC is the cost of transporting the biomass from the edge of the field to the conversion facility ($/dt), WGSNF is the nitrogen fertilization rate for the soybean-wheat double-crop grain and straw enterprise (lb/acre), SWGSDF is diesel fuel used in the production of the production of the soybean-wheat double-crop grain and straw enterprise (gal/acre), SWGSVC is the other variable costs for wheat grain and straw that do not vary in the simulation ($/acre), and SWGSFC is the fixed costs for producing the soybean-wheat double-crop grain and straw enterprise.

Simulation of Crop and Biomass Yields

Typically, historical yield estimates are used to generate information about expected yields and the distribution (variability) of yields. Generally speaking, however, this type of information is not readily available for a specific crop on different soil as required for this analysis. The lack of appropriate historical yield data is most problematic for the switchgrass, corn stover, and wheat straw options. Therefore, simulation of crop yields was used to represent the risk and return for crops on alternative soils for the representative West Tennessee farm.

Crop simulation models can be applied to evaluate the relationship between crop productivity and selected growing environment factors such as soils and weather. There are several models including CERES (Ritchie et al, 1989), SOYGRO (Jones et al, 1989), EPIC (Environmental Policy Integrated Climate)(Williams et al, 1989), and ALMANAC (Agricultural Land Management Alternatives with Numerical Assessment Criteria)(Kiniry et al., 1992). In many cases these process based, daily time-step crop models have been developed for specific locations and are designed to simulate the growth and development of one crop. In this case, multiple crops are requiring simulation to maintain consistency among simulated yields and for ease of operation.

ALMANAC was selected as the crop growth simulator for the analysis. The ALMANAC model is a daily-time-step, process based general crop model that uses daily weather data to simulate crop yield distribution under different fertility, crop rotation, and tillage regimes. It simulates the processes of crop growth and development balances including light interception by leaves, dry matter production, and partitioning of biomass into grain. The model also tracks a variety of soil parameters including daily soil water and soil nutrient balances. ALMANAC simulates a grain yield based on harvest index, which is grain yield as a fraction of total aboveground dry matter at maturity. The model also simulates perennial grasses such as switchgrass (Kiniry et al., 1996; Kiniry et al. 2005). In addition, ALMANAC has the ability to simulate annual double-crop and annual crops produced in a rotation as required for this analysis. The model has been extensively evaluated under a variety of soil and weather conditions (Kiniry et al., 2005).

ALMANAC was used to simulate random crop yields for the continuous crop and crop rotations on the Loring, Memphis, and Collins soils for the representative farm. A summary of the fertility practices and the planting and harvest dates for each crop enterprise is presented in Appendix A, Table 1. The production inputs and machinery operations used in the crop simulation were from University of Tennessee Extension budgets developed by Gerloff (2007a; 2007b). A 99 year distribution of crop yields for each enterprise alternative on each soil type were simulated using 100 years of daily weather data. For the soybean-wheat double-crop enterprise, winter wheat yields were not generated in the first year because the wheat crop was planted in the previous calendar year. Therefore, all crop net revenues were calculated using simulation years two through 100. It was assumed that 70 percent of biomass yields were harvested in each year of the simulation.

Historical rainfall and temperature averages from a weather station in Dresden, Tennessee, located in Weakley County (Latitude 36.2833N; Longtitude 88.7W) were used to calibrate parameters in the ALMANAC weather generator for the simulation of the 100 years of daily weather. To maintain consistence among the simulated crop yields, the same set of simulated weather values were used to generate the random yields for each crop enterprise on each soil type. The tillage practice assumed was no-tillage, consistent with the dominant practice in West Tennessee. Yield statistics for each simulated crop enterprise for the Collins, Memphis, and Loring soils are presented in Appendix A, Tables 2, 3, and 4, respectively.

Simulation of Crop and Biomass Input and Output Prices

A 99-year set of real, detrended, and correlated prices for corn, soybeans, wheat, wheat straw, corn stover, switch grass, nitrogen fertilizer, and diesel fuel were simulated using the @Risk simulation model in Decision Tools (Palisade Corporation, 2007). A summary of the simulated crop and input prices is presented in Appendix A, Table 2.

Simulated Crop and Input Prices

Tennessee average yearly corn, soybean, and wheat prices for 1977 through 2006 were used to calculate distribution parameters for each crop price distribution (Tennessee Department of Agriculture, 1978-2006 Annual Issues). Price data for estimating the nitrogen fertilizer and diesel fuel distribution parameters were obtained using 1977 through 2006 prices reported in *Agricultural Statistics* (USDA-NASS, 1977 through 2007 Annual Issues). The crop input and output prices were inflated to 2006 dollars by the Implicit Gross Domestic Product Price Deflator (U.S. Congress, Council of Economic Advisors, 2007). The inflated prices then were detrended using procedures described by Pelletier (2002) to remove the long-term downward trend in real crop prices.

Simulated Biomass Prices

The end use for the biomass produced by the representative farm was assumed to be the production of ethanol. Energy equivalent price series for switchgrass, corn stover, and wheat straw as an ethanol based energy substitute for gasoline were constructed using wholesale gasoline price data for 1977 through 2004 (U.S. DOE, 2007). The number of gallons of ethanol that can be produced per dry ton of biomass was assumed to be 69.2 gallons for wheat straw, 72 gallons for corn stover, and 76 gallons for switchgrass (Wang, Saricks, and Santini, 1999). A net energy conversion factor of 1.8 was used to derive net energy gallons per ton of biomass after processing of 30.8 gallons for wheat straw $[((1.8-1)\div1.8) \times69.2]$, 32.0 gallons for corn stover $[((1.8-1)\div1.8) \times72]$, and 33.8 gallons for switchgrass $[((1.8-1)\div1.8) \times76]$ (Wang, Saricks, and Santini, 1999). Assuming an energy value of 76,000 BTUs per gallon of ethanol (Wang, Saricks, and Santini, 1999), the net energy gallons of ethanol produced for each biomass product was multiplied by 76,000 to estimate the net BTUs per ton of biomass. The net energy values from ethanol per ton of biomass were estimated to be 2.337 million BTUs per dry ton for wheat straw, 2.432 million BTUs per dry ton for corn stover, and 2.567 million BTUs per dry ton for switchgrass. The net energy BTUs per dry ton of biomass for each crop was multiplied by the average Tennessee gasoline price per million BTUs for 1977 through 2004 (U.S. DOE, 2007) to create a price series for each biomass crop. Before creating the biomass price series, gasoline prices were inflated to 2006 dollars by the Implicit Gross Domestic Product Price Deflator (U.S. Congress, Council of Economic Advisors, 2007).

Simulation of Crop and Biomass Production Costs

Corn, soybean, wheat, and soybean-wheat production costs were derived from University of Tennessee Extension budgets (Gerloff, 2007a). All three biomass crops were assumed to be harvested using a large round bale system with the bales being moved to the edge of the field before transport to the user facility. Switchgrass production costs were estimated using a budget produced by University of Tennessee Extension (Gerloff, 2007b). The switchgrass budget assumes a contract length of five years

(Gerloff, 2007b). Thus, the budget assumes that the perennial switchgrass stand is replanted every 5 years with the planting and replanting costs amortized over the 5 years. The costs of harvesting corn stover and wheat straw in larger round bales for ethanol production, and wheat straw in small square bales for sale to garden centers or other retail businesses (additional machinery ownership, materials, and labor costs) were estimated using modified University of Tennessee Extension forage budgets (Bowling, McKinley, and Rawls, 2006). The cost of transporting the biomass to the biomass conversion facility was assumed to be $10/dt harvested (English et al., 2004). All of the crop budgets were modified to include random nitrogen fertilizer and diesel fuel prices. Labor for all production activities on the farm was charged out using a wage rate of $8.50 per hour (Gerloff, 2007a).

The planting incentive modeled in the analysis provided for the establishment of the perennial switchgrass stand. It was assumed that seed or a cash payment for the cost of seed would be provided to farmers who plant switchgrass. The reduction in establishment costs was assumed to be worth $130.05/acre based on Extension budget costs for seeding and reseeding the stand every five years (Gerloff, 2007b). Thus, the reduction in annual amortized establishment costs was $32.74/acre when compared with the cost of switchgrass establishment without the planting incentive.

Analysis

A base set of risk efficient farm plans in the absence of biomass crops for different levels of absolute risk aversion [λ in Equation (1)] were generated using the quadratic programming model. For the base set of solutions, the absolute risk aversion coefficient was calculated using the method described by McCarl and Bessler (1989) and Dillon (1999). The formula for calculating the risk aversion parameter is:

(21)
$$\lambda = \frac{2 \times Z_\alpha}{\sigma_{RNWFNR}},$$

where Z_α is the standardized normal Z-value level of significance, and σ_{RNWFNR} is the risk neutral standard deviation of whole-farm net revenues for the base solution. Risk significance levels (α) of 50, 60, 70, 80, and 90 percent were used to generate risk-efficient farm plans for different levels of absolute risk aversion. The risk levels model the certainty of obtaining or exceeding a maximized lower level confidence limit on net revenues (Dillon, 1999). Thus, for a risk neutral decision maker a 50% percent certainty that the actual net revenues will meet or exceed expected net revenues. For risk averse decision makers, a higher probability of certainty is required on net revenues; thus, a risk significance levels (α) of higher than 50% is required.

The base farm plan solutions were then compared with where biomass crops can be produced under the spot price contract, standard marketing contract, acreage contract, and gross revenue contract scenarios. Risk efficient farm plans were generated using switchgrass contract prices ranging from $30/dt to $80/dt. Contract prices for corn stover and wheat straw were multiplied by 0.95 and 0.91, respectively, to reflect the lower BTU content of these two materials relative to switchgrass. The expected yield levels evaluated for the standard marketing contracts with the model were 50%, 75%, and 100% or expected yield.

Results and Discussion

Base Scenario Risk Efficient Farm Plans Without Biomass Crops

The profit-maximizing farm plan that does not consider biomass crop production alternatives is presented in Appendix A, Table 6. The profit maximizing farm plan in the absence of biomass crop alternatives produced 528 acres of continuous corn on the Loring soil and 1,200 acres of continuous corn on the Loring soil. A combination of 100 acres of continuous corn, 420 acres of wheat grain and straw, and 152 acres of soybean-wheat, double-crop grain and straw were produced on the Memphis soil.

Because of its relative profitability, the farm produced the maximum amount of straw for sale to wholesalers/retailers given the constraint on available harvest time. Mean farm net revenue for the base profit maximizing farm plan was $472,175 with a standard deviation of net revenues of $152,926. In general, mean crop net revenues were the largest on the Memphis soil and the smallest on the Collins soil. The coefficient of variation of crop net revenues, a measure of relative risk (variation) of net revenues, was generally higher (riskier) for crop enterprises on the poorer quality Collins soil and lower (less risky) on the higher quality Memphis and Collins soils.

Risk significance levels of 50, 60, 70, 80, and 90 percent were used to generate risk-efficient farm plans for different levels of absolute risk aversion. Parameterization of the programming model to include absolute risk aversion did not change the risk efficient crop mix from the base profit maximizing solution for the 50, 60, 70, and 80 percent risk significance levels. For these levels of risk significance, no other combination of crop enterprises on the three soil types provided a more favorable risk-return tradeoff. In these cases, the most profitable crop enterprise was also the least risky. For the 90 percent risk significance level the crop mix became more diversified on the Memphis and Loring soils. Crops produced on the Loring soil were 274 acres of continuous corn, 134 acres of soybeans, 112 acres of continuous winter wheat grain and straw, and 152 acres of soybean-wheat, double-crop grain and straw. For the Loring soil, the optimal crop mix changed from all continuous corn to a combination of 913 acres of continuous corn and 287 acres of continuous wheat grain and straw.

Risk Efficient Farm Plans With Biomass Crops

Spot Price Contract (SPOT) Scenario

Optimal farm plan results when biomass crops are a production option using biomass prices based on a yearly spot-market price are presented in Appendix A, Table 7. Under the SPOT scenario, biomass prices averaged $29.44/dt (standard deviation of $9.34/dt) for wheat straw, $29.44/dt (standard deviation of $15.50/dt) for corn stover, and $34.77/dt (standard deviation of $7.43/dt) for switchgrass. When biomass crops were priced annually based on the energy equivalent price, the production of biomass crops did not enter into the optimal crop mix for any risk significance level except the most risk averse 90 percent level. For this level of risk aversion, only 36 acres on switchgrass was planted on the poorest quality Collins soil. No other biomass crops were planted on the rest of the farm. Thus, an average of only 324 dt of biomass would be supplied by the representative farm under the SPOT contract scenario. In general, the net revenues from biomass crops were not high enough under SPOT contract prices to induce biomass production Results indicate that a contract price above the energy equivalent price would be needed to encourage biomass production on the representative farm.

Standard Marketing Contract (STANDARD) Scenario

Under the STANDARD contract, a portion of the price risk on expected production from producing biomass crops is shifted from the farmer to the processor. For a risk neutral decision maker, a STANDARD contract price of $40/dt or more on 50 percent of expected yield was needed to induce biomass production on the representative farm (Appendix B, Figure 1) An average of 1,044 dt of corn stover was produced for contract prices between $40/dt and $55/dt. The 365 acres of corn grain and stover was planted on the higher quality Memphis (152 acres) and Loring (213 acres) soils. No switchgrass was planted for contract prices between $30/dt and $60/dt. Thus, a contract price of at least $65/dt was needed to induce the planting of switchgrass when no planting incentive was offered. Switchgrass was first planted on the poorer quality Collins soil at the $65/dt contract price, and was planted on both the Collins and Memphis soils for contract prices greater than $65/dt. Expected stover and stwitchgrass biomass production of 8,919 dt was maximized at a contract price of $75/dt. A higher price of $80/dt did not induce additional biomass production. At the $75/dt contract price, all of the 528 acres of poorer quality Collins soil were planted to switchgrass and 229 acres of the 672 acres of the Memphis soil; were planted

to switchgrass. No switchgrass was planted on the Loring soil. Corn stover production was constrained by available time to harvest in the model.

As indicated in Appendix B, Figure 1, as more of the farm area was planted into biomass crops at the higher contract prices, the greater the annual variation in biomass supplied to the processing plant. Thus, for a processor, there may be a relationship between the annual variation in biomass material supplied and the cost of biomass materials. A higher contract price may induce more production on an individual farm. This could result in fewer farms in a more concentrated geographic area being needed to supply the plant. The biomass materials transportation cost may be lower but biomass storage costs incurred to ensure a steady supply of feedstock to the plant may be higher with the increased variability of annual biomass production with higher contract prices.

The planting incentive induced switchgrass production at a lower contract price under the 50 percent of expected yield STANDARD contract (Appendix B, Figure 1). At the $60/dt price with the planting incentive, 5,119 dt of switchgrass would be produced for the processing facility. No switchgrass was produced at the $60/dt contract price when there was no planting incentive. Expected biomass production was maximized at a contract price of $75/dt with 8,963 tons being delivered to the processor. Results suggest that a planting incentive may be effective at inducing biomass production at a lower price and may be a way for the processor to reduce average per ton cost of material at the plant gate.

The amount of biomass supplied by the representative farm was higher when 75 percent of expected production was priced at the contract price and 25 percent was priced at the spot market price under the STANDARD contract (Appendix B, Figure 2). With the planting incentive, switchgrass was planted at a contract price of $50/dt and had expected production of 562 dt on 58 acres of the Collins soil. Biomass production was maximized at a contract price of $75/dy with 15,583 dt of material being delivered to the processing plant. The higher $80/dt contract price did not induce additional production of biomass on the representative farm. Furthermore, contracting 100% of expected yield did not result in addition production of biomass on the representative farm (figure not shown).

The planting of switchgrass provided risk management benefits under the STANDARD contract for a risk averse decision maker (Appendix B, Figure 3 and Appendix B, Figure 4). For the 90 percent risk significance level (i.e., the most risk averse decision maker), switchgrass was planted at lower STANDARD contract prices and more biomass tonnage was supplied to the processor than was produced under the assumption of a risk neutral decision maker For example, 3,640 dt of biomass were produced for a contract price of $40/dt on 50 percent of expected yield with the planting incentive under the assumption of risk aversion. By comparison, no biomass production was induced with a contract price of $40/dt on 50 percent of expected yield under the assumption of risk neutrality (Appendix B, Figure 3).

Acreage Contract (ACREAGE) Scenario

With the ACREAGE contract, all of the biomass price risk is shifted from the farmer to the processor. The producer still incurs all of the yield production risk. Assuming risk neutrality and no planting incentive, an ACREAGE contract price of at least $50/dt was needed to induce the planting of switchgrass (Appendix B, Figure 5). By comparison, a contract price of at least $65/dt with the STANDARD contract price on 50 percent of expected yield was needed to induce switchgrass production (Appendix B, Figure 1). Thus, at the $50/dt ACREAGE contract price, the average biomass tonnage delivered to the processing plant was 4,129 dt compared with an average biomass tonnage of 1,044 dt being produced STANDARD contract price on 50 percent of expected yield. Maximum biomass production was achieved at an ACREAGE contract price of $75/dt with expected production of 15,583 dt per year.

For the risk neutral decision maker, the planting incentive with the ACREAGE contract did not lower the minimum contract price of $50/dt at which switchgrass was planted on the representative farm (Appendix B, Figure 5). Nevertheless, the planting incentive increased the amount of switchgrass produced at the $50/dt contract price—2,607 dt without the incentive compared with 6,115 dt with the incentive. The maximum amount of biomass was produced at a contract price of $65/dt. Additional biomass production did not occur with higher ACREAGE contract prices. Expected production at the

$60/dt contract price was 15,648/dt with all of the tonnage coming from switchgrass. With the ACREAGE contract and the planting incentive, switchgrass was the only biomass crop produced with contract prices above $60/dt.

In general, the ACREAGE contract did not induce as much biomass production by risk averse decision makers at higher contract prices when compared with the biomass production under the STANDARD contract (Appendix B, Figure 6). As an example, at the $70/dt contract price, 8,645 dt of biomass was produced under the ACREAGE contract assumption with no planting incentive. By comparison, 10,845 dt of biomass was produced under the STANDARD contract price on 50 percent of expected yield. The ACREAGE contract provided protection against price risk but did not provide any protection against yield risk. Thus, the variability of switchgrass yields was sufficiently high to limit the biomass supplied under the ACREAGE contract relative to the STANDARD contract for a risk averse decision maker (Appendix A, Tables 2, 3, and 4).

Gross Revenue Contract (REVENUE) Scenario

Under the assumption of risk neutrality, the same amount of biomass was supplied by the representative farm under the REVENUE contract as under the ACREAGE contract (Appendix B, Figure 5 and Figure 7). Expected biomass crop net revenues were identical for both contract structures. However, because the REVENUE contract reduced the biomass net revenue variability relative to the ACREAGE contract, the REVENUE contract was risk efficient relative to the REVENUE contract. In addition, because of the greater price and yield protection offered with the REVENUE contract, swtichgrass production was generally induced at lower contract prices than with the STANDARD contract (Appendix B, Figure 8). For the 90 percent risk significance level (i.e., the most risk averse decision maker), switchgrass was planted at lower REVENUE contract prices and more biomass tonnage was supplied to the processor than was produced under the assumption of a risk neutral decision maker. For example, 6,032 dt of biomass were produced for a contract price of $40/dt with the planting incentive under the assumption of risk aversion compared to no biomass production under the assumption of risk neutrality (Appendix B, Figure 7). Assuming risk aversion for the 90 percent significance level, the amount of biomass production induced under REVENUE contract was about twice as much as was produced under the STANDARD contract.

Conclusions

This study developed a farm-level model to evaluate the ability and willingness of farmers to provide biomass feedstocks for a northwest Tennessee 2,400-acre grain farm. A quadratic programming model incorporating farm labor and land quality constraints, biomass yield variability, crop and energy price variability, alternative contractual arrangements, and risk aversion was developed for the analysis. The four potential types of contracts analyzed in this study that could be used to encourage biomass production offer different levels of biomass price, yield, and production cost risk sharing between the representative farm and the processor. The spot market contract (SPOT) based on the yearly energy equivalent value with gasoline assumes that all of the output price, yield, and production cost risk from biomass production is incurred by the farmer. With the standard marketing contract (STANDARD), a portion of the price risk on expected production is shifted from the producer to the processor. All of the price risk is shifted from the farmer to the processor with an acreage contract (ACREAGE) that pays a specified price for all production produced on the contracted acreage. However, the ACREAGE contract does not provide any protection against yield risk and production cost risk. On the other hand, the gross revenue contract (REVENUE) provides the greatest potential risk benefits to the farmer because all of the biomass price and yield risk is assumed by the processor. In addition, a contract provision for switchgrass that provides a financial incentive to reduce production cost risk by covering the materials cost of establishing the switchgrass stand was also modeled.

The important findings from this research were as follows. First, under the spot market price contract scenario, the net revenues from biomass crops were not high enough induce biomass production on the

representative farm. Results indicate that a price above the energy equivalent price would be needed to encourage biomass production on the representative farm. Biomass prices under the SPOT contract scenario averaged $29.44/dt (standard deviation of $9.34/dt) for wheat straw, $29.44/dt (standard deviation of $15.50/dt) for corn stover, and $34.77/dt (standard deviation of $7.43/dt) for switchgrass.

Second, the ACREAGE and REVENUE contracts were more effective at inducing maximum farm biomass production at lower contract prices than the STANDARD contract for a risk neutral decision maker (Figure 1 on page iv). Under the assumption of risk neutrality, the same amount of biomass was supplied by the representative farm under the REVENUE contract as under the ACREAGE contract. Expected biomass crop net revenues were identical for both contract structures. Most of the biomass supplied by the representative farm under the STANDARD, ACREAGE, and REVENUE contracts was from switchgrass. In addition, some corn stover was produced but no wheat straw was supplied for ethanol production by the representative farm.

Third, because the REVENUE contract reduced biomass crop net revenue variability relative to the ACREAGE contract, the REVENUE contract provided more risk benefits to the representative farm under the assumption of risk aversion (Figure 2 on page v). In addition, because of the greater price and yield protection offered with the REVENUE contract, swtichgrass production was generally induced at lower contract prices than with the STANDARD contract. Fourth, results of this study suggest that a planting incentive to offset part of the cost of establishing switchgrass may be effective at inducing biomass larger production at lower contract prices. The incentive may provide a method for the processor to reduce average per ton cost of material at the plant gate for perennial biomass crops such as switchgrass.

Finally, as more of the farm crop area was planted into biomass crop at higher contract prices, the greater the annual variation in biomass supplied to the processing plant. Thus, for a processor, there may be a relationship between the annual variation in biomass material supplied and the cost of biomass materials. A higher contract price may induce more production on an individual farm. This could result in fewer farms in a more concentrated geographic area being needed to supply the plant. The biomass materials transportation cost may be lower but the biomass storage cost incurred to ensure a steady supply of feedstock to the plant may be higher with the increased variability of annual biomass production with higher contract prices.

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Appendix A: Tables

Table 1. Summary of Crop Management Practices for the West Tennessee Farm[a]

Crop or Crop Rotation	N lb/acre	P_2O_5 Lb/acre	K_2O lb/acre	Planting Date	Harvest Date
Continuous Corn Grain	170	70	70	1-May	1-Oct
Continuous Soybean Oilseed	0	20	40	1-Jun	1-Nov
Continuous Wheat Grain	80	40	20	1-Nov	15-Jun
Soybean-Wheat Double Crop					
Soybean Oilseed	0	0	0	15-Jun	1-Nov
Wheat Grain	40	60	60	15-Nov	1-Jun
Soybean-Corn Rotation					
Soybean Oilseed	0	0	0	1-Jun	1-Nov
Corn Grain	130[c]	70	70	1-May	1-Oct
Soybean-Corn Rotation					
Soybean Oilseed	0	20	40	1-Jun	1-Nov
Corn Grain	130[c]	70	70	1-May	1-Oct
Corn Grain	170	70	70	1-May	1-Oct
Continuous Corn Grain & Stover	170	70	70	1-May	1-Oct
Continuous Wheat Grain & Straw for Sale	80	40	20	1-Nov	15-Jun
Continuous Wheat Grain & Straw for Ethanol	80	40	20	1-Nov	15-Jun
Soybean-Wheat Double Crop					
Soybeans	0	0	0	15-Jun	1-Nov
Wheat Straw for Sale	40[c]	60	60	15-Nov	1-Jun
Soybean-Wheat Double Crop					
Soybean Oilseed	0	0	0	15-Jun	1-Nov
Wheat Straw for Ethanol	40[c]	60	60	15-Nov	1-Jun
Soybean-Corn Rotation					
Soybean Oilseed	0	20	40	1-Jun	1-Nov
Corn Grain & Stover for Ethanol	130[c]	70	70	1-May	1-Oct
Soybean-Corn Rotation					
Soybean Grain	0	20	40	1-Jun	1-Nov
Corn Grain & Stover for Ethanol	130[c]	70	70	1-May	1-Oct
Corn Grain & Stover for Ethanol	170	70	70	1-May	1-Oct
Switch Grass for Ethanol	60	40	80	15-May	1-Dec

A Crop production costs based on University of Tennessee Extension budgets (Gerloff, 2007a; Gerloff, 2007b; Bowling, McKinley, and Rawls, 2006).

[b]Assumes that 2 tons of lime is applied every 4 years.

[c]Assumes a 40 lb acre nitrogen fertilizer credit for crops grown after soybeans.

Table 2. Simulated No-Tillage Crop Yields for the Collins Soil Type

Crop/Rotation	Unit	Mean	Std Dev	Minimum	Maximum
Continuous Corn Grain	(bu/acre)	143	18	92	175
Continuous Soybean Oilseed	(bu/acre)	42	10	27	65
Continuous Wheat Grain	(bu/acre)	47	12	19	82
Soybean-Wheat Doublecrop					
Soybean Oilseed	(bu/acre)	44	11	19	70
Wheat Grain	(bu/acre)	37	8	13	63
Soybean-Corn Rotation					
Soybean Oilseed	(bu/acre)	42	9	27	63
Corn	(bu/acre)	139	19	94	171
Soybean-Corn-Corn Rotation					
Soybean Oilseed	(bu/acre)	41	10	26	57
Corn Grain	(bu/acre)	128	26	66	175
Continuous Corn					
Grain	(bu/acre)	143	18	92	175
Stover for Ethanol	(ton/acre)	4.59	0.55	3.06	5.59
Continuous Wheat					
Grain	(bu/acre)	47	12	19	82
Straw for Sale	(ton/acre)	2.52	0.64	1.01	4.43
Continuous Wheat					
Grain	(bu/acre)	47	12	19	82
Straw for Ethanol	(ton/acre)	2.52	0.64	1.01	4.43
Soybean-Wheat Doublecrop					
Soybean Oilseed	(bu/acre)	44	11	19	70
Wheat Grain	(bu/acre)	37	8	13	63
Straw for Sale	(ton/acre)	2.00	0.42	0.67	3.32
Soybean-Wheat Doublecrop					
Soybean Oilseed	(bu/acre)	44	11	19	70
Wheat Grain	(bu/acre)	37	8	13	63
Straw for Ethanol	(ton/acre)	2.00	0.42	0.67	3.32
Soybean-Corn Rotation					
Soybean Oilseed	(bu/acre)	42	9	27	63
Corn	(bu/acre)	139	19	94	171
Stover for Ethanol	(ton/acre)	4.45	0.59	3.01	5.46
Soybean-Corn-Corn Rotation					
Soybean Oilseed	(bu/acre)	41	10	26	57
Corn Grain	(bu/acre)	132	24	71	175
Stover for Ethanol	(ton/acre)	4.45	0.49	3.01	5.57
Switchgrass	(ton/acre)	9.69	2.29	3.22	14.53

Table 3. Simulated No-Tillage Crop Yields for the Memphis Soil Type

Crop/Rotation	Unit	Mean	Std Dev	Minimum	Maximum
Continuous Corn Grain	(bu/acre)	153	16	103	187
Continuous Soybean Oilseed	(bu/acre)	52	7	34	69
Continuous Wheat Grain	(bu/acre)	56	15	23	95
Soybean-Wheat Doublecrop					
Soybean Oilseed	(bu/acre)	53	9	26	73
Wheat Grain	(bu/acre)	40	8	13	62
Soybean-Corn Rotation					
Soybean Oilseed	(bu/acre)	52	7	34	67
Corn	149	17	103	182	
Soybean-Corn-Corn Rotation					
Soybean Oilseed	(bu/acre)	55	6	37	64
Corn Grain	(bu/acre)	143	12	103	178
Continuous Corn					
Grain	(bu/acre)	153	16	103	187
Stover for Ethanol	(ton/acre)	4.88	0.51	3.29	5.94
Continuous Wheat					
Grain	(bu/acre)	56	15	23	95
Straw for Sale	(ton/acre)	3.02	0.81	1.23	5.12
Continuous Wheat					
Grain	(bu/acre)	56	15	23	95
Straw for Ethanol	(ton/acre)	3.02	0.81	1.23	5.12
Soybean-Wheat Doublecrop					
Soybean Oilseed	(bu/acre)	53	9	26	73
Wheat Grain	(bu/acre)	40	8	13	62
Straw for Sale	(ton/acre)	2.15	0.45	0.67	3.30
Soybean-Wheat Doublecrop					
Soybean Oilseed	(bu/acre)	53	9	26	73
Wheat Grain	(bu/acre)	40	8	13	62
Straw for Ethanol	(ton/acre)	2.15	0.45	0.67	3.30
Soybean-Corn Rotation					
Soybean Oilseed	(bu/acre)	52	7	34	67
Corn	(bu/acre)	149	17	103	182
Stover for Ethanol	(ton/acre)	4.76	0.55	3.29	5.79
Soybean-Corn-Corn Rotation					
Soybean Oilseed	(bu/acre)	52	6	34	64
Corn Grain	(bu/acre)	148	12	103	178
Stover for Ethanol	(ton/acre)	4.71	0.39	3.29	5.67
Switchgrass	(ton/acre)	9.96	4.21	3.00	16.65

Table 4. Simulated No-Tillage Crop Yields for the Loring Soil Type

Crop/Rotation	Unit	Mean	Std Dev	Minimum	Maximum
Continuous Corn Grain	(bu/acre)	151	15	103	177
Continuous Soybean Oilseed	(bu/acre)	49	8	34	68
Continuous Wheat Grain	(bu/acre)	52	12	23	83
Soybean-Wheat Doublecrop					
Soybean Oilseed	(bu/acre)	51	9	26	70
Wheat Grain	(bu/acre)	39	8	13	64
Soybean-Corn Rotation					
Soybean Oilseed	(bu/acre)	49	7	34	67
Corn	(bu/acre	148	16	103	174
Soybean-Corn-Corn Rotation					
Soybean Oilseed	(bu/acre)	49	8	34	62
Corn Grain	(bu/acre)	145	13	103	177
Continuous Corn					
Grain	(bu/acre)	151	15	103	177
Stover for Ethanol	(ton/acre)	4.84	0.49	3.29	5.68
Continuous Wheat					
Grain	(bu/acre)	52	12	23	83
Straw for Sale	(ton/acre)	2.77	0.63	1.21	4.45
Continuous Wheat					
Grain	(bu/acre)	52	12	23	83
Straw for Ethanol	(ton/acre)	2.77	0.63	1.21	4.45
Soybean-Wheat Doublecrop					
Soybean Oilseed	(bu/acre)	41	15	12	71
Wheat Grain	(bu/acre)	74	9	51	95
Straw for Sale	(ton/acre)	3.99	0.47	2.74	5.13
Soybean-Wheat Doublecrop					
Soybean Oilseed	(bu/acre)	41	15	12	71
Wheat Grain	(bu/acre)	74	9	51	95
Straw for Ethanol	(ton/acre)	3.99	0.47	2.74	5.13
Soybean-Corn Rotation					
Soybean Oilseed	(bu/acre)	49	7	34	67
Corn	(bu/acre)	148	16	103	174
Stover for Ethanol	(ton/acre)	4.71	0.52	3.29	5.54
Soybean-Corn-Corn Rotation					
Soybean Oilseed	(bu/acre)	49	8	34	62
Corn Grain	(bu/acre)	145	13	103	177
Stover for Ethanol	(ton/acre)	4.67	0.40	3.29	5.67
Switchgrass	(ton/acre)	9.12	3.87	3.00	15.58

Table 5. Summary Statistics for the Simulated Commodity Prices for Estimating
Net Revenues for the West Tennessee Quadratic Programming Model

Commodity	Unit	Mean	Standard Deviation	Minimum	Maximum
Corn Grain[a]	$/bu	2.72	0.33	2.14	3.90
Soybean Oilseed	$/bu	4.64	2.17	1.36	8.45
Wheat Grain	$/bu	3.89	0.46	2.60	5.21
Switchgrass	$/ton	34.77	7.43	25.59	56.11
Corn Stover	$/ton	29.44	15.50	20.28	35.78
Wheat Straw					
Sale	$/ton	183.12	42.69	108.75	285.65
Ethanol	$/ton	27.68	9.29	20.00	44.00
Nitrogen Fertilizer	$/lb	0.40	0.06	0.31	0.54
Diesel Fuel	$/gallon	1.83	0.77	1.06	5.41

Table 6. Risk Efficient Net Revenues, Crop Area, and Labor Usage without Biomass Crop Enterprises (Base Scenario)

Item	Risk Significance Level (Percent)				
	50	60	70	80	90
Whole-Farm Net Revenue	--------------------------------$--------------------------------				
Mean	472,175	472,175	472,175	472,175	472,440
Standard Deviation	152,926	152,926	152,926	152,926	141,091
Certainty Equivalent	472,175	437,096	390,323	343,550	277,878
Collins Soils Crops	-----------------------------Acres-----------------------------				
Corn	528	528	528	528	528
Memphis Soils Crops	-----------------------------Acres-----------------------------				
Corn	100	100	100	100	274
Soybean	0	0	0	0	134
Wheat grain & straw	420	420	420	420	112
Soybean-wheat grain & straw	152	152	152	152	152
Loring Soils Crops	-----------------------------Acres-----------------------------				
Corn	1,200	1,200	1,200	1,200	913
Wheat grain & straw	0	0	0	0	287
Labor Use	-----------------------------Hours-----------------------------				
Jan-Feb	13	13	13	13	13
Mar-Apr	50	50	50	50	74
May Jun	1,375	1,375	1,375	1,375	1,344
Jul-Aug	2	2	2	2	2
Sep-Oct	679	679	679	679	682
Nov-Dec	80	80	80	80	77
Total	2,199	2,199	2,199	2,199	2,192
Hired Labor	-----------------------------Hours-----------------------------				
May-June	778	778	778	778	743
Sep-Oct	105	105	105	105	107
Total	883	883	883	883	851

Table 7. Risk Efficient Net Revenues, Crop Area, and Labor Usage Assuming Spot Market Biomass Contract Pricing with the User Facility

| Item | Risk Significance Level (Percent) | | | | |
	50	60	70	80	90
Whole-Farm Net Revenue	----------------------------------$----------------------------------				
Mean	472,175	472,175	472,175	472,175	449,666
Standard Deviation	152,926	152,926	152,926	152,926	139,154
Certaint Equivelant	472,175	437,096	390,323	343,550	277,987
Collins Soils Crops	------------------------------Acres------------------------------				
Corn	528	528	528	528	492
Switchgrass	0	0	0	0	36
Memphis Soils Crops	------------------------------Acres------------------------------				
Corn	100	100	100	100	282
Soybean	0	0	0	0	125
Wheat grain & straw	420	420	420	420	113
Soybean-wheat grain & straw	152	152	152	152	152
Loring Soils Crops	------------------------------Acres------------------------------				
Corn	1,200	1,200	1,200	1,200	917
Wheat grain & straw	0	0	0	0	283
Labor Use	------------------------------Hours------------------------------				
Jan-Feb	13	13	13	13	13
Mar-Apr	50	50	50	50	72
May Jun	1,375	1,375	1,375	1,375	1,340
Jul-Aug	2	2	2	2	2
Sep-Oct	679	679	679	679	671
Nov-Dec	80	80	80	80	130
Total	2,199	2,199	2,199	2,199	2,227
Hired Labor	------------------------------Hours------------------------------				
May-June	778	778	778	778	739
Sep-Oct	105	105	105	105	95
Total	883	883	883	883	834

Appendix B: Figures
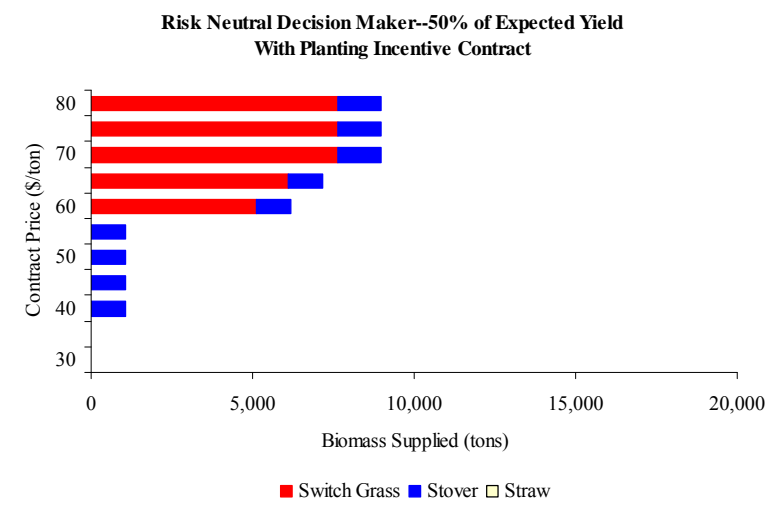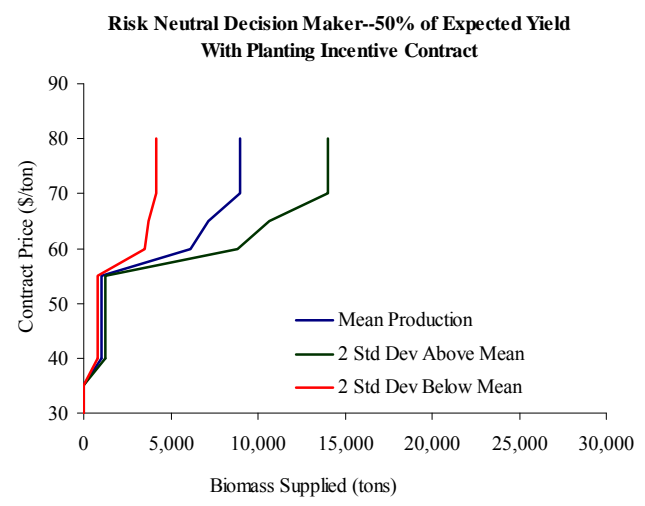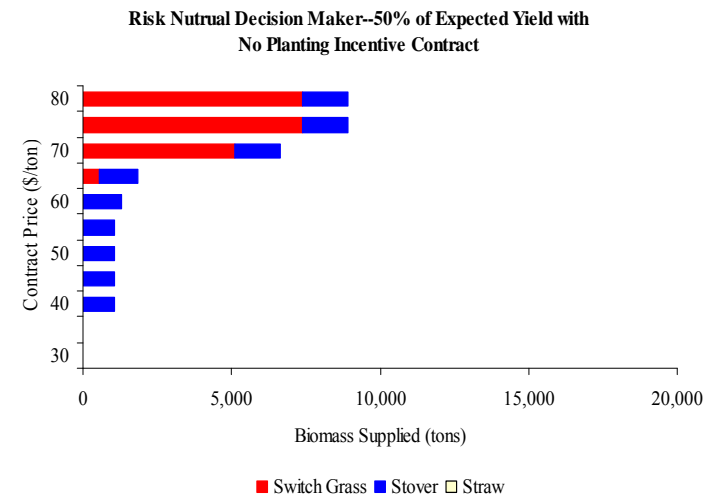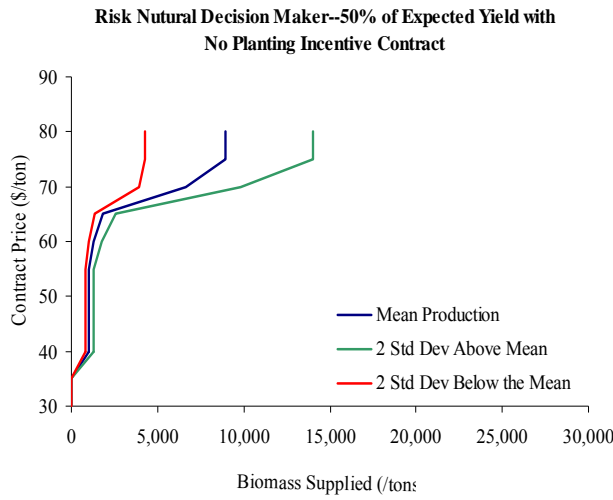
Figure 1. Risk Neutral (50 Percent Risk Significance) Farm Biomass Supply Curves for the Standard Marketing Contract at 50% of Expected with and Without a Planting Incentive for Contract Prices Ranging From $30/Dry Ton to $80/Dry Ton

**Risk Neutral Decision Maker--75% of Expected Yield with No Planting Incentive Contract**

Risk Neutral Decision Maker--75% of Expected Yield with No Planting Incentive Contract

Risk Neutral Decision Maker--75% of Expected Yield With Planting Incentive Contract

Risk Neutral Decision Maker--75% of Expected Yield With Planting Incentive Contract
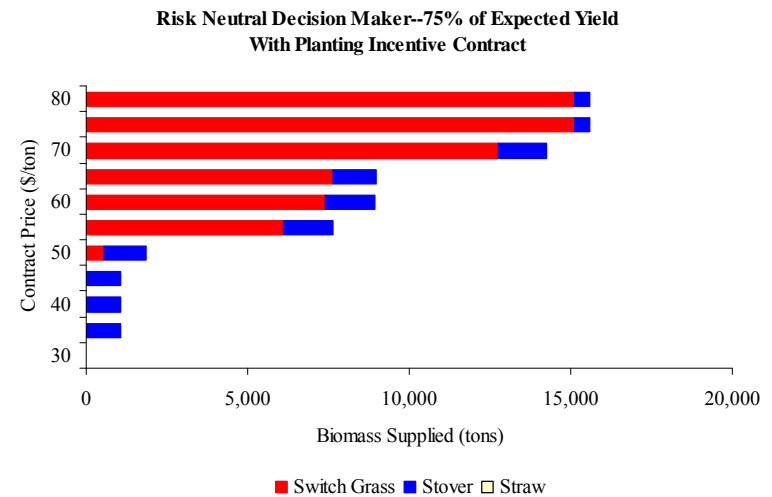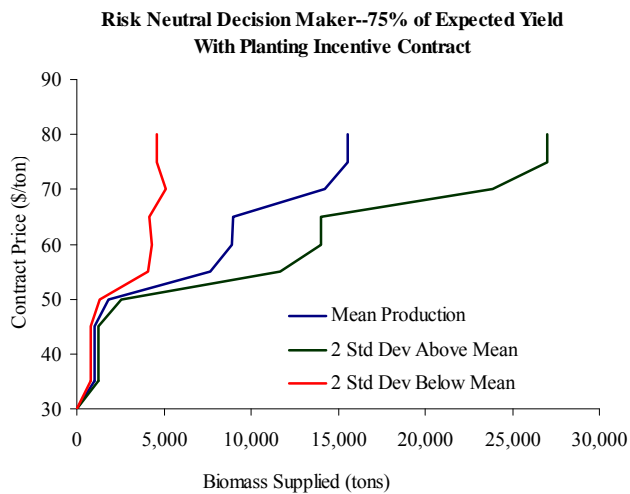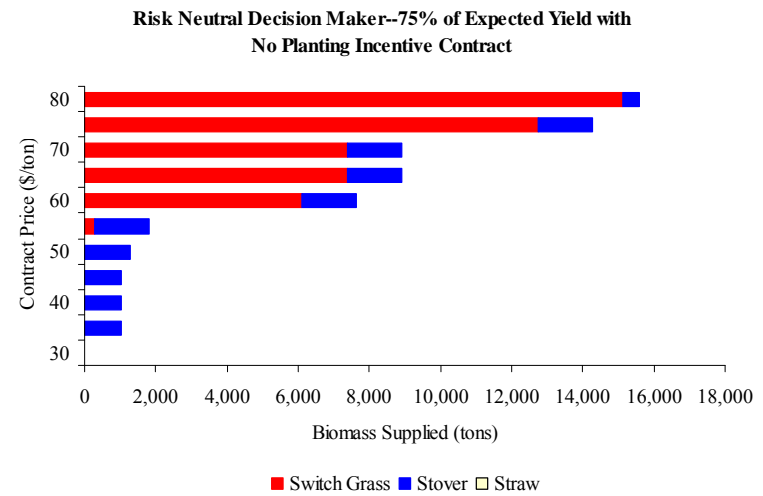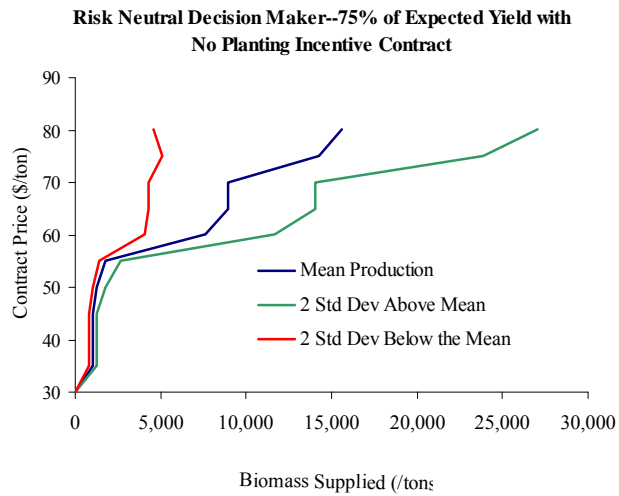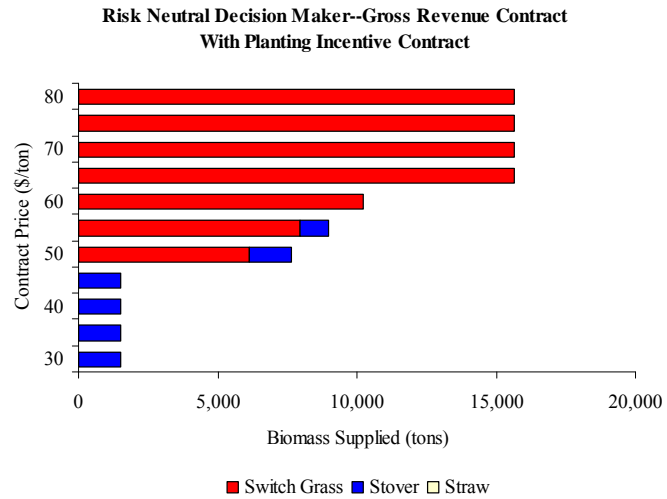
Figure 2. Risk Neutral (50 Percent Risk Significance) Farm Biomass Supply Curves for the Standard Marketing Contract at 75% of Expected With and Without a Planting Incentive for Contract Prices Ranging From $30/Dry Ton to $80/Dry Ton
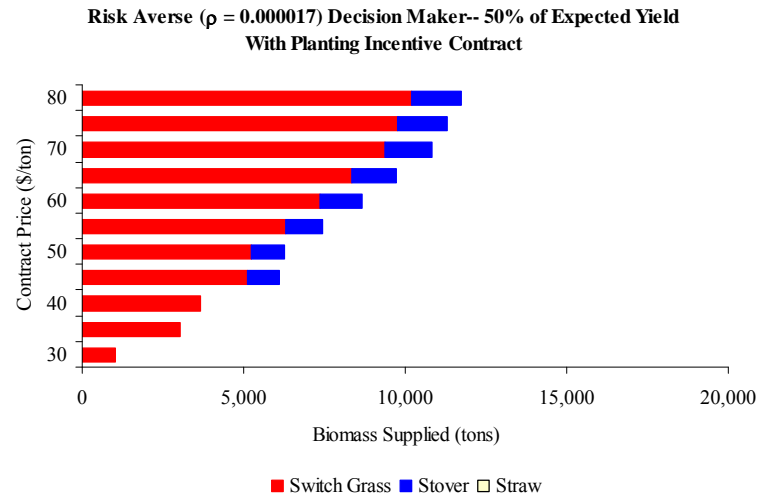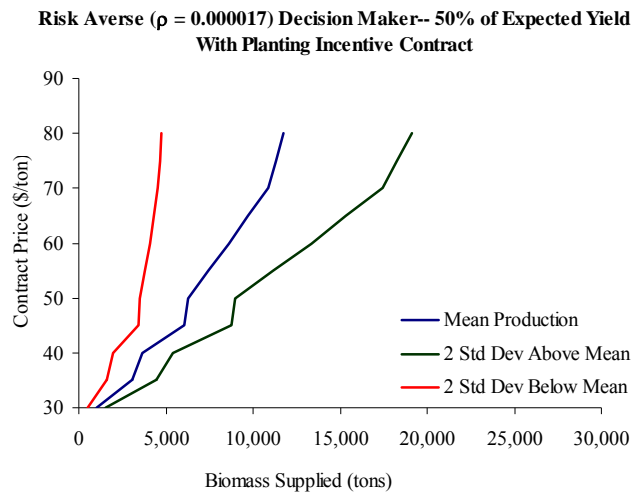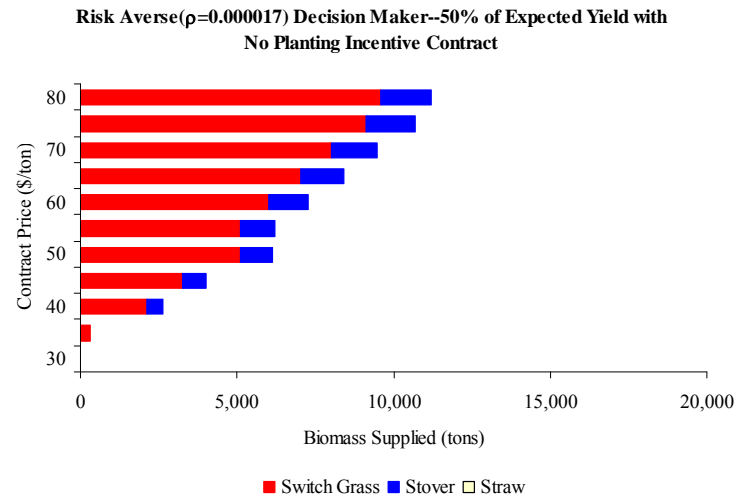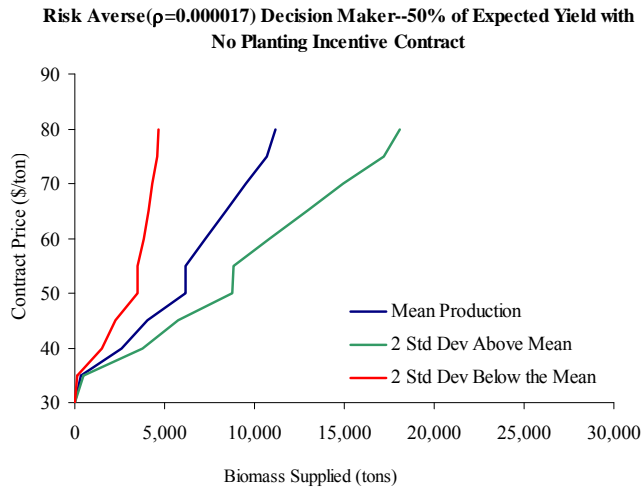
Figure 3. Risk Averse (90 Percent Risk Significance) Farm Biomass Supply Curves for the Standard Marketing Contract at 50% of Expected With and Without a Planting Incentive for Contract Prices Ranging From $30/Dry Ton to $80/Dry Ton
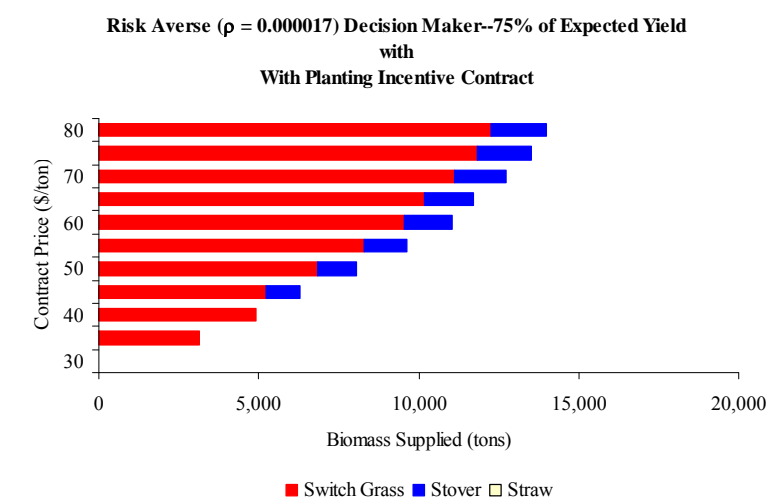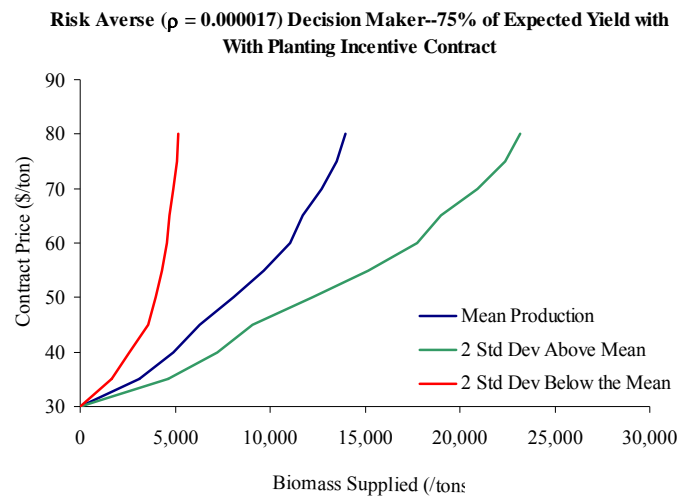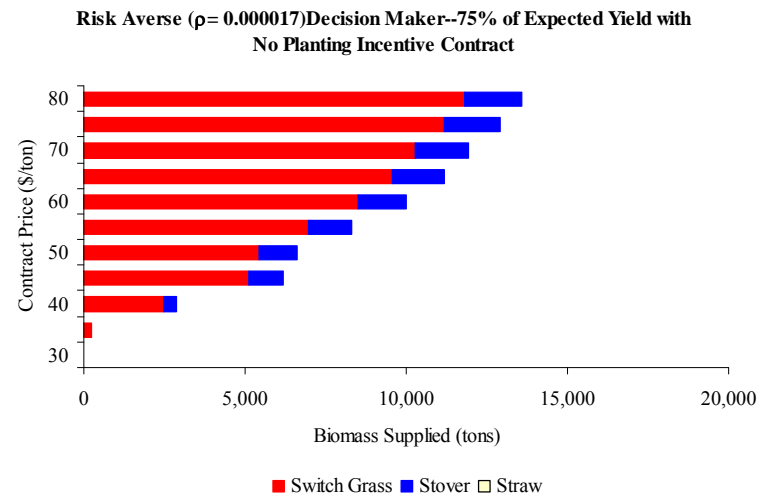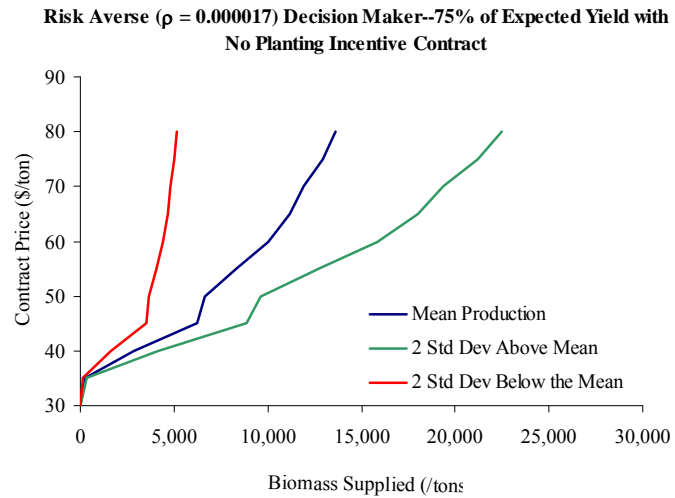
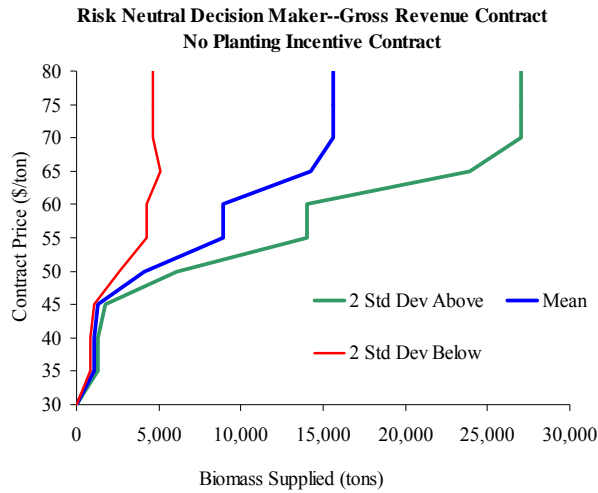Figure 4. Risk Averse (90 Percent Risk Significance) Farm Biomass Supply Curves for the Standard Marketing Contract at 75% of Expected With and Without a Planting Incentive for Contract Prices Ranging From $30/Dry Ton to $80/Dry Ton
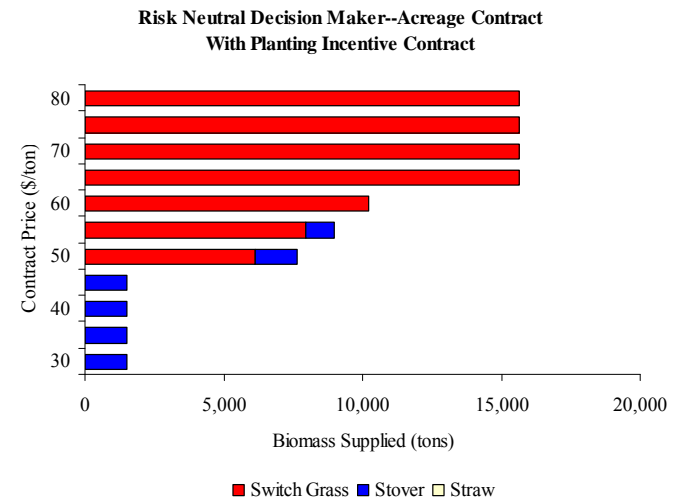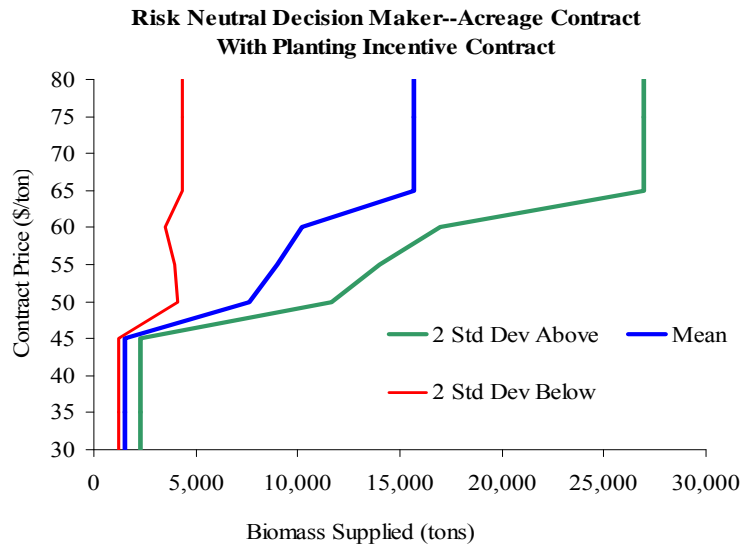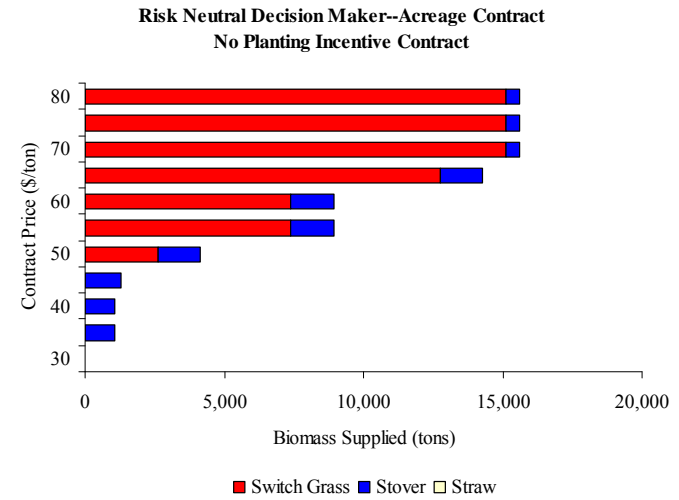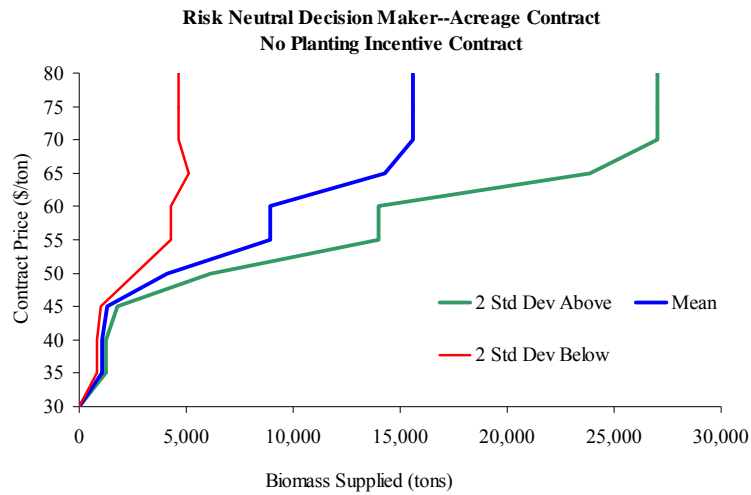
Figure 5. Risk Neutral (50 Percent Risk Significance) Farm Biomass Supply Curves for the Acreage Contract With and Without a Planting Incentive for Contract Prices Ranging From $30/Dry Ton to $80/Dry Ton
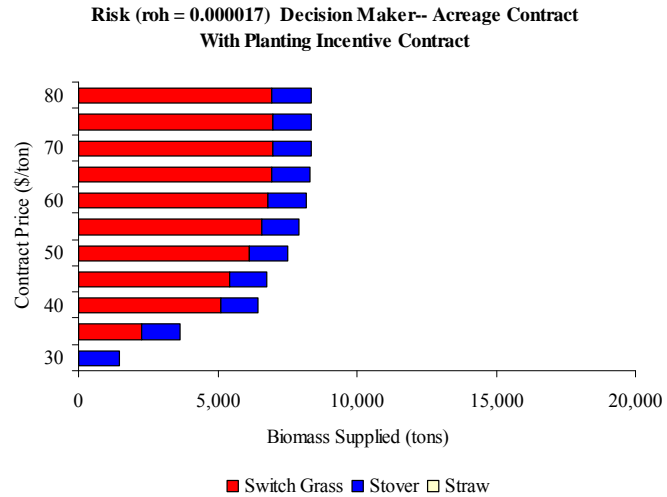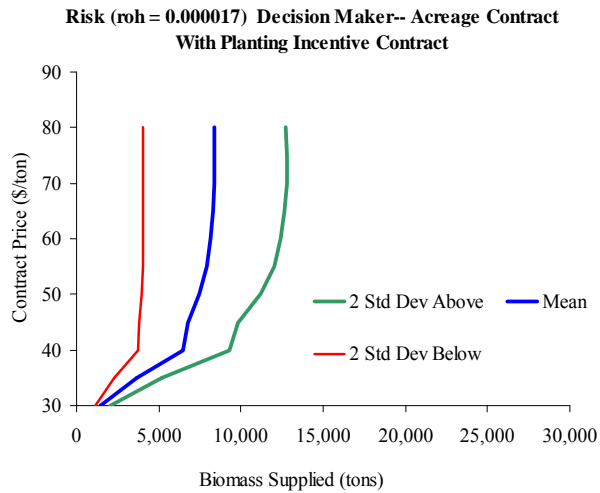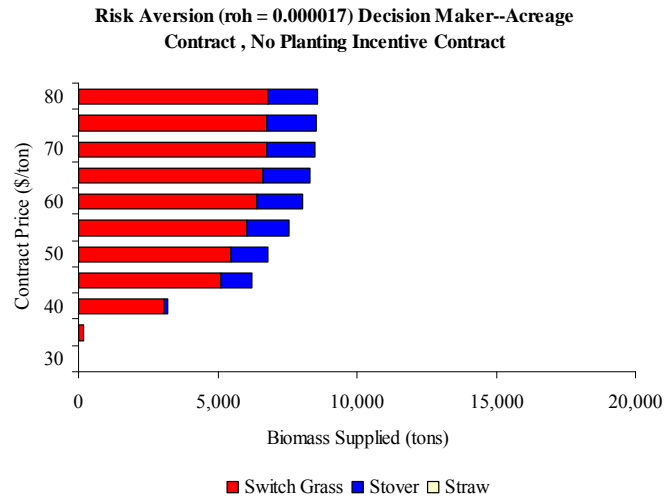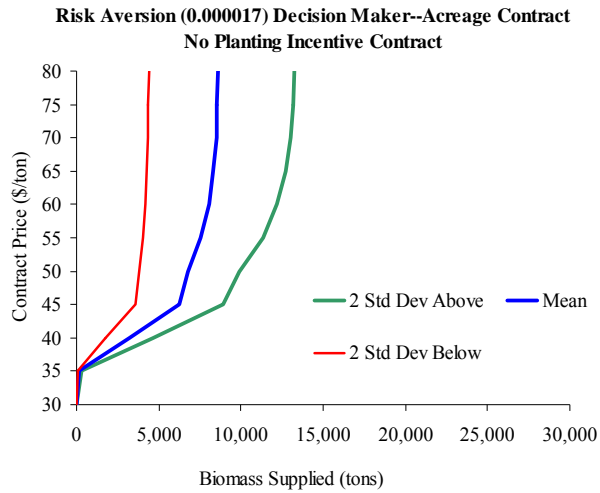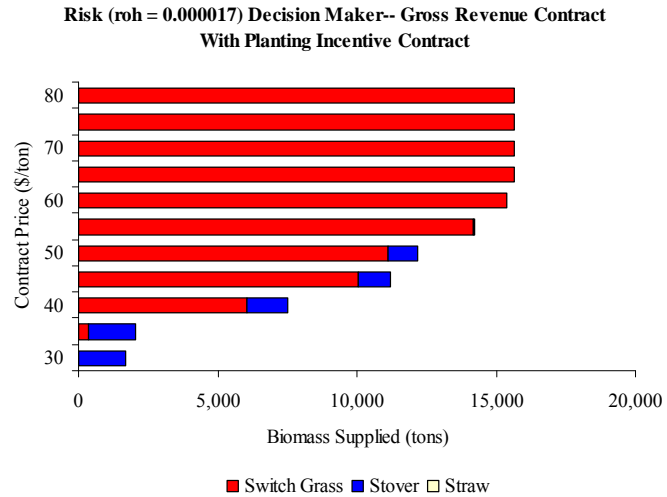
Figure 6. Risk Averse (90 Percent Risk Significance) Farm Biomass Supply Curves for the Acreage Contract With and Without a Planting Incentive for Contract Prices Ranging From $30/Dry Ton to $80/Dry Ton
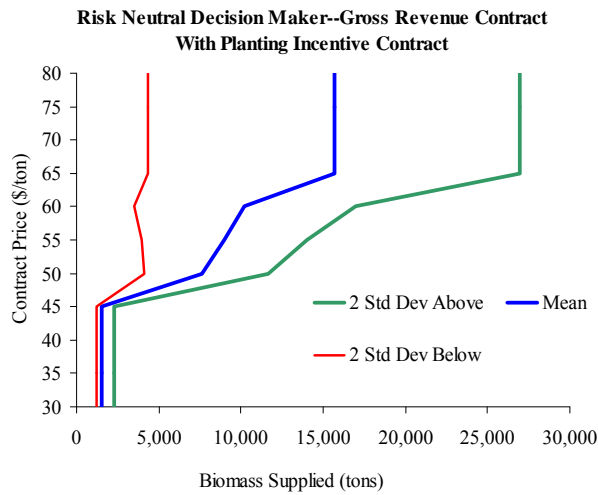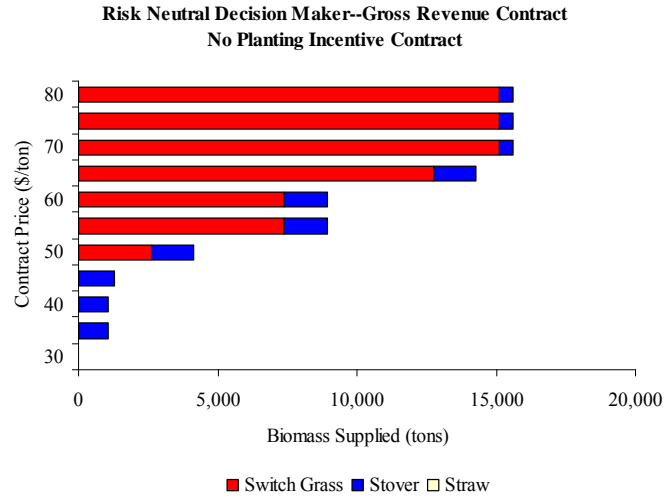
Figure 7. Risk Neutral (50 Percent Risk Significance) Farm Biomass Supply Curves for the Gross Revenue Contract With and Without a Planting Incentive for Contract Prices Ranging From $30/Dry Ton to $80/Dry Ton
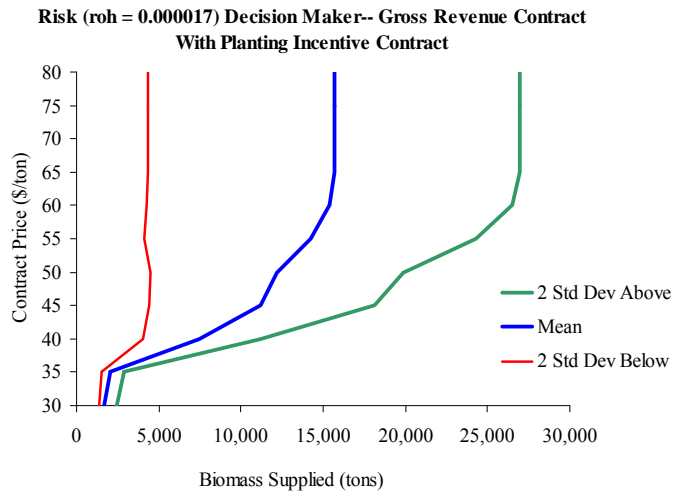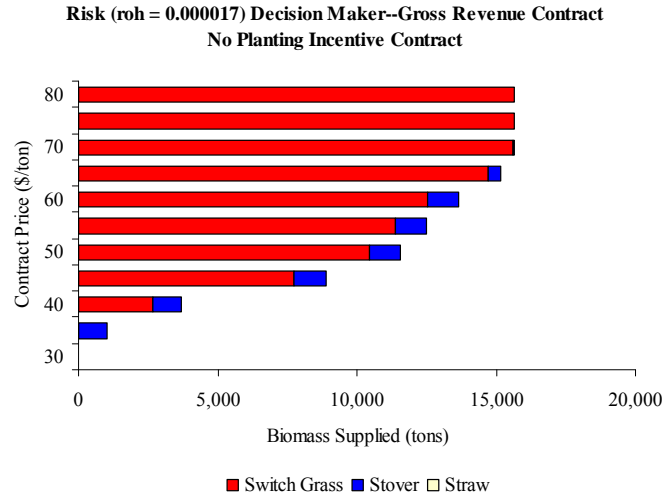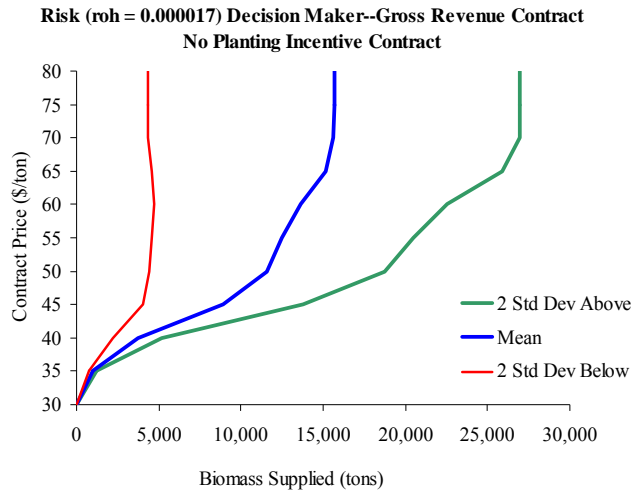
Figure 8. Risk Averse (90 Percent Risk Significance) Farm Biomass Supply Curves for the Gross Revenue Contract With and Without a Planting Incentive for Contract Prices Ranging From $30/Dry Ton to $80/Dry Ton