The Viability of Harvesting Corn Cobs and Stover for Biofuel Production in North Dakota

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Abstract

This study examines the impact of stochastic harvest field time, corn cob and stover harvest technologies, increases in farm size, and alternative tillage practices on profit maximizing potential of corn cob and stover collection in North Dakota. Using three mathematical programming models, we analyze farmers' harvest activities under 1) corn grain only harvest option, 2) simultaneous corn grain and cob harvest "one-pass" option 3) separate corn grain and stover harvest "two-pass" option. Under the first corn grain only option, farmers are able to complete harvesting corn grain and achieve maximum net income in a fairly short amount of time with existing combine technology. However, under the simultaneous corn grain and cob one-pass harvest option, our findings indicate that farmers generate lower net income as compared to the net income of corn grain only harvest option. This is due to the slowdown in combine harvest capacity as a consequence of attaching cob harvester to the back of combine. Under the third option of a two-pass harvest system, time allocation is the main challenge and our evidence shows that with limited harvest field time available, farmers find it optimal to allocate most of their time harvesting grain, and then proceed to bale stover if time permits at the end of harvest season. As farm size increases, farmers are especially challenged in finding time to harvest both corn grain and cobs/stover. We show that a small decrease in corn yield due to changes in tillage practice can result in a large decline in the net profit of harvesting corn grain and cobs/stover.

1 Introduction

Following gasoline shortages in the 1970's, interest in biofuels was primarily motivated by rising crude oil prices. This interest waned following oil price declines in the mid 80's. Today, interest in biofuels has rebounded, especially cellulosic biofuels. In addition to rising oil prices, rural development opportunities (Leistritz and Nancy, 2008), risks associated with oil exploration in the Gulf of Mexico, political instability in the Middle East, and climate change are additional motivating considerations. Growing evidence suggests that combustion of fossil fuels which emit large amounts of greenhouse gases (GHG), are a causal factor behind climate change (IPCC, 2007). McCarl et al. (2009) showed that cellulosic biofuel has higher GHG offset rates than grain-based biofuel. Hence, comparatively more GHG can be reduced through the use of cellulosic feedstock such as corn stover comprised of stalk, leaves, husks and cobs than corn grain to produce biofuel. However, greater reliance on corn stovers as a bioenergy feedstock poses a logistical challenge for farmers who face limited fall harvest field time. Harvest in fall 2009 was especially difficult in the northern plains as cool temperatures and wet conditions resulted in sizeable acreage that had to be left unharvest. About 68.7 million bushels of corn in North Dakota were reported to be left unharvest in 2009 (O'Brien, 2010).

Following passage of Renewable Fuel Standard (RFS) and the Energy Independence and Security Act of 2007 (EISA), the U.S. ethanol demand has steadily increased. Most domestic ethanol production utilizes corn grain as feedstock. Rising corn prices are encouraging current and potential ethanol producers to seek alternative feedstocks, especially cellulosic sources. EISA defines three classes of biofuels, conventional, advanced, and cellulosic. These classes are differentiated based on potential reduction of GHG emissions of 20, 50, and 60 percent respectively. Because of its potential in reducing GHG emissions, corn-cob-based ethanol would be qualified as cellulosic biofuel per the federally mandated renewable fuels standard. By 2022, cellulosic ethanol production of 21 billion gallons per year will be required, creating a niche market opportunity. Existing biofuel producers are striving to develop cellulosic biofuels that qualify under EISA.

Collecting corn cobs can be a challenge while trying to get the grain harvest done on time because of the limitation in available harvest field days. In addition, corn producers do not have sufficient information to evaluate the economic investment returns from producing corn cobs. The goal of this study is to investigate the economics of producing not only corn cobs but stover in North Dakota. Specifically, our purpose is three folds: i) to estimate on-farm costs of harvesting corn cobs and stover, ii) to assess the viability of farmers' investment in corn cob and stover harvest business utilizing optimization and simulation models under different harvest options, and 3) to analyze economic tradeoffs between corn grain and cobs/stover harvest activities given limited availability of harvest field time. In addition, the impact of increases in farm size and tillage practice on net farm revenue will be examined. Results from this study will contribute to the growing literature on the economics of producing alternative feedstock in the U.S.

2 Related Literature

Many studies (Sokhansanj and Turhollow 2002; Gallagher et al. 2003; Perlack and Turhollow 2003, Petrolia 2008, Turhollow and Sokhansanj 2007 and Gustafson et al. 2011) have examined the economics of corn stover supply for biofuel production. While these studies have focused on estimating costs of harvesting corn stover as whole, only a few studies have particularly given emphasis on examining costs of supplying corn cobs as a potential feedstock using up-to-date harvesting technologies. Chippewa Valley Ethanol Company (CVEC, 2009) has published a feasibility report on the use of corn cobs as a sustainable source of biomass for providing thermal energy for its corn grain ethanol process. The company utilized two different cob harvest systems to demonstrate cob harvesting on 3,200 acres of land. The cost of harvesting and delivering corn cob to CVEC was evaluated to be at $33 per acre or $66 per ton. The CVEC's report did not provide details on how cob harvest costs were computed. Zych (2008) estimated potential U.S. corn cob production and reviewed logistical issues associated with collection and storage of corn cobs. However, no cost estimates for cobs were provided in his study.

The aforementioned studies did not take into account the viability and profitability of farmer investment in cob and stover harvest business. Using stochastic linear programming model, Bouzaher and Offutt (1992) investigated the feasibility and profitability of farm residue collection. In their model, they considered the sensitivity of grain and residue collection to the availability of days suitable for field work at harvest time. In addition, they considered the three harvesting alternatives: own baling, custom baling and simultaneous cob collection and grain harvest. Overall, they found that the custom baling alternative yielded higher net returns than the other two alternatives. Apland et al. (1981) employed the discrete stochastic programming model to examine the impact of production process, sequential decision making and fall field time availability on crop residue supply in mid-western U.S. grain farms. The authors showed that crop residue production would be price responsive and that the development of new harvest techniques and storage were important to the economic viability of crop residues as energy sources. Using their Farm Plan Model, Erickson and Tyner (2010) examined the economics of harvesting corn cobs for energy generation. They showed that in general harvesting corn cobs could become feasible only if the cob price reaches at about $100 per ton. The authors also showed that corn cob operation is more attractive for relatively large farms (greater than or equal to 2000 corn acres) because their per unit cob harvest costs are lower.

3 Corn Stover and Cobs Availability in North Dakota

The amount of corn stover available for collection is partially a function of residue levels needed to be maintained for soil health. Excess removal of corn residues from the agricultural fields can have negative impacts on soil productivity. Some residue must remain in the field for soil erosion control, maintenance of soil organic matter, maintenance/enhancement of soil carbon and wildlife habitat. Moreover, surface crop residues reflect light and protect soil from high temperatures and evaporative losses (Sauer et al., 1996). The maximum amount of crop residue which can be removed without affecting soil erosion depends on many site specific factors such as soil type and fertility level, slope characteristics, tillage system, climate and crops. Many studies (see Hall et al. 1993; Nelson 2002; McAloon et al. 2000; Perlack et al. 2005) have examined the impact of removing corn stover on soil health. These studies have examined the amount of corn residues needed to remain in the field in order to bring erosion below the soil loss tolerance level or maintain soil organic matter.

3.1 Estimation of Corn Stover Yield

Crop residue cover is very important for preventing water and wind erosion during winter months following harvest. Wind erosion is a serious problem in North Dakota, especially in the eastern part of the state (Cihacek et al., 1993; Van Donk et al., 2008). The amount of stover that can be removed for biofuel production can be estimated using the following equation:

$$Rstover = Grain\ Yield \times Weight \times SGR \times Removal\% \times [1\text{-}Moisture\%] \qquad (1)$$

Rstover is the quantity of removable stover in dry ton per acre. Grain yield is the weighted average yield of grain crop in bushels per acre. Weight is the weight of grain in short ton per bushel converted by dividing bushel weight of 56 pounds per bushel with 2,000 pounds per short ton. *SGR* is defined as a stover-to-grain ratio and it is assumed to be 1:1 based on Lal (2005). *Removal%* is the percent of stover that can be removed for biofuel production. Considering wind erosion and other factors, we assume that 35 percent of corn stover can be removed from farm fields (Hall et al., 1993). *Moisture%* is the percent of moisture content contained in stover and is assumed to be 20 percent. Grain yield data were obtained from the USDA National Agricultural Statistics Service. The yield data are based on the five-year (2005 to 2009) average data by county in North Dakota. Estimated results for corn stover availability in dry ton in North Dakota are reported in Table 3.1 by climatic region. Details of estimated yield data for corn stover (and cobs described below) by county and climatic region map are given in Appendix I & II.

3.2 Estimation of Corn Cob Yield

Corn cobs are desirable as a sustainable feedstock because they represent about 12 percent of corn stover remaining on the field, their removal has negligible impact on soil carbon and they have limited nutrient value to the soil (CVEC, 2009; Roberts, 2009). The availability of corn cobs can be estimated as,

$$Rcob = Grain\ Yield \times Weight \times CGR \times Removal\% \times [1\text{-}Moisture\%] \qquad (2)$$

where *Rcob* is the quantity of harvestable corn cobs in dry ton per acre. *CGR* is defined as a cob-to-grain ratio and it is calculated as 1:5.6 based on Wiselogel et al. (1996). Since the literature suggests that removal of corn cobs may have little impact on soil productivity, *Removal%* in equation (2) defined as percent of cobs that can be removed from farm fields each year is assumed to be one. Similar to stover, the moisture content of corn cob is assumed to be 20 percent. Estimated results for corn cob availability in dry ton are reported in Table 3.1 by North Dakota climatic region.

Table 3.1 Estimated Corn Stover and Cob Yield by North Dakota Climatic Division (2005-2009 Average)

Region	Harvested Acres (acre)	Land Area (acre)	Density (%)	Stover Availability		Cob Availability	
				(ton/acre)	(ton)	(ton/acre)	(ton)
Northwest	13,538	5,852,864	0.23	0.44	5,917	0.22	3,019
North Central	72,434	4,379,872	1.65	0.61	43,981	0.31	22,439
North East	190,637	5,451,379	3.50	0.75	143,355	0.38	73,140
West Central	36,781	5,523,571	0.67	0.61	22,467	0.31	11,463
Central	206,691	4,531,546	4.56	0.79	163,703	0.40	83,522
East Central	493,067	3,545,363	13.91	0.99	486,232	0.50	248,078
Southwest	29,792	5,114,694	0.58	0.33	9,964	0.17	5,083
South Central	92,891	5,006,605	1.86	0.57	52,689	0.29	26,882
Southeast	684,987	4,738,701	14.46	1.03	704,635	0.52	359,508
State Total	**1,820,818**	**44,144,595**	**4.60***	**0.68***	**1,632,943**	**0.35***	**833,134**

Note: Harvested acres are weighted by yield. ***** represents state average.

4 Farm Level Corn Grain, Cob and Stover Harvest Cost Estimation

4.1 Cost Estimation for Corn Grain Harvesting

Corn grains are assumed to be harvested using a 275 HP combine. Combine horse power, corn head width, life, annual hours of use, speed, field efficiency, fuel price, list price (includes corn and grain head prices) and labor costs listed in Table 4.1 were obtained from Lazarus and Smale (2010). Fuel consumption, capacity of combine, fixed and repair costs are computed based on the method and formulas illustrated in Edwards (2009). Fuel cost is obtained by multiplying fuel consumption with fuel price. Lubrication cost is assumed to be 15% of fuel cost. Variable cost is calculated by adding up repair, fuel, lubrication and labor costs. As can be seen in the table below, total harvest cost for corn grain using 275 HP combine is estimated to be $28.71 per acre.

Table 4.1 Estimated Corn Grain Harvest Cost

Variable	Corn Combine
Horse Power (hp)	275.00
Corn Head Width (ft)	20.00
Life (year)	12.00
Annual Hours of Use	300.00
Fuel Consumption (gal/hr)	12.10
Speed (mph)	4.00
Field Efficinecy (%)	0.70
Capacity (acre/hr)	6.79
Fuel Price ($/gal)	$ 2.60
List Price ($)	$ 334,795.32
Fixed Cost ($/hr)	$ 104.02
Repair Cost ($/hr)	$ 37.20
Fuel Cost ($/hr)	$ 31.46
Lubrication Cost ($/hr)	$ 4.72
Labor Cost ($/hr)	$ 17.50
Variable Cost ($/hr)	$ 90.88
Total Cost ($/hr)	$ 194.90
Total Cost ($/acre)	$ 28.71

4.2 Cost Estimation for Simultaneous Corn Grain and Cob Harvesting

Harvest cost for corn cobs is estimated using whole cob harvest option. According to Shirek (2008) and Wehrspann (2009), one-pass cob harvester like Cob Caddy involves little modification to the combine and uses equipment available commercially to harvest whole cobs. Due to its simplicity, efficiency and commercial availability, the one-pass cob harvest method is employed to estimate corn cob harvest cost. We assume that the one-pass cob harvest method requires farmers to use a self-propelled 275 HP corn combine harvester and a pull-behind wagon-style cob harvester. Table 4.2 describes the machinery operation and estimated cost information for cob collection operation. The method of cost estimation for corn combine in Table 4.2 is exactly the same as that in Table 4.1 above. The main difference between the two tables in corn combine usage is the speed traveled and the capacity of combine.

Harvesting corn cobs requires an attachment of cob harvester to the back of corn combine. According to CVEC (2009), this can slow down the corn grain harvest time by as much as half. In Table 4.2 below, the speed of corn combine is assumed to reduce by 50 percent (i.e.

from 4 mph to 2 mph) because of the use of cob harvester. This would result in the corn combine capacity being reduced by half as compared to the combine capacity in corn grain only harvest option. As a result of this reduction in corn combine speed and capacity, total harvest cost for corn grain harvest would increase from $28.71 per acre to $57.43 per acre. Using the procedures described in Edwards (2009), similar cost computations are implemented for cob harvester as shown in the table[1]. Since cob harvester is attached to the back of corn combine, no additional labor is required to operate the machine and its capacity is dependent on the capacity of corn combine. As shown in Table 4.2, cost of harvesting corn cob is estimated to be $19.36 per acre. Table 4.3 reports the scenarios for the impact of changes in corn combine speed/capacity due to the use of cob harvester on corn grain and cob harvest costs. The table clearly shows that the impact of corn combine speed/capacity on grain and cob harvest costs can be significant.

Table 4.2 Estimated Grain and Cob Harvest Cost Using Cob Caddy Harvest Method

Variable	**Corn Combine**	**Cob Harvester**	**Total**
Horse Power (hp)	275.00	115.00	
Corn Head Width (ft)	20.00		
Life (year)	12.00	10.00	
Annual Hours of Use	300.00	300.00	
Fuel Consumption (gal/hr)	12.10	2.50	
Speed (mph)	2.00	2.00	
Field Efficinecy (%)	0.70	0.70	
Capacity (acre/hr)	3.39	3.39	
Fuel Price ($/gal)	$ 2.60	$ 2.60	
List Price ($)	$ 334,795.32	$ 120,000.00	
Fixed Cost ($/hr)	$ 104.02	$ 40.24	$ 144.26
Repair Cost ($/hr)	$ 37.20	$ 18.00	$ 55.20
Fuel Cost ($/hr)	$ 31.46	$ 6.50	$ 37.96
Lubrication Cost ($/hr)	$ 4.72	$ 0.98	$ 5.69
Labor Cost ($/hr)	$ 17.50		$ 17.50
Variable Cost ($/hr)	$ 90.88	$ 25.48	$ 116.35
Total Cost ($/hr)	$ 194.90	$ 65.72	$ 260.61
Total Cost ($/acre)	$ 57.43	$ 19.36	$ 76.79

[1] The data for cob harvester were obtained by personal communication with Vermeer Corporation.

Table 4.3 Impact of Corn Combine Speed/Capacity on Grain and Cob Harvest Cost

	Corn Grain Harvest Cost	**Corn Cob Harvest Cost**	**Total**
Scenario	**$ per Acre**		
50% Speed/Capacity Reduction (Base)	57.43	19.36	76.79
25% Speed/Capacity Reduction	38.28	12.91	51.19
No Speed/Capacity Reduction	28.71	9.68	38.39

4.3 Cost Estimation for Separate Corn Grain and Stover Harvesting

Under this option, stovers are assumed to be harvested using a tractor and a baler. Similar to above, corn grains are assumed to be harvested using a self-propelled 275 HP corn combine. Because corn grains and stovers are harvested separately, there will be no slowdown in combine speed/capacity. Thus, corn grain harvest cost will be identical to that of Table 4.1. It is assumed that a 130 HP MFWD Tractor is used along with 3x3 Large Rectangular Baler to harvest stover. Specifications and data for the tractor and baler obtained from Lazarus and Smale (2010) are given in Table 4.4. Following Edwards (2009), total harvest costs for the tractor and the baler are estimated in the table below and they sum up to be $10.76 per acre. In addition, stover shredding and raking costs would need to be included. Shredding of stover may be necessary because some of them will be in stalks anchored to the ground after grain harvesting. The anchored pieces of biomass are difficult to cut and bale in a single operation. Large pieces of biomass would make better bales but shredding followed by raking or windrowing will accelerate field drying (Sokhansanj and Turhollow, 2002). Based on the Petrolia's (2008) estimation, total shredding and raking cost of $12.02 per acre is added to total variable and fixed costs to come up with total harvest cost of $22.78 per acre (or $33.53 per ton converted using stover yield of 0.68 ton per acre).

Table 4.4 Estimated Stover Harvest Cost

	Tractor		Baler
Horse Power (hp)	130.00		
Baler Width (ft)			20.00
Bale Weight (ton)			
Life (year)	12.00		12.00
Annual Hours of Use	450.00		250.00
Fuel Use (gal/hr)	5.72		
Speed (mph)	5.00		5.00
Field Efficinecy (%)	0.80		0.80
Capacity (acre/hr)			9.70
Fuel Price ($/gal)	$ 2.60		
List Price ($)	$ 118,889.00	$	96,667.00
Fixed Cost ($/hr)	$ 21.96	$	34.34
Repair Cost ($/hr)	$ 2.20	$	11.28
Fuel Cost ($/hr)	$ 14.87		
Lubrication Cost ($/hr)	$ 2.23		
Labor Cost ($/hr)	$ 17.50		
Variable Cost ($/hr)	$ 36.80	$	11.28
Total Cost ($/hr)	$ 58.77	$	45.61
Total Cost ($/acre)	$ 6.06	$	4.70

5 Methodology

This section starts with the description corn grain harvest methodology and then followed by the descriptions of simultaneous corn grain and cob harvest method (or one-pass harvest method) and separate corn grain and stover harvest method (or two-pass harvest method).

5.1 Corn Grain Harvesting

The following linear programming model which maximizes net income is used to examine the production of corn grain.

Max $\quad \pi = P_c \,.\, Q_c - \sum_{j=1}^{4} C_j \, X_j \quad (1)$

s.t. $\quad -\sum_{j=1}^{4} Yld_{c,j} \, X_j + Q_c \leq 0 \quad (2)$

$a_j X_j \leq CFT_j \quad (3)$

$b_j X_j \leq LFT_j$ (4)

$\sum_{j=1}^{4} X_j \leq L$ (5)

$Q_c \geq 0;\ X_j \geq 0,\ j = 1, \ldots, 4$

Based on Apland (1990) and Bouzaher and Offutt (1992), we assume that j$= 1, \ldots, 4$ represent four two-week harvest periods which run from the end of September till the end of November. P_c is the price of corn grain in dollar per short ton. Q_c is denoted as the quantity of corn grain sold in tons. C_j is defined as corn grain harvest and production costs in dollar per acre. X_j is denoted as acres of corn grain harvested. $Yld_{c,j}$ represents per acre corn grain yield in each harvest period j. a_j and b_j are respectively denoted as labor and combine time required per acre to harvest corn grain in each harvest period. Both combine and labor time is respectively constrained by CFT_j and LFT_j which represent stochastic combine and labor harvest field time expressed in hours. L is defined as total farm land acres that are available for corn grain harvest.

The objective function (Equation (1)) of the optimization problem is to quantify the net return of corn grain harvesting at the farm level. Equation (2) balances corn grain sales with production. Equations (3) and (4) constrain the total amount of combine and labor time available for harvesting corn grain. Equation (5) limits the amount of land available for grain farming.

5.2 Simultaneous Corn Grain and Cob Harvesting

The following linear programming model is used to examine the viability of producing corn grain and cob simultaneously.

Max $\pi = P_c \,.\, Q_c + P_{cb} \,.\, Q_{cb} - \sum_{j=1}^{4} C_j X_j - \sum_{j=1}^{4} D_j X_j$ (1.1)

s.t $-\sum_{j=1}^{4} Yld_{c,j} X_j + Q_c \leq 0$ (2.1)

$-\sum_{j=1}^{4} Yld_{cb,j} X_j + Q_{cb} \leq 0$ (3.1)

$e_j X_j \leq CFT_j$ (4.1)

$f_j X_j \leq LFT_j$ (5.1)

$\sum_{j=1}^{4} X_j \leq L$ (6.1)

$Q_c \geq 0;\ Q_{cb} \geq 0;\ X_j \geq 0,\ j = 1, \ldots, 4$

P_{cb} is the price of corn cob in dollar per short ton. Q_{cb} is denoted as the quantity of corn cobs sold in ton. D_j is defined as corn cob harvest cost in dollar per acre. X_j is denoted as acres of corn grain or cob harvested. $Yld_{cb,j}$ represents per acre corn cob yield in each harvest period j. e_j is denoted as combine and cob harvester (attached to the back of combine) time required per acre to harvest corn grain and cob in each harvest period and is constrained by available combine harvest field time. Similarly f_j is denoted as labor time required per acre to harvest corn grain and cob and is restricted by the available labor harvest field time. L is defined as total farm land acres that are available for corn grain and cob harvest.

The objective function (Equation 1.1) of the optimization problem is to quantify the net return potential associated with the adoption of corn cob harvesting technology. Equation (3.1) balances corn cob sales with production. Equations (4.1) and (5.1) constrain the total amount of machine and labor time available for harvesting corn grain and cob simultaneously. Equation (6.1) limits the amount of land available for corn grain and cob farming.

5.3 Separate Corn Grain and Stover Harvesting

Following Bouzaher and Offutt (1992), the linear programming model which maximizes net return is used to investigate the profitability of producing corn grain and stover separately during harvest time. The model is written as follows,

Max $\quad \pi = P_c . Q_c + P_{cs} . Q_{cs} - \sum_{j=1}^{4} C_j X_j - \sum_{i=2}^{4}\sum_{j=1}^{3} G_{i,j} Y_{i,j} \quad (1.2)$

s.t $\quad -\sum_{j=1}^{4} Yld_{c,j} X_j + Q_c \leq 0 \quad (2.2)$

$-\sum_{i=2}^{4}\sum_{j=1}^{3} Y_{i,j} + Q_{cs} \leq 0 \quad (3.2)$

$a_j X_j \leq CFT_j \quad j = 1, \ldots, 3 \quad (4.2)$

$b_1 X_1 \leq LFT_1 \quad (5.2)$

$b_i X_i + \sum_{j=1}^{i-1} h_{i,j} Y_{i,j} \leq LFT_i \quad i = 2, 3 \quad (6.2)$

$\sum_{j=1}^{3} h_{4,j} Y_{4,j} \leq LFT_4 \quad (7.2)$

$\sum_{j=1}^{i-1} k_{i,j} Y_{i,j} \leq BFT_i \quad i = 2, \ldots, 4 \quad (8.2)$

$\sum_{j=1}^{3} X_j \leq L \quad (9.2)$

$$\sum_{i=j+1}^{4} Y_{i,j} - m_j X_j \leq 0 \quad j = 1, \ldots, 3 \quad (10.2)$$

$$Q_c \geq 0; \; Q_{cs} \geq 0; \; X_j \geq 0; \; Y_{i,j} \geq 0;$$

P_{cs} is the price of corn stover in dollar per ton. Q_{cs} is denoted as the quantity of corn stover sold in ton. $Y_{i,j}$ is denoted as corn stover harvested in ton in period *i* of corn grain harvested in period *j* with *i* > *j*. $G_{i,j}$ is defined as corn stover harvest cost in dollar per ton. b_i is denoted as labor time required per acre to harvest corn grain in period i. $h_{i,j}$ is denoted as labor time required per ton to harvest corn stover in period *i* of corn grain harvested in period *j*. $k_{i,j}$ is defined as baling time required per ton to bale corn stover in period *i* of corn grain harvested in period *j*. BFT_i represents stochastic baling field time expressed in hours available in each period i. L is defined as total farm land acres available for corn grain harvest. m_j represents stover yield in ton per acre of grain harvested in period *j*.

The objective function (Equation 1.2) of the optimization problem is to quantify the net return potential associated with harvesting corn grain and stover separately using conventional technology. Equation (3.2) balances corn stover sales with production. Since corn grain and stover are harvested separately, in the first period only corn grain can be harvested. All grain harvests are assumed to be completed by the end of the third period (i.e. $j = 1, \ldots, 3$). Stover baling starts in the second period and ends in the final period (i.e. $i = 2, \ldots, 4$). Equation (5.2) limits the total amount of labor time available for harvesting corn grain in the first period. Equation (6.2) constrains the total amount of labor time available for harvesting both corn grain and stover. Equation (7.2) restricts the total amount of labor time available for harvesting and baling corn stover in the final period. Equation (8.2) prohibits stover baling time from exceeding the limits. Equation (9.2) limits the total land acres available for corn grain harvesting. Equation (10.2) restricts the total corn stover harvested in future period *i* to not exceed the total current supply availability in period *j*.

6 Description of the Assumptions and Data

6.1 Corn Grain Harvesting

Assumptions and data used to analyze the grain model are described in the following Table 6.1. Corn price and production cost are respectively assumed to be $142.86 per ton (or $4 per bushel) and $356.92 per acre. The production cost of corn varies depending on the size of farm. In this particular case, the size of farm is assumed to be 2,000 acres. Production cost includes cost of using seed, fertilizer, chemicals, insurance, land, machinery, building etc. Corn yield is assumed to be 4.04 ton per acre (or 144.27 bushel per acre). Cost and yield data are based on five-year (2005-2009) average North Dakota data and obtained from FINBIN Farm Financial Database. Corn harvest cost of $28.71 per acre is based on our estimated result in Table 3.1. Corn combine and labor have harvest capacity of 6.79 and 5.43 acres per hour respectively. The combine capacity data is based on Lazarus and Smale (2010) and labor capacity data is determined based on a factor of 1.25. Harvest field day data (Table 6.2) for the state were collected from Crop Progress and Condition Report (USDA-NASS). As mentioned above, each period of harvest field day is assumed to last for two weeks.

Table 6.1 Assumptions Used in Corn Grain Harvest Model

Corn Price ($/ton)	142.86
Production Costs ($/ac)	356.92
Corn Harvest Cost ($/ac)	28.71
Corn Yield (ton/ac)	4.04
Combine Capacity (ac/hr)	6.79
Labor Capacity (ac/hr)	5.43
Total Corn Acres	2,000.00

Table 6.2 Harvest Field Day Data

	From	**To**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean Average**
Period 1	24-Sep	7-Oct	9.90	11.60	11.70	11.10	9.30	**10.72**
Period 2	8-Oct	21-Oct	10.70	10.30	9.60	8.20	4.30	**8.62**
Period 3	22-Oct	5-Nov	11.90	10.90	13.10	10.20	5.40	**10.30**
Period 4	6-Nov	19-Nov	9.00	-	12.70	6.40	12.90	**10.25**

6.2 Simultaneous Corn Grain and Cob Harvesting

Under this option, assumptions for corn price, corn production cost, corn yield and harvest field time remain the same as corn grain only harvest option. Cob price of $55 per ton (Table 6.3) is based on the contract price of a large ethanol company currently operating. Corn grain harvest cost increases from $28.71 to $57.43 per acre due to an additional use of cob harvester attached to the back of combine assumed to slow down grain harvest capacity by half or 50 percent. Cob harvest cost of $19.36 per acre is based on our estimated result in Table 4.2. Corn cob yield of 0.35 ton per acre is based on the estimated average cob yield in North Dakota (Table 4.1). Because of the use of cob harvester, corn combine capacity is assumed to reduce by half from 6.79 to 3.39 acre/hour as shown in the table below.

Table 6.3 Assumptions Used in Simultaneous Corn Grain and Cob Harvest Model

Cob Price ($/ton)	55.00
Corn Harvest Cost ($/ac)	57.43
Cob Harvest Cost ($/ac)	19.36
Cob Yield (ton/ac)	0.35
Combine Capacity (ac/hr)	3.39
Labor Capacity (ac/hr)	5.43
Total Corn/Cob Acres	2,000.00

6.3 Separate Corn Grain and Stover Harvesting

Under this option, corn grains and stovers are assumed to be harvested separately and stovers can be harvested only after grains are harvested. Stovers are assumed to be harvested using a tractor and a square baler. Table 6.4 describes the data assumptions used. Since, corn grain and stover are harvested separately there will be no slowdown in combine capacity. Corn price, production and harvest costs, corn yield, combine and labor harvest capacities are identical to the data assumptions used in corn grain only harvest option. Stover price is assumed to be $45 per ton based on the contract price of an existing large ethanol company. Our estimated stover harvest cost and state-average yield are $33.53 per ton and 0.68 ton per acre respectively. Similarly, baler and labor baling capacities are respectively calculated to be 9.7 and 7.76 acre per hour. Labor baling capacity data is determined based on a factor of 1.25.

Table 6.4 Assumptions Used in Separate Corn Grain and Stover Harvest Model

Stover Price ($/ton)	45.00
Corn Harvest Cost ($/ac)	28.71
Stover Harvest Cost ($/ton)	33.53
Stover Yield (ton/ac)	0.68
Combine Capacity (ac/hr)	6.79
Labor Capacity for Grain Harvest (ac/hr)	5.43
Baler Capacity (ac/hr)	9.70
Labor Capacity for Baling (ac/hr)	7.76
Total Corn/Stover Acres	2,000.00

7 Empirical Results and Discussions

7.1 Corn Grain Harvesting

7.1.1 Deterministic Results

Results can be deterministic or stochastic as farmer's net return will change if corn price, yield and field time fluctuate. Deterministic results are the results that contain no risk or random component. On the other hand, stochastic results are estimated using a random component (in this case random harvest field time) to generate a sample of outcomes. By incorporating data assumptions into the corn grain only harvest optimization model, deterministic optimal outcomes for net farm profit, corn grain sold, and harvested acres are generated and shown in the following Table 7.1 for two scenarios with differing harvest field time expressed in hours in each period. For each period, the table shows the positive correlation between corn acres harvested and harvest field time. With more harvest field hours available in each period in scenario one, more corn grain acres can be harvested until farmers finish harvesting all corn acres in the final period. In scenario one, the shadow price of $191.52 suggests that farmers are able to complete harvesting all 2000 corn acres and if an additional corn acre is available for harvesting farmers can increase their net profit by $191.52. In scenario two, about 106 corn acres are left unharvest due to harvest time limit and the shadow price of $1,040.80 suggests that if corn combine time can be increased by an additional hour, then farmers can benefit from their net profit increase from $362,783 to $363,823.

Table 7.1 Deterministic Results for Corn Grain Production

	Scenario 1	Shadow Price ($)	Scenario 2	Shadow Price ($)
Net Profit ($)	383,048.80		362,782.60	
Corn Grain Sold (Tons)	8,080.00		7,652.51	
Corn Harvested Acres				
Period 1	699.13		697.07	
Period 2	562.17		307.66	
Period 3	671.74		461.79	
Period 4	66.96		427.66	
Total Corn Harvested Acres	2,000.00	191.52	1,894.18	0.00
Harvest Field Time (Hours)				
Period 1	128.64	0.00	128.26	1,040.89
Period 2	103.44	0.00	56.61	1,040.89
Period 3	123.60	0.00	84.97	1,040.89
Period 4	123.00	0.00	78.69	1,040.89
Total Harvest Field Time	478.68		348.53	

7.1.2 Stochastic Results

Corn harvest field days can be limited in North Dakota due to the rainfall and early frost. Deterministic outcomes do not describe how farmers would likely change their harvesting priorities or to what degree profitability is affected when faced with harvest time risk and limited field days. Using historical field day data and @Risk simulation software (Palisade Corporation, 2009), 1000 random numbers of field days (expressed in hours) are generated based on a uniform distribution. These random field days are incorporated into the corn grain only harvest model to estimate random outcomes which show the impact of harvest field time variations on net farm income, corn grain sold and corn acres harvested (assuming that all other variables such as corn price, yield and cost remain unchanged). GAMS software (GAMS Development Corporation) is used to simulate these random outcomes.

Simulated outcomes are reported in the following table and figures. Table 7.2 indicates that variations in harvest field time will have an impact on the net farm profit. Maximum net income that farmers can obtain is $383,049 with all 2000 farm acres harvested as can be seen in the table and Fig 7.1 below. The figure implies that harvest field time and net profit are positively correlated until all farm acres are harvested i.e. until profit maximization is achieved. As shown in the figure, farmers in North Dakota would need a total of 31 harvest field days with 12 working hours each day to finish harvesting 2000 corn acres. Fig 7.2 depicts distribution histograms for total harvest field days available and net farm income. It shows that with 90% confidence total harvest field days range from 30.91 to 42.69 days. Similarly, it shows that with 90% confidence the net farm profit ranges from $379,870 to $384,210.

Table 7.2 Stochastic Results for Corn Grain Harvesting

Variable	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Net Profit ($)	382,338.10	4,232.43	329,838.33	383,048.80
Corn Grain Sold (Tons)	8,065.01	89.28	6,957.58	8,080.00
Corn Harvested Acres				
Period 1	684.79	45.21	358.88	451.42
Period 2	489.13	120.55	166.05	412.73
Period 3	591.74	134.63	208.39	505.21
Period 4	230.64	170.93	179.55	496.59
Total Corn Harvested Acres	1,996.29	22.10	1,722.18	2,000.00
Harvest Field Time (Hours)				
Period 1	126.00	0.69	111.60	140.40
Period 2	90.00	1.85	51.60	128.40
Period 3	111.00	2.22	64.80	157.08
Period 4	115.80	1.88	76.80	154.68
Total Harvest Field Time	442.80	3.57	316.92	550.32

Figure 7.1 Relationship between Corn Grain Harvested Acre and Availability of Harvest Field Days

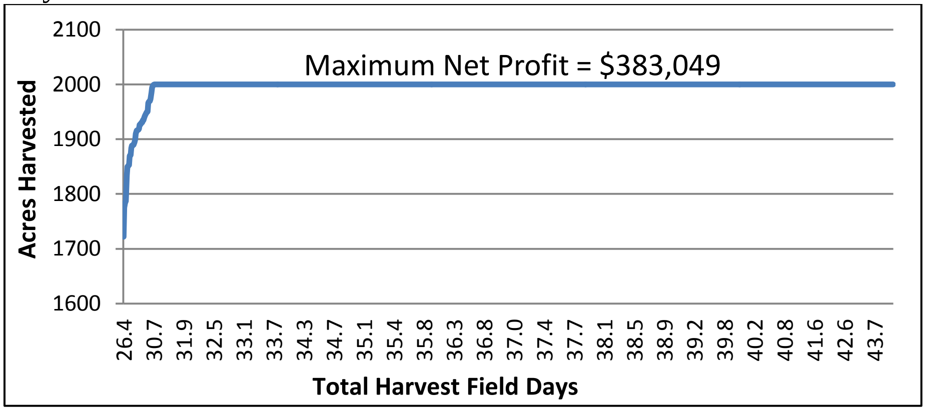
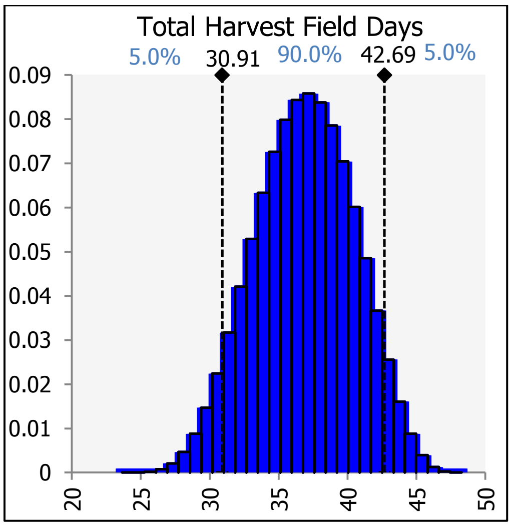
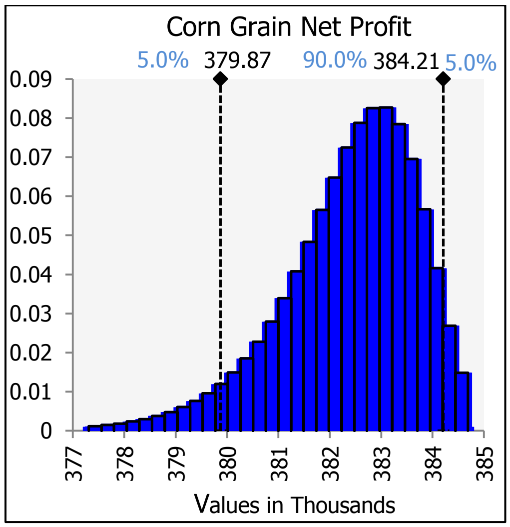


Figure 7.2 Histograms for Harvest Field Days and Corn Grain Net Farm Profit



Distribution: Beta General



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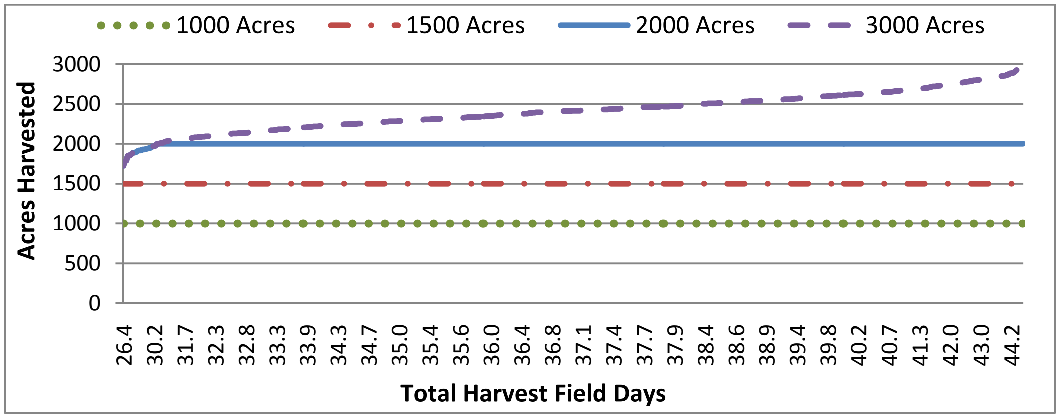
7.1.3 Impact of Farm Size on Corn Grain Harvesting

Assuming that combine harvest capacity remains unchanged, as farm size increases farmers need more harvest field time to cover additional land acres. Fig 7.3 reports the simulated results for different farm sizes ranging from 1,000 to 3,000 acres. During the simulation, it was assumed that all other variables such as price, yield, combine harvest capacity and production cost remain constant and the only variables changing are the farm size and harvest field time. The figure shows that for 1000- to 2000-acre farm sizes, farmers are able to finish harvesting in a short amount of time and maximize their profit potential. However, as farm size increases to 3,000 acres, farmers would require more harvest field time to complete harvesting corn grain. Given limited harvest field time, the figure suggests that as farm size increases to 3,000 acres and above, farmers need to invest in additional labor and combine capacities in order to finish harvest early or they could hire custom operators to complete their harvests.

Figure 7.3 Impact of Farm Size on Net Farm Profit for Corn Grain Harvesting



7.1.4 Impact of Tillage Practice on Corn Grain Harvesting

Tillage practices in North Dakota can be grouped into two classes: conservation tillage (no tillage or reduced tillage) and conventional tillage. Conservation tillage reduces the frequency and intensity of tillage, retains crop residues as mulch on soil surface, reduces the risks of runoff and soil erosion, increases the soil organic carbon content of the surface soil, and reduces carbon dioxide emissions (Lal and Kimble, 1997; Reicosky, 1999; Al-Kaisi and Yin, 2005). Moreover, conservation tillage with residue cover usually results in less soil erosion than conventional tillage (Benoit and Lindstrom, 1987; Andrews, 2006).

Historically conventional tillage systems were more common, although conservation tillage systems have recently been found to have an advantage over conventional tillage systems (Uri, 1999). This could be due to the uncertainties associated with adopting a conservation tillage practice which requires investment in physical and human capital. In addition, conservation tillage usually leads to lower yields in early years before soil nutrients build up (Kurkalova et al., 2006). In Table 7.3 below, the yield and cost of corn grain are compared under different tillage systems for North Dakota. Yield and cost data for conventional tillage system are not specifically available but included in "All" tillage system in the table. "All" tillage system in the table could reflect conventional tillage system as most farmers in the region could likely use conventional tillage system for growing corn. The table shows that yield and cost per acre are lower with no till and reduced till than with other tillage systems.

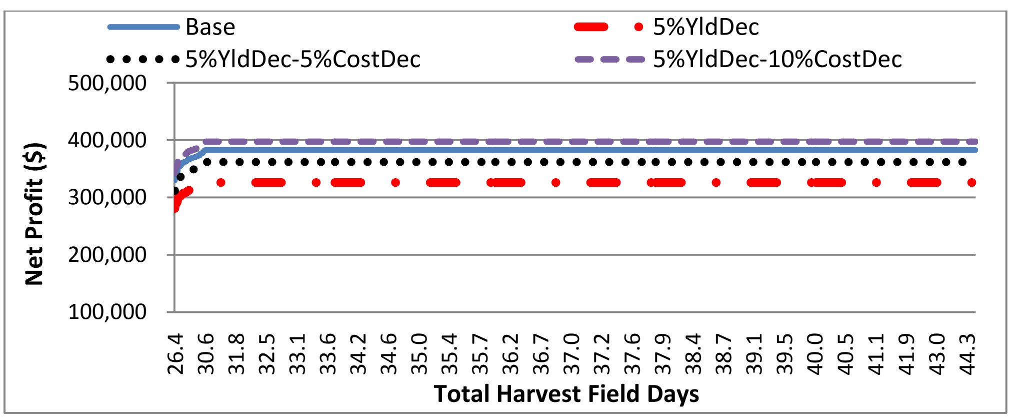
Employment of different soil tillage practices results in different corn yields and production costs across farms with different soil types and climates (Harper 1996; Weersink et al. 1992; Mueller et al. 1985). Changes in both yields and costs impact the net farm profit of harvesting corn grain. Fig 7.4 illustrates scenarios for the impact of decrease in yield and production cost on net farm profit of corn grain production. The figure shows that a small rate of decrease in corn yield (5 percent decrease) can have a negative impact on the net profit of harvesting corn grain. In addition, the figure shows that a decrease in corn yield followed by a decrease in production cost would have a positive impact on net farm profit only if the rate of decrease in corn production cost is much higher than the rate of decrease in corn yield.

Table 7.3 Five Year Average (2005-2009) Yield and Production Cost of Corn Grain by Tillage Practice (Include All Different Types of Farm/Enterprise Size)

Yield/Cost	No Till	Chisel/Reduced Till	All
Yield (bu/ac)	101.77	83.11	114.2
Variable Cost ($/ac)	204.01	210.07	262.42
Fixed Cost ($/ac)	55.71	42.02	57.13
Total Cost ($/ac)	259.72	252.09	319.55

Source: FINBIN Farm Financial Database

Figure 7.4 Scenarios for Impact of Yield and Production Cost on Net Farm Profit for Corn Grain (assumed 2000 acre farm size)



7.2 Simultaneous Corn Grain and Cob Harvesting

7.2.1 Deterministic Results

Deterministic results for simultaneous corn grain and cob harvesting are generated and reported in the following Table 7.4 (a & b). As can be seen in the table, results are generated based on three different corn combine capacity slowdown scenarios. If we assume that additional cob harvesting would not reduce corn combine harvest capacity, then farmers can generate additional revenue of $19,140 ($402,188.80 minus $383,048.80) from selling 700 tons of corn cobs in addition to selling 8,080 tons of corn grain. However, if additional cob harvesting results in the slowdown of corn combine harvest capacity, then farmers can incur a loss of $6,460 for 25% capacity reduction scenario or a loss of $119,054 for 50% capacity reduction scenario. The loss in revenue is mainly due to the slowdown in harvest capacity as a result of cob harvesting. Given that corn harvest time is constrained by the limited availability of harvest field days (expressed in hours in the table) in each period, farmers would not be able to maximize their net returns because of the slowdown. The 25% combine capacity reduction scenario in the table shows that all 2,000 acres of grain and cob can be harvested but net profit is reduced compared with no capacity reduction scenario. This is because the 25% slowdown in combine harvest capacity results in an increase in corn grain and cob harvest costs which decrease net profit. The table also shows that about 377 corn acres are left unharvest if combine capacity slows down by 50%. Either the availability of harvest field time would have to increase or farmers would have to invest in additional harvest equipment and labor to finish all the harvesting to achieve maximum profit potential. Shadow prices correspond to the three scenarios are given in Table 7.4 (b). They can be interpreted in a similar manner as was done for the corn grain only harvest case.

Table 7.4 (a) Deterministic Results for Simultaneous Corn Grain and Cob Production

	50% Speed/Capacity Reduction	**25% Speed/Capacity Reduction**	**No Speed/Capacity Reduction**
Net Profit ($)	263,995.10	376,588.80	402,188.80
Corn Grain Sold (Tons)	6,555.48	8,080.00	8,080.00
Corn Cob Sold (Tons)	567.93	700.00	700.00
Corn Grain/Cob Harvested Acres			
Period 1	436.07	656.33	699.13
Period 2	350.64	527.76	562.17
Period 3	418.98	630.61	671.74
Period 4	416.95	185.31	66.96
Total Corn Grain/Cob Harvested Acres	1,622.64	2,000.00	2,000.00
Harvest Field Time (Hours)			
Period 1	128.64	128.64	128.64
Period 2	103.44	103.44	103.44
Period 3	123.60	123.60	123.60
Period 4	123.00	123.00	123.00

(b) Correspondent Shadow Price

	Shadow Price ($)		
	50% Speed/Capacity Reduction	25% Speed/Capacity Reduction	No Speed/Capacity Reduction
Total Corn Grain/Cob Harvested Acres	0.00	188.29	201.09
Harvest Field Time (Hours)			
Period 1	551.51	0.00	0.00
Period 2	551.51	0.00	0.00
Period 3	551.51	0.00	0.00
Period 4	551.51	0.00	0.00

7.2.2 Stochastic Results

Assuming that other variables such as corn grain and cob prices, costs and yields remain unchanged, variations in harvest field time will change the net farm income of producing corn grain and cob as indicated in the tables below for two different slowdown scenarios (Table 7.5 a & b). Increase in the availability of harvest field time would increase the amount of corn grain and cobs harvested and thus increase the net farm profit. Correlations between harvest field time, corn grain/cob acreage harvested and net farm profit across different scenarios are examined in Fig 7.5 (a & b). For a 2000-acre farm, all grains and cobs can be harvested within 33 harvest field days for all the scenarios except 50% harvest capacity reduction scenario (Fig 7.5 a). Harvest field time and net farm profits are positively correlated until all farm acres are harvested (Fig 7.5 b). For the 50% harvest capacity reduction scenario, more harvest field days will be needed to finish all the harvesting and achieve profit maximization. Results in the figure do not favor the simultaneous corn grain and cob harvesting if it causes corn combine to reduce its maximum potential harvest capacity. So, in that sense corn grain harvesting alone might be a better option. Fig 7.6 shows that with 90% confidence the net farm profit generated from corn grain and cob sales ranges from $204,600 to $282,500 for 50% capacity reduction scenario, and from $398,850 to $403,410 for no capacity reduction scenario respectively.

Table 7.5 Stochastic Results for Simultaneous Corn Grain and Cob Harvesting

(a) 50% Capacity Reduction

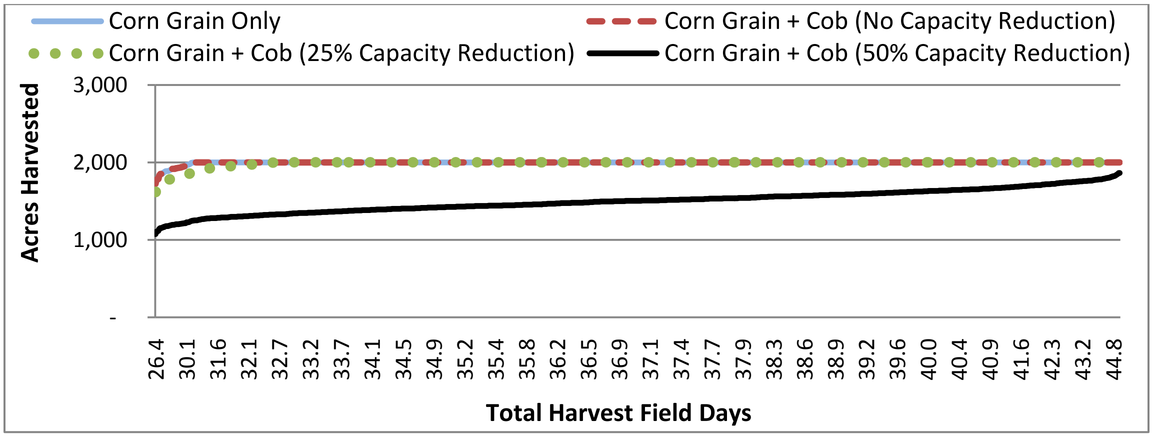
Variable	Mean	Std. Dev.	Minimum	Maximum
Net Profit ($)	244,208.08	23,607.72	174,761.36	303,510.54
Corn Grain Sold (Tons)	6,064.13	586.22	4,339.65	7,536.72
Corn Cob Sold (Tons)	525.36	50.79	375.96	652.93
Corn Grain/Cob Harvested Acres				
Period 1	427.12	28.20	378.34	475.90
Period 2	305.08	75.19	175.05	435.12
Period 3	376.27	90.47	219.70	532.61
Period 4	392.55	76.37	260.51	524.51
Total Grain/Cob Harvested Acres	1,501.02	145.10	1,074.17	1,865.53
Harvest Field Time (Hours)				
Period 1	126.00	0.69	111.60	140.40
Period 2	90.00	1.85	51.60	128.40
Period 3	111.00	2.22	64.80	157.08
Period 4	115.80	1.88	76.80	154.68
Total Harvest Field Time	442.80	3.57	316.92	550.32

(b) No Capacity Reduction

Variable	Mean	Std. Dev.	Minimum	Maximum
Net Profit ($)	401,442.59	4,443.91	346,319.53	402,188.80
Corn Grain Sold (Tons)	8,065.01	89.28	6,957.58	8,080.00
Corn Cob Sold (Tons)	698.70	7.73	602.76	700.00
Corn Grain/Cob Harvested Acres				
Period 1	684.79	45.21	606.58	762.99
Period 2	489.13	120.55	280.65	697.61
Period 3	591.74	134.63	352.23	853.91
Period 4	230.64	170.93	0.00	738.15
Total Grain/Cob Harvested Acres	1,996.29	22.10	1,722.18	2,000.00
Harvest Field Time (Hours)				
Period 1	126.00	0.69	111.60	140.40
Period 2	90.00	1.85	51.60	128.40
Period 3	111.00	2.22	64.80	157.08
Period 4	115.80	1.88	76.80	154.68
Total Harvest Field Time	442.80	3.57	316.92	550.32

Figure 7.5 Comparison of Stochastic Scenario Results

(a) Correlation between Harvest Field Time and Acres Harvested



(b) Correlation between Harvest Field Time and Net Farm Profit

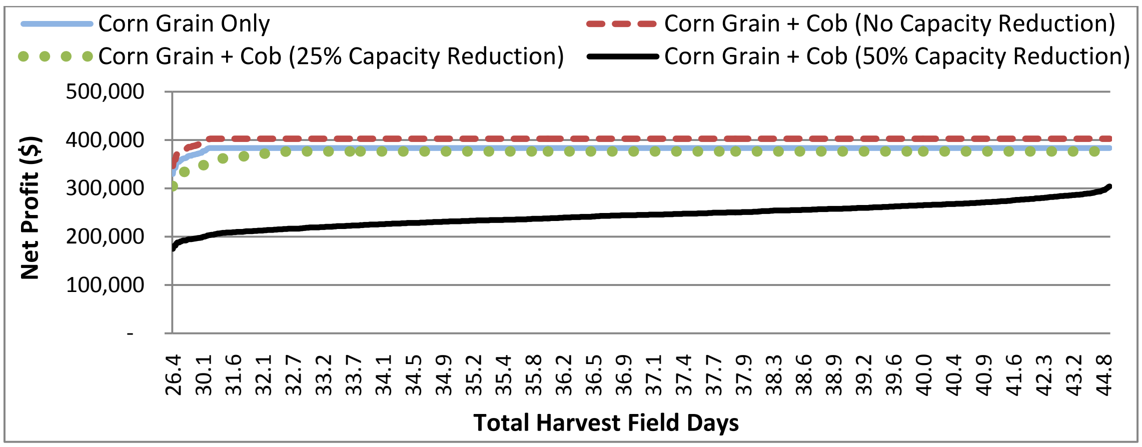
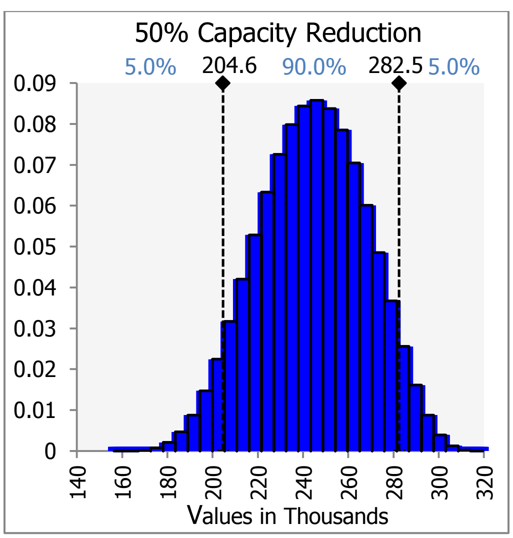
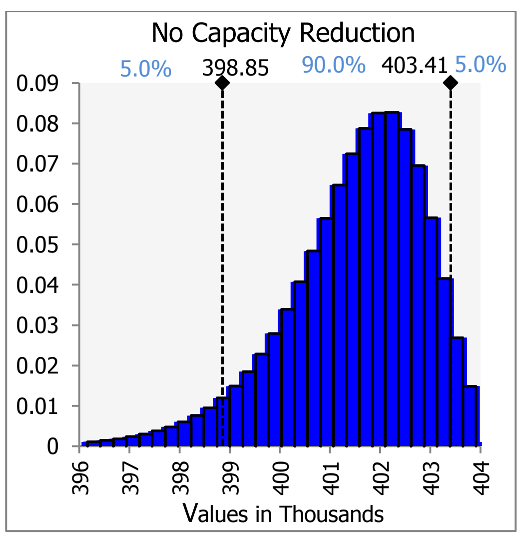


Figure 7.6 Histograms for Net Farm Profit of Corn Grain and Cob Production





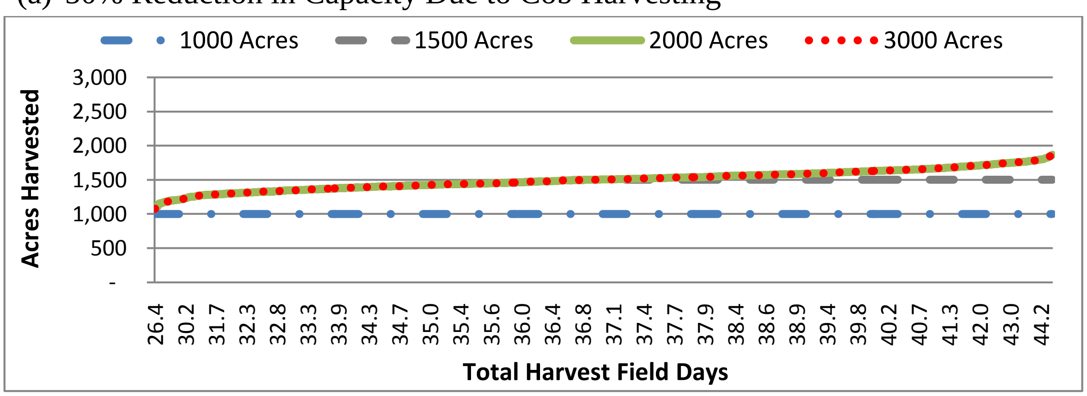
Distribution: Beta General Weibull

7.2.3 Impact of Farm Size on Simultaneous Corn Grain and Cob Harvesting

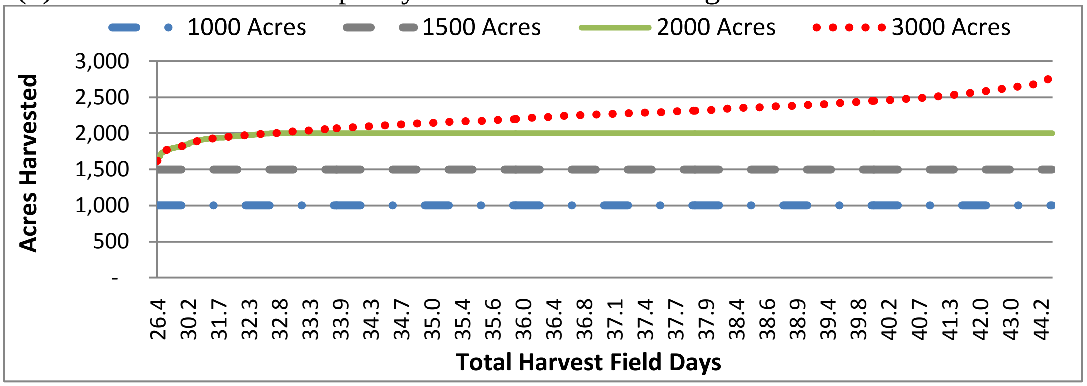
Fig 7.7 (a & b) reports the simulated results for two different capacity reduction scenarios with different farm sizes ranging from 1000 to 3000 acres. During the simulation it was assumed that all other variables such as price, yield and production cost remain constant and the only variables changing are the farm size and harvest field time. All scenarios in the figures indicate that harvesting both grains and cobs in a relatively small 1000-acre farm is not constrained by limited harvest days and capacity. However, when farm size increases, harvest time and capacity factors come into play. For example, for the 50% harvest capacity slowdown scenario, farmers with 1,500 acres of land would require more harvest field days to complete harvesting and reach their profit maximizing potential. As the assumption of harvest capacity slowdown decreases from 50% to 25%, harvest field time factor would become less relevant for farmers with 1,500 acres of land tracts. For comparatively large 2000- and 3000-acre farms, both harvest field time and capacity factors become very relevant. For example, farmers with 3000-acre of land tracts would not be able to maximize their profit potential if cob harvesting slowdown corn grain harvest capacity as shown in the figures. Given limited harvest field days, the figures indicate that as farm size increases farmers would be necessary to expand their harvest capacity for both grain and cob in order to finish all their harvesting activities. Generally, our results suggest that as farm size increases the opportunity costs of harvesting corn cobs would become increasingly high such that if farmers' opportunity costs of harvesting cobs cannot be offset by revenues generated by harvesting those cobs then the farmers would be better off not harvesting any cobs at all.

Figure 7.7 Scenarios for Impact of Farm Size on Net Farm Profit for Simultaneous Corn Grain and Cob Harvesting

(a) 50% Reduction in Capacity Due to Cob Harvesting



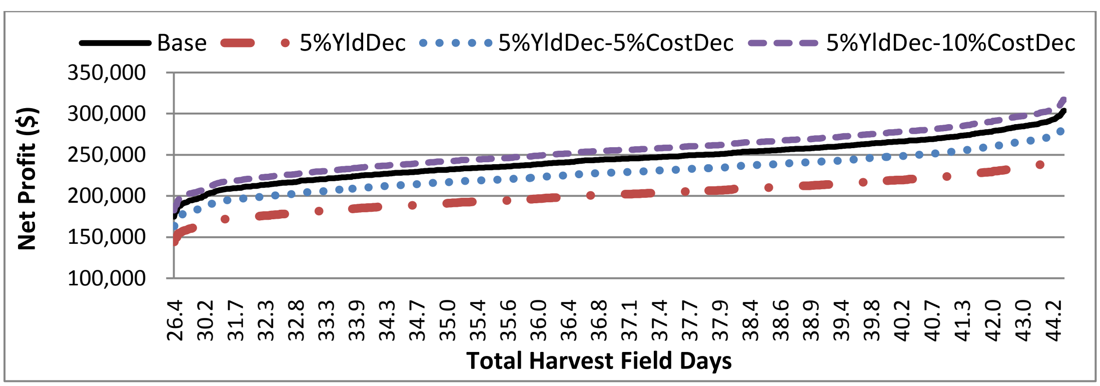
(b) 25% Reduction in Capacity Due to Cob Harvesting



7.2.4 Impact of Tillage Practice on Simultaneous Corn Grain and Cob Harvesting

As we have mentioned, the use of different soil tillage practices can result in different yields and production costs across farms with different soil types and climates. This would have an impact on net farm profit of harvesting corn grain and cob. Fig 7.8 illustrates scenarios for the impact of decrease in yield and production cost on net farm profit for simultaneous corn grain and cob harvesting. Similar to the corn grain only harvest option, the figure shows that a small rate of decrease in corn yield can have a significant negative impact on the net profit of harvesting corn grain and cob. Additionally, the figure shows that a decrease in corn yield followed by a decrease in production cost would have a positive on net farm profit only if the rate of the rate of decrease in corn yield is more than offset by the rate of decrease in corn production cost. Overall, the figure shows the volatility of simultaneous corn grain and cob harvest system because changes in yield and cost due to changes in tillage practices would result in fluctuations in net farm profits.

Figure 7.8 Scenarios for Impact of Yield and Production Cost on Net Farm Profit for Simultaneous Corn Grain and Cob Harvesting (assumed 50% capacity reduction)



7.3 Separate Corn Grain and Stover Harvesting

7.3.1 Deterministic Results

Table 7.6 below reports the deterministic results for corn grain and stover harvested separately. Results in the table are generated based on two different field time scenarios. In both scenarios we assume that farmers can spend 12 hours per day harvesting and baling stover using the available harvest field time. As described in the methodology section, there are a total of four harvest periods and corn grain harvest must be completed within the first three periods. Stover harvesting and baling can take place only when corn grain harvest is completed. Hence, no stover can be harvested and baled in the first period and no corn grain can be harvested in the final period. All grain and stover harvest activities need to be completed within four harvest periods. In scenario one, total acres of corn grain harvested (1,933 acres) fell short of maximum 2,000 acres. This is because part of the farmers' time has been allocated to harvesting and baling stover in the final period and some acres of corn would be left unharvest.

The first scenario in the table also shows that no stover is harvested in the second and third periods. This is due to the fact that farmers find it optimal to allocate all of their time to harvest corn grain instead of stover during these two periods. The negative shadow price of $186.3 in the first scenario implies that if farmers were to attempt to harvest corn stover in either second or third harvest period their net profit would decrease by $186.3 per ton of stover harvested. As suggested in the table, all stover harvest time is optimally allocated to the final period since no grain can be harvested during this final period. The shadow prices of $1,040.89 (for grain) and $60.37 (for stover) in the first scenario indicate that it would be much more valuable for farmers to harvest corn grain than stover if an additional harvest field hour is available.

In the second scenario as compared to the first scenario, we assume that the more harvest field time is available in each period. As can be seen in the table, farmers are able to finish harvesting all 2,000 corn acres in this second scenario as more time is available. The shadow price of $60.37 in the second scenario suggests that if an extra harvest field hour is available, famers are better off harvesting stover since they are assumed to have perfect information and expect to complete harvesting all corn grain acres on time. The maximum amount of stover harvested for the first scenario is about 647 tons and for the second scenario is 960 tons. The difference in net profit between the first and second scenarios can be explained by the difference in corn stover sold or harvested.

Table 7.6 Deterministic Results for Corn Grain and Stover Production

	Scenario 1	Shadow Price ($)	Scenario 2	Shadow Price ($)
Net Profit ($)	377,650.31		394,060.00	
Corn Grain Sold (Tons)	7,809.50		8,080.00	
Corn Stover Sold (Tons)	647.37		959.64	
Corn Grain Acres Harvested				
Period 1	699.13		733.70	
Period 2	562.17		690.00	
Period 3	671.74		576.30	
Total Corn Grain Acres Harvested	1,933.04	0.00	2,000.00	180.42
Corn Stover Harvested in Tons				
Period 2	0.00	-186.30	0.00	0.00
Period 3	0.00	-186.30	201.21	0.00
Period 4	647.37	0.00	758.43	0.00
Harvest Field Time (Hours)				
Period 1	128.64	1,040.89	135.00	60.37
Period 2	103.44	1,040.89	126.96	60.37
Period 3	123.60	1,040.89	144.27	60.37
Period 4	123.00	60.37	144.10	60.37
Total Harvest Field Time	478.68		550.33	

7.3.2 Stochastic Results

Fluctuations in harvest field time will have an impact on the amount of corn grain and stover harvested which in turn will have an effect upon the net farm income as indicated in Table 7.7 below. Results in the table were simulated under the assumption that all other variables remain constant except harvest field time. The table suggests that as the availability of harvest field time increases farmers are willing to allocate a little more of their time to harvest stover in the second and third periods although the final period remains the critical period when farmers spend most of their time on harvesting and baling stover.

Fig 7.9 analyzes the relationship between corn grain and stover harvested in tons as the availability of harvest field time increases. The figure shows that for a 2000-acre farm the amount of corn grain and stover harvested can fluctuate depending on the harvest field time availability in each period. The fluctuations of corn grain and stover harvested as available field time changes in each period can be explained numerically using Table 7.8. For example, if we compare the scenarios 1, 2 and 3 in the table, the differences in stover harvested in tons can be explained by the differences in harvest field time in the final period 4 when most stover harvesting and baling take place. In the table, harvest field time in the final period for the scenario 3 is higher than that of the scenario 1 or 2, and consequently total stover harvested in the third scenario would be higher. Given the limited availability of harvest time, as more (less) labor time is allocated to harvesting stover less (more) would be available for harvesting corn grain and this would have an impact on net farm profit as illustrated in the first three scenarios in the table.

When overall total availability of harvest field time increases to above 40 days as shown in the table (scenario 5-8), farmers would be able to finish harvesting all 2000 corn grain acres within the first three periods and allocate their remaining time on harvesting stover. From the table (scenario 5-8), we can see that once farmers realize that they can finish harvesting corn grain on time, they are willing to increase their time and effort on harvesting and baling stover as the availability of harvest field time increases. This results in an increase in tons of stover harvested and consequently in net profit. This explains why grain and stover lines in Fig 7.9 are getting smoother rather than fluctuating up and down once total harvest field days exceed above 40. Generally, the figure shows that as harvest field time increases the quantities of corn grain and stover harvested tend to trend upward gradually.

Table 7.7 Stochastic Results for Corn Grain and Stover Harvesting

Variable	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Net Profit ($)	345,284.50	34,234.02	248,631.24	394,055.77
Corn Grain Sold (Tons)	7,133.24	717.34	5,097.87	8,080.00
Corn Stover Sold (Tons)	620.64	123.44	404.47	959.63
Corn Grain Acres Harvested				
Period 1	684.79	45.21	606.58	762.99
Period 2	488.82	120.44	280.65	697.61
Period 3	592.04	134.98	352.23	853.91
Total Grain Acres Harvested	1,765.65	177.56	1,261.85	2,000.00
Corn Stover Harvested in Tons				
Period 2	0.30	5.64	0.00	160.74
Period 3	10.87	34.74	0.00	224.53
Period 4	609.48	118.57	404.47	814.37
Harvest Field Time (Hours)				
Period 1	126.00	0.69	111.60	140.40
Period 2	90.00	1.85	51.60	128.40
Period 3	111.00	2.22	64.80	157.08
Period 4	115.80	1.88	76.80	154.68
Total Harvest Field Time	442.80	3.57	316.92	550.32

Figure 7.9 Relationship between Corn Grain and Stover Harvest

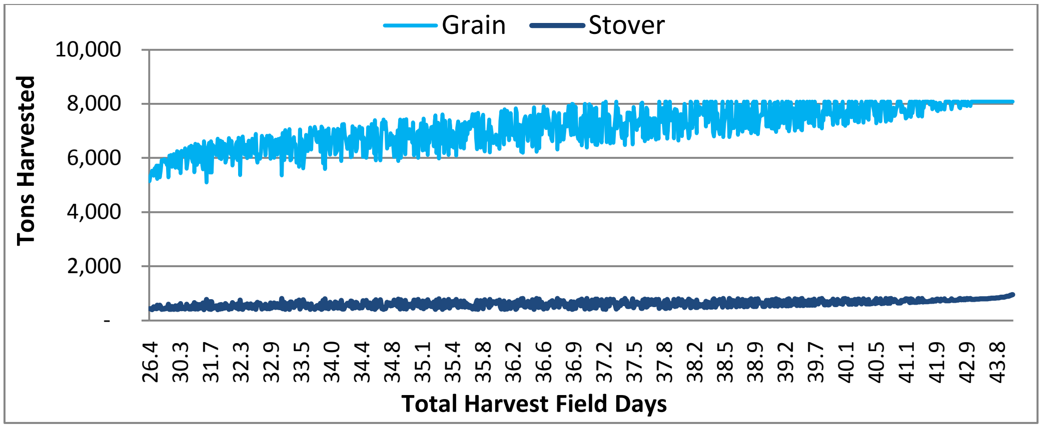


Table 7.8 Stochastic Results for Corn Grain and Stover Harvesting

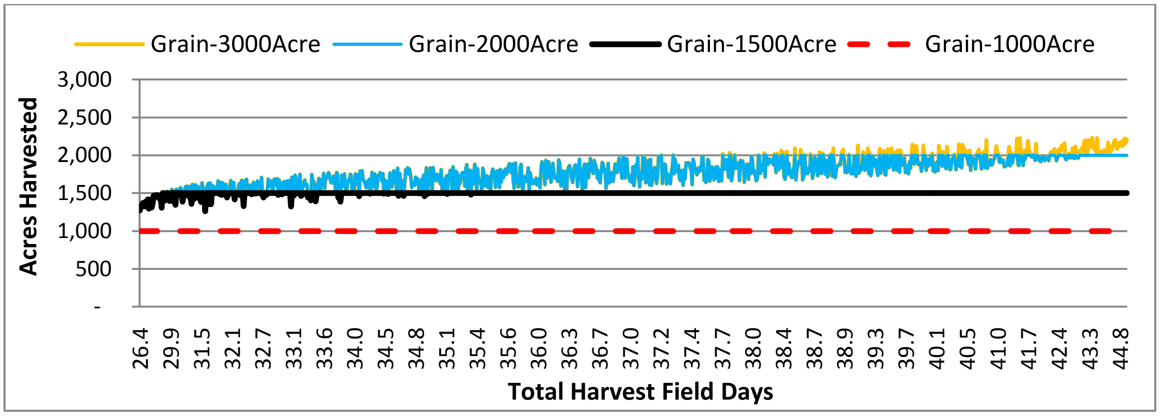
	Harvest Field Time (Days)								
Scenario	Period1	Period2	Period3	Period4	Total	Stover (Tons)	Grain (Tons)	Acres Harvested	Net Profit ($)
1	9.32	4.56	5.63	6.90	26.41	435.90	5,139.14	1,272.07	248,631.24
2	9.49	6.14	8.09	6.44	30.15	406.42	6,247.95	1,546.52	300,858.30
3	9.87	6.62	6.31	12.30	35.10	776.95	6,005.55	1,486.52	293,616.77
4	9.35	10.22	10.34	10.09	40.00	637.26	7,881.73	1,950.92	380,958.94
5	11.29	10.55	11.66	11.57	45.08	910.00	8,080.00	2,000.00	393,486.50
6	10.56	10.40	11.84	12.55	45.34	926.74	8,080.00	2,000.00	393,678.47
7	10.74	10.46	12.94	11.35	45.48	935.53	8,080.00	2,000.00	393,779.29
8	10.65	9.81	12.68	12.71	45.84	958.53	8,080.00	2,000.00	394,043.10

7.3.3 Impact of Farm Size and Corn Yield on Separate Corn Grain and Stover Harvesting

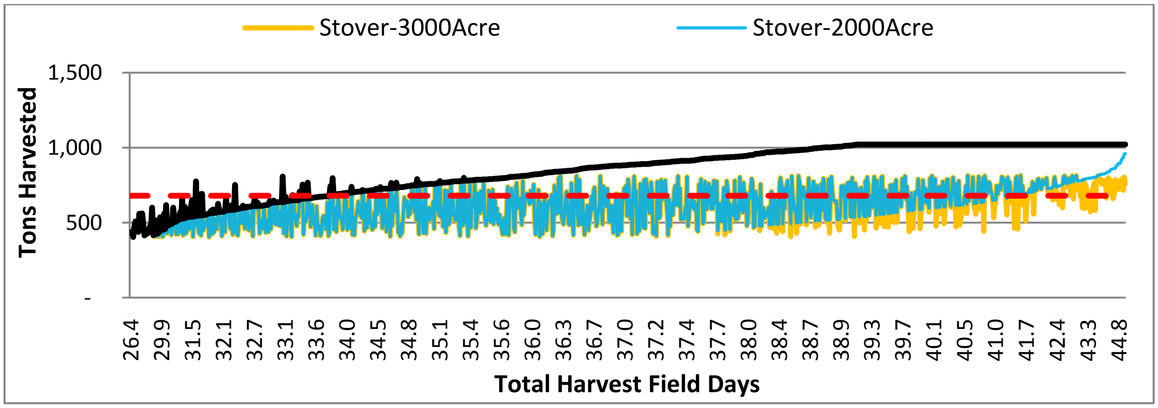
Fig 7.10 (a & b) reports the simulated results for different farm sizes ranging from 1000 to 3000 acres. During the simulation, it was assumed that all other variables remain constant except the size of farm and harvest field time. The figure indicates that farmers with 1000-acre land tracts are able to finish harvesting both grain and stover within a short period of time. As farm size increases to 1500 acres, farmers would require a longer period of time to complete harvesting both grain and stover. For relatively large 2000- and 3000-acre farms, harvest field time could become a limited factor and farmers would find it difficult to allocate their time on harvesting both grain and stover. Given limited harvest field time, Fig 7.10 (b) indicates that farmers with 1500-acre land tracts would have potential to harvest more quantities of corn stover than those of their counterparts with comparatively large 2000- and 3000-acre land tracts. This is because for a relatively small farm, grain harvest can be completed within a short amount of time and hence more time can be allocated to harvesting stover. Our findings suggest that as farm size increases (assuming that harvest capacity and other variables remain constant), farmers would find less amount of time allocated to harvesting stover. Similar to the simulated results shown in simultaneous corn grain and cob harvest case, a small rate of decrease in corn yield due to changes in tillage practice system can have a large negative impact on the net profit of harvesting corn grain and stover (not reported).

Figure 7.10 Impact of Farm Size on Corn Grain and Stover Harvesting

(a) Corn Grain



(b) Corn Stover



8 Summary and Conclusions

In this study, corn cob and stover availability in North Dakota were first estimated on a per acre basis. In addition, harvest costs for corn grain, cob and stover were estimated using machinery cost estimation procedures. By employing three linear programming models with different corn grain and residue harvest options, net farm returns were analyzed under changing harvest field time in order to gain insights into the economic tradeoffs between corn grain and residue harvest activities in the region. Emphasis was placed on understanding the impact of harvest field time, cob and stover harvest technologies, farm sizes and tillage practice on profit maximizing potential of corn farmers. Harvest field time can be very limited in North Dakota because of rainfall and early frost. Randomized fall harvest field time were incorporated into our models to create stochastic outcomes which show that variations in the availability of field time can have a great impact on net farm profits. Harvest field time and net farm returns are found to be positively correlated until all farm acres are harvested.

Under corn grain only harvest option, farmers are able to complete harvesting grain and achieve profit maximization in a fairly short amount of time. However, under the simultaneous corn grain and cob (one-pass) harvest option, farmers' harvest activities are not only constrained by the slowdown in harvest capacity but also by the limited availability of harvest field time. When corn cob harvest option was added to our grain model, corn grain harvest capacity was reduced due to the attachment of cob harvester to the back of combine. Given the limited amount of harvest field time available, this reduction in harvest capacity resulted in some corn acres being left unharvest and consequently caused a loss in net farm revenue. This calls into question the viability of using cob harvester to harvest corn cobs for energy production.

Time allocation is the major problem when farmers choose the option of harvesting corn grain and stover separately under the two-pass harvest method. If more labor time is allocated to harvesting stover, less would be available for harvesting corn grain and this would impact farmers' net profits. Because part of the farmers' time has to be allocated to harvesting and baling stover, with limited availability of harvest field time some acres of corn grain could be left unharvest. Our results show that farmers may find it optimal to allocate most of their time to harvest stover during the last harvest period when corn grain harvests are completed or nearly completed.

Changes in farm sizes can also have an impact on the amount of corn grain and residue harvested. Our findings suggest that under the grain and cob one-pass harvest option as farm size increases farmers would need to add more harvest capacity to finish harvesting both grain and cobs (as compared to the corn grain only harvest option) since additional use of cob harvester attached to the back of corn combine slows down the harvest. Under the grain and stover two-pass harvest option, as farm size increases the availability of harvest field time could become a very limited factor. Farmers would increasingly find it difficult to allocate their labor time on harvesting both grain and stover as farm size increases. We find that farmers with relatively small acres of land tracts have potential to harvest more quantities of corn stover than those of their counterparts with comparatively large land tracts.

Variations in the use of soil tillage system would result in changes in yield and production cost among farms with different soil types. This would have an impact on farmers' net returns of harvesting corn grain and residue. Our evidence shows that a small decrease in corn yield due to changes in tillage practice results in a large decline in the net profit of harvesting corn grain and residue. The rate of decrease in yield must be more than offset by the rate of decrease in production cost in order for net farm profit to at least remain unaffected. Overall, findings in this paper show the volatility of corn grain and residue harvest business not only because of changes in yield but because of issues related to harvest capacity slowdown, time allocation and unpredictability in the availability of harvest field time.

To summarize, simultaneous corn grain and cob one-pass harvest method may not be an optimal choice for biofeedstock production unless farmers are compensated for their potential losses due to harvest capacity slowdown. On the other hand, under the two-pass harvest system, farmers may find it challenging on how to allocate time between harvesting grain and stover. Harvest field time could become very limited as the size of land needed to be harvested increases. Based on our evidence in this paper, we believe that it would be more efficient economically to allow a second party (either a biofuel firm or a firm that specializes in collecting crop residues) to participate in cob/stover harvest business.

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Appendix I

Estimated Corn Stover and Cob Yield by North Dakota Climatic Region and County (2005-2009 Average)

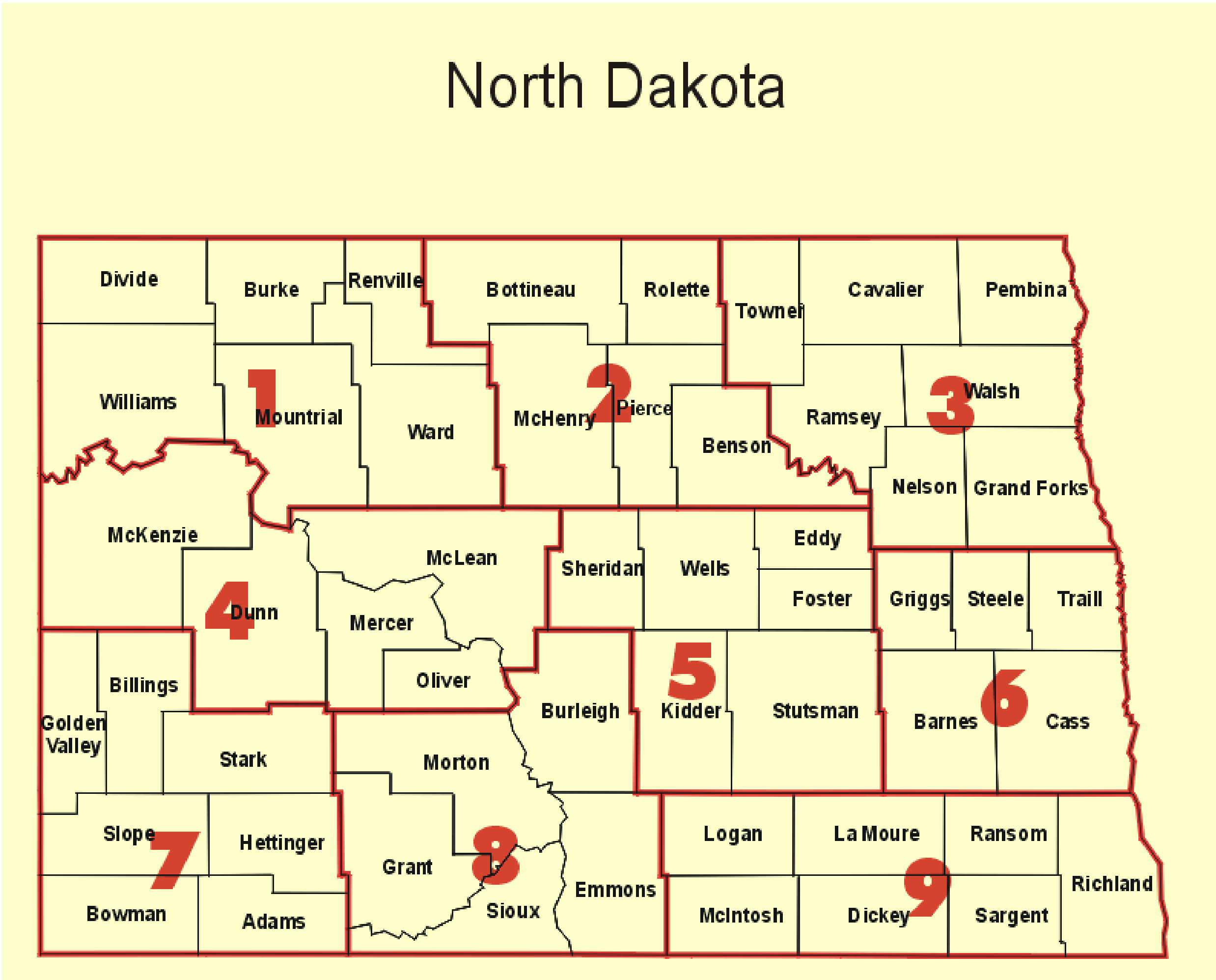
Region/County	Harvested Acres (acre)	Land Area (acre)	Density (%)	Stover Availability (ton/acre)	Stover Availability (ton)	Cob Availability (ton/acre)	Cob Availability (ton)
Northwest	**13,538.23**	**5,852,864.00**	**0.23**	**0.44**	**5,917.46**	**0.22**	**3,019.11**
Burke	-	706,259.20	-	-	-	-	-
Divide	1,580.33	806,099.20	0.20	0.25	388.05	0.13	197.98
Mountrail	-	1,167,315.20	-	-	-	-	-
Renville	2,400.00	559,852.80	0.43	0.10	243.10	0.05	124.03
Ward	7,713.47	1,288,243.20	0.60	0.54	4,183.57	0.28	2,134.47
Williams	1,844.43	1,325,094.40	0.14	0.60	1,102.74	0.31	562.62
North Central	**72,433.62**	**4,379,872.00**	**1.65**	**0.61**	**43,980.83**	**0.31**	**22,439.20**
Benson	36,071.75	883,584.00	4.08	0.72	25,825.52	0.37	13,176.29
Bottineau	2,997.22	1,067,897.60	0.28	0.21	625.99	0.11	319.38
McHenry	19,781.36	1,199,417.60	1.65	0.55	10,964.57	0.28	5,594.17
Pierce	11,591.11	651,404.80	1.78	0.50	5,845.03	0.26	2,982.16
Rolette	1,992.19	577,568.00	0.34	0.36	719.71	0.18	367.20
North East	**190,636.60**	**5,451,379.20**	**3.50**	**0.75**	**143,355.09**	**0.38**	**73,140.35**
Cavalier	2,011.63	952,614.40	0.21	0.27	542.53	0.14	276.80
Grand Forks	60,446.61	920,198.40	6.57	0.90	54,432.32	0.46	27,771.59
Nelson	20,197.40	628,236.80	3.21	0.62	12,423.95	0.31	6,338.75
Pembina	25,576.10	716,000.00	3.57	0.72	18,439.51	0.37	9,407.91
Towner	9,474.17	655,712.00	1.44	0.31	2,916.14	0.16	1,487.82
Ramsey	48,346.61	758,304.00	6.38	0.77	37,115.34	0.39	18,936.40
Walsh	24,584.08	820,313.60	3.00	0.71	17,485.30	0.36	8,921.07
West Central	**36,781.47**	**5,523,571.20**	**0.67**	**0.61**	**22,467.28**	**0.31**	**11,462.90**
Dunn	6,133.08	1,286,144.00	0.48	0.45	2,776.33	0.23	1,416.50

McKenzie	1,948.64	1,754,892.80	0.11	0.51	998.22	0.26	509.30
McLean	15,984.63	1,350,368.00	1.18	0.58	9,261.11	0.30	4,725.06
Mercer	4,265.20	669,113.60	0.64	0.66	2,805.54	0.34	1,431.40
Oliver	8,449.93	463,052.80	1.82	0.78	6,626.07	0.40	3,380.65
Central	**206,690.92**	**4,531,545.60**	**4.56**	**0.79**	**163,702.87**	**0.40**	**83,521.87**
Eddy	11,960.17	403,276.80	2.97	0.64	7,660.82	0.33	3,908.58
Foster	30,234.60	406,528.00	7.44	0.67	20,115.15	0.34	10,262.83
Kidder	11,346.42	864,505.60	1.31	0.73	8,281.80	0.37	4,225.41
Sheridan	5,400.36	621,920.00	0.87	0.31	1,652.06	0.16	842.89
Stutsman	104,165.66	1,421,696.00	7.33	0.89	92,233.44	0.45	47,057.88
Wells	43,583.70	813,619.20	5.36	0.77	33,759.59	0.40	17,224.28
East Central	**493,067.30**	**3,545,363.20**	**13.91**	**0.99**	**486,232.02**	**0.50**	**248,077.56**
Barnes	107,852.14	954,656.00	11.30	0.96	103,276.79	0.49	52,692.24
Cass	189,400.55	1,129,747.20	16.76	1.03	194,848.62	0.52	99,412.56
Griggs	23,688.20	453,440.00	5.22	0.90	21,305.28	0.46	10,870.04
Steele	63,595.05	455,910.40	13.95	0.94	59,640.76	0.48	30,428.96
Traill	108,531.36	551,609.60	19.68	0.99	107,160.57	0.50	54,673.76
Southwest	**29,792.44**	**5,114,694.40**	**0.58**	**0.33**	**9,963.62**	**0.17**	**5,083.48**
Adams	3,554.42	632,262.40	0.56	0.28	995.40	0.14	507.86
Billings	1,216.68	736,902.40	0.17	0.24	287.12	0.12	146.49
Bowman	2,977.19	743,712.00	0.40	0.37	1,104.97	0.19	563.76
Golden Valley	4,468.76	641,273.60	0.70	0.33	1,464.46	0.17	747.18
Hettinger	9,751.40	724,640.00	1.35	0.35	3,397.48	0.18	1,733.41
Slope	1,563.92	779,481.60	0.20	0.33	523.30	0.17	266.99
Stark	6,260.08	856,422.40	0.73	0.35	2,190.89	0.18	1,117.80
South Central	**92,890.85**	**5,006,604.80**	**1.86**	**0.57**	**52,688.55**	**0.29**	**26,881.91**
Burleigh	18,052.32	1,045,177.60	1.73	0.52	9,462.71	0.27	4,827.91

Emmons	44,563.46	966,323.20	4.61	0.72	31,989.00	0.37	16,320.92
Grant	13,595.46	1,062,054.40	1.28	0.21	2,914.13	0.11	1,486.80
Morton	12,579.62	1,232,812.80	1.02	0.61	7,692.69	0.31	3,924.84
Sioux	4,100.00	700,236.80	0.59	0.15	630.02	0.08	321.44

Southeast	**684,986.69**	**4,738,700.80**	**14.46**	**1.03**	**704,634.80**	**0.52**	**359,507.55**
Dickey	116,634.18	723,840.00	16.11	1.06	123,482.20	0.54	63,001.12
La Moure	121,380.71	734,195.20	16.53	1.04	126,280.60	0.53	64,428.88
Logan	19,518.50	635,289.60	3.07	0.72	13,958.95	0.36	7,121.91
McIntosh	18,889.97	624,121.60	3.03	0.77	14,469.11	0.39	7,382.20
Ransom	69,962.12	552,160.00	12.67	1.07	75,002.30	0.55	38,266.48
Richland	241,653.62	919,494.40	26.28	1.03	248,756.30	0.53	126,916.48
Sargent	96,947.59	549,600.00	17.64	1.06	102,685.34	0.54	52,390.48

Appendix II



1 Northwest
2 North Central
3 Northeast
4 West Central
5 Central
6 East Central
7 Southwest
8 South Central
9 Southeast

Source: http://www.cpc.noaa.gov/products/analysis_monitoring/regional_monitoring/CLIM_DIVS/states_counties_climate-divisions.shtml.