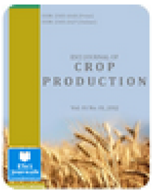
Available Online at ESci Journals
ESci Journal of Crop Production
ISSN: 2305-2627 (Online), 2306-4064 (Print)
http://www.escijournals.net/EJCP



ECONOMIC AND ENERGETIC ANALYSIS OF WINTER WHEAT-BASED CROPPING SYSTEMS FOR POTENTIAL BIOFUEL INDUSTRY: IMPLICATIONS OF GENERAL TRENDS TO SHARE WITH CROP PRODUCERS

[a]Samantha S. Shoaf, [b]Lori J. Unruh Snyder, [c]Craig L. Dobbins
[a] *Department of Plant and Soil Sciences, Oklahoma State University, Stillwater, OK.*
[b] *Crop Science Department, North Carolina State University Raleigh, NC.*
[c] *Department of Agricultural Economics, Purdue University, West Lafayette, IN.*

ABSTRACT

Wheat double-crop systems within the Midwestern States of USA present potential liquid biofuel and gross energy products that can yield economic gains for crop producers. Potential energetic analysis of fifteen winter wheat double-crop systems and five single crop systems will be discussed herein. Energy yield was measured using the mean Dry Matter (DM) yield of ensiled biomass, grain crops, and agricultural residue and assumptions of productivity from recent literature. In conclusion, winter wheat based cropping systems shows the potential to provide sufficient biomass to aid in energy for biofuels systems.

Keywords: Biofuel, Biomass, Economic, Energy, and Wheat.

INTRODUCTION

Double crop (winter-cereal-grass/legume) systems have the potential for increasing incomes in the Midwest, USA, particularly if considering the potential economic opportunities as bioenergy or biofuels, where the incentive allows for numerous second-crops to be utilized for additional economies. Indiana has the infrastructure to produce 3.71 × 10^9 liters of ethanol annually from eleven plants, which comprises 7% of the ethanol industry in the USA (ICMC, 2010). All of Indiana's current ethanol production is from corn (*Zea mays*) grain fermentation. In order to increase ethanol yield, the input grain must be finely ground and combined with water, one liter of water for each 5.6 kg corn (Pimentel and Patzek, 2005). A major limitation to ethanol production is the removal of wastewater added to carry out the fermentation. At completion, the broth is 8% ethanol and 92 % water (Pimintel and Patzek, 2005). Distilling the ethanol from the water is a time and energy intensive process. Stover of grain corn production can be converted into biofuels, in the form of organic liquid products by liquefaction or pyrolysis or to bioethanol by hydrolysis and fermentation (Demirbas, 2008). In addition to corn, sorghum and sweet sorghum (*Sorghum bicolor*) can also be planted following wheat. Sweet sorghum juice is economically feasible on the production side; it is not competitive with a corn-only ethanol production system for an ethanol plant operator in Texas (Morris *et al*., 2009). Soybean is advantageous compared to other oil crops such as canola (*Brassica spp*.) and sunflower *(Helianthus annuus)* to produce biodiesel because soybean requires no nitrogen fertilizer, a major economic and energetic cost to biodiesel production (Pimintel and Patzek, 2005).

Ethanol conversion efficiency of corn stover, as with other plant feedstocks, is highly correlated with lignin content and *In vitro* true dry matter digestibility (IVDMD), parameters widely tested to asses forage quality. Furthermore, these are heritable factors which could contribute to breeding corn for ethanol production from stover (Lorenz *et al*., 2009). Economic analysis has shown that the ideal plant size for corn-stover based ethanol production in Minnesota, USA is 2000-4000 dry Mg stover processed each day (Huang *et al*., 2009). The same study also tested the ethanol yield of four potential biomass feedstocks and found that the rank of production based on 2000 dry Mg per day was aspen

---

* Corresponding Author:
Email ID: Lori_Unruh-Snyder@ncsu.edu

(*Populus spp*.) wood, switchgrass (*Panicum virgatum)*, hybrid poplar (*Populous spp.)* wood then corn stover. This result was due to the relatively high cellulose and hemicellulose content of the aspen. However, on a cost basis, corn stover was the optimal biomass feedstock choice.

Therefore, the primary objective of this research is to identify practical approaches to determine the potential biomass yields and costs associate with the potential economic, liquid biofuel, and gross energy yield of fifteen winter wheat double-crop systems and five single crop systems. The assets and the limitations of utilizing wheat-based cropping systems lends itself to a diverse exchange of possibilities for the world market for creating potential alterative energies as presented within this document.

EXPERIMENTAL DESIGN AND ECONOMIC CALCULATIONS

The quantitative forage analyses procedures and statistical parameters are described within Shoaf, 2012. The average yield of four replications was used to calculate annual net returns (profit), liquid biofuel and total energy yield. For the economic analysis, all grain yields were converted to the industry standard moisture content: 15.5% for corn, 13.5% for wheat, sorghum and 13% for soybeans. All forage crops were converted to 35% dry matter content. In the liquid fuel and total energy calculations, DM yield was used.

The budgets were created to assess the economic return of each production system, whether single- or double-crop. The costs associated with land and other fixed annual costs are divided between the two crops. To formulate the enterprise budgets, the same method used in Navarro (2009) and Navarro *et al*. (2012) was used. These budgets give an opportunity to compare production systems with differing end products in a single unit, dollars. The input costs of each species-specific system were used in developing the budgets.

These feedstocks were analyzed for their capacity to produce liquid fuel as either ethanol (ETOH) feedstock or in the case of soybeans, a biodiesel (BD) feedstock. To calculate the ethanol conversion efficiency, reference numbers from peer reviewed literature were used.

The following calculations were used to reach kg ETOH/ kg DM:

(1) Corn grain: 2.75 gal/bushel *1bus/56 lbs*1gal/0.2642 gal*
0.789 kg ETOH/1 LETOH*1 lb/0.4536kg DM= 0.3233 Kg ETOH/KG DM (USDA, 2006)

(2) Corn silage: 36.8 g ETOH/100g DM (Xu, *et al*., 2010)

(3) Soybean grain: 0.37kg oil/kg DM*0.95 kg biodiesel/kg oil = 0.3515kg BD/kg DM (Carretto *et al*., 2004)

(4) Wheat grain: 93.3 gal ETOH/2000 LB DM = 0.396 L/kgDM *0.789 kg ETOH/L= 0.31kg ETOH/kgDM (USDA, 2006)

(5) Ensiled Triticale hay (DM at harvest not reported, value used for winter wheat hay): 0.33g ETOH/g DM (Chen, *et al*., 2007)

(6) Ensiled Wheat straw: 0.15 g ETOH/G DM (Chen, *et al*., 2007)

(7) Sorghum grain: 2.70 gal/bushel *1bus/60 lbs*1gal/0.2642 gal*
0.789 kg ETOH/1 LETOH*1 lb/0.4536kg DM= 0.2962 kg ETOH/KG DM (USDA, 2006)

(8) Sorghum silage: 27gETOH/100g DM (Li *et al*., 2010)

Total energy content of the biomass, gross energy (GE), also called heat of combustion, was measured in MJ/kg DM and was found in the literature also. All of the studies determined gross energy by bomb calorimetry, not proximal analysis. If the observation of gross energy content was determined as a dependent variable of the study, the control (unmodified) values were used; all values are on a dry matter basis. The heat of combustion of sorghum grain is 17.33 MJ kg^{-1} (Lafitte and Loomis, 1988). The heat of combustion for wheat and triticale grain and straw was 18.64 MJ kg^{-1} (Jørgensen *et al*., 2007). Whole corn grain has a GE content of 18.89 MJ kg^{-1} (Moe, *et al*., 1973) and whole plant corn silage is 19.25 MJ kg-1 (Alexander *et al*., 1963). Soybean grain has 22.7 MJ kg^{-1} (Amthor *et al*., 1994). Sorghum silage is reported to contain 16.93 MJ kg^{-1} when harvested at 23.1% moisture and 17.5 MJ kg^{-1} when harvested at 28.2% moisture (Owen and Kuhlman, 1967). The value closest to the harvest dry matter content was used in calculations. Likewise, for whole plant wheat silage, total energy content established by Barry (1973) for whole plant grass silages was used. Barry found a GE content of 22.2 MJ kg^{-1} in mixed grass silage harvested early (during early head emergence of the grass) (DM content unreported) and 24.3 MJ kg^{-1} in the same species harvested at a typical haymaking date (when seed fill was near completion) (20% moisture).

Revenue of each system was determined using enterprise budgets developed by Navarro *et al*. (2009) and updated by Navarro *et al*. (2012).

Table 1. General trends of potential profit, gross energy, gross energy cost, wheat conversion factors of winter wheat cropping systems at West Lafayette, Indiana, averaging years of 2009-10.

Planting Schedule	**1st- Harvest at Boot Stage**	**2nd-Harvest at Head Stage**	**3rd- Harvest at Grain Stage**	**3-Harvest at Straw Stage**
	Dry Matter Basis			
Wheat Total Costs ($/ha)[a]	$803	$799	$752	
Wheat Gross Energy (GJ/ha)	130	195		150
Gross Energy Cost=Wheat Total Costs/ Wheat Gross Energy (($/ha)/(GJ/ha))= $/GJ	$6	$4		
Wheat Conversion for Gross Energy (GJ/Mg)[b]	22.2	24.3		18.8
Wheat Conversion for Ethanol (Mg ETOH/Mg)[c]	0.33	0.33	0.31	0.15

[a] All calculations were based on the enterprise budgets previously completed by Navarro (2009).

[b] Calculations was based on the work for Jorgensen (2007).

[c] Calculations was based on the work for Chen (2007).

Table 2. General trends of potential profit, gross energy, ross energy cost, ethanol and bioenergy of corn grain and silage planted at wheat boot stage (1st) or wheat maturity stage (2nd) either in bareground of wheat stubble at 7 cm at West Lafayette, Indiana, averaging years 2009-10.

	Corn Grain			**Corn Silage**		
Planting Environment	No-till-Bareground	Wheat Stubble 7 cm		No-till Bareground	Wheat Stubble 7 cm	
Planting Schedule	1st- Harvest at Boot Stage	1st- Harvest at Boot Stage	2nd- Harvest at Head Stage	1st- Harvest at Boot Stage	1st- Harvest at Boot Stage	2nd- Harvest at Head Stage
	Dry Matter Basis					
Corn Total Costs ($/ha)[a]	$1,740	$1,490	$1,205	$1,720	$1,400	$1,310
Corn Gross Energy (GJ/ha)	223	175	155	332	256	264
System Gross Energy (GJ/ha) [b]	223	305	350	332	386	459
Gross Energy Cost=Corn Total Costs/Systems Gross Energy (($/ha)/(GJ/ha))= $/GJ	$8	$5	$3	$5	$4	$3
Corn Conversion for Gross Energy (GJ/Mg) [c]	18.9	18.9	18.9	19.3	19.3	19.3
Corn Conversion for Ethanol (Mg ETOH/Mg) [d]	0.32	0.32	0.32	0.37	0.37	0.37
Ethanol (ETOH) Fuel Yield (Mg/ha) [e]	3.78	4.9	5.27	6.35	6.81	7.69
Total Bioenergy (GJ/ha) [f]	100.5	131	141	170	182	205

[a] All calculations were based on the enterprise budgets previously completed by Navarro (2009).

[b] Wheat gross energy + corn gross energy.

[c] Moe (1973) and Alexander (1963) cited for conversion unit.

[d] USDA (2008) and Xu (2010) cited for conversion unit.

[e] Ethanol (ETOH) fuel yield = wheat ETOH yield + corn crop ETOH yield.

[f] Total bioenergy is total ETOH(Mg) *26.7 (GJ) + biodiesel (Mg)*37.8(GJ) from: NC State Extension (2008).

Table 3. General trends of potential profit, gross energy, gross energy cost, ethanol and bioenergy yield of grain sorghum, silage sorghum and sweet sorghum planted at wheat stage (1st-Boot), wheat maturity stage (2nd), after harvest either in bareground, wheat stubble at 7 cm or 30 cm at West Lafayette, Indiana, averaging years 2009-10.

	Grain Sorghum		Silage Sorghum					Silage Sweet Sorghum		
Planting Environment	No-till Bareground	Wheat Stubble 7 cm	No-till Bareground	Wheat Stubble 7 cm			Wheat Stubble 30 cm	Wheat Stubble 7 cm		Wheat Stubble 30 cm
Planting Schedule	2nd-Harvest at Head Stage	2nd-Harvest at Head Stage	1st- Harvest at Boot Stage	1st-Harvest at Boot Stage	2nd-Harvest at Head Stage	3rd-Harvest after Grain	3rd-Harvest after Grain	2nd-Harvest at Head Stage	3rd-Harvest after Grain	3rd-Harvest after Grain
	Dry Matter Basis									
Sorghum Total Costs ($/ha) [a]	$1,370	$1,130	$1,340	$991	$960	$1,045	$1,125	$1,060	$1,050	$1,130
Sorghum Gross Energy (GJ/ha)	142	152	298	225	253	213	194	263	163	179
System Gross Energy (GJ/ha) [b]	142	346	298	321	448	362	343	458	312	329
Gross Energy Cost=Sorghum Total Costs/System Gross Energy (($/ha)/(GJ/ha))= $/ha	$10	$3	$4	$3	$2	$3	$3	$2	$3	$3
Sorghum Conversion for Gross Energy (GJ/Mg) [c]	17.3	17.3	17.5	17.5	17.5	16.9	16.9	17.5	17.5	17.5
Sorghum Conversion for Ethanol (Mg ETOH/Mg) [d]	0.37	0.37	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Ethanol (ETOH) Fuel Yield (Mg/ha) [e]	3.01	5.86	4.6	5.41	6.56	5.27	4.96	6.71	4.38	4.63
Total Bioenergy (GJ/ha) [f]	80	157	123	145	175	141	133	179	117	124

[a] All calculations were based on the enterprise budgets previously completed by Navarro (20.09).

[b] Wheat gross energy + sorghum gross energy.

[c] Owen and Kuhlman (1967) cited for conversion unit.

[d] USDA (2006) and Li (2010) cited for conversion unit.

[e] Total ETOH fuel yield = wheat ETOH yield + sorghum crop ETOH yield.

[f] Total bioenergy is total ETOH(Mg) *26.7 (GJ) + biodiesel (Mg)*37.8(GJ) from: NC State Extension (2008) and Goshadrou et al. (2011).

In double crop systems, the fixed costs associated with land are split between each crop. Costs include input, labor, machinery, drying and handling expenses. the costs and prices of products were held constant between the years, for this particular paper, the years (2009 and 2010) were averaged to show general trends for each cropping system.

RESULTS

First wheat harvest/planting date: The two corn silage systems generated the most fuel on both an ethanol and biofuel energy basis. The silage corn conversion factor of 0.37 indicated the most efficient potential conversion to ethanol, and subsequently the bioenergy yield for the bare ground and wheat double-crop systems of silage corn were the largest. Soybeans generated very little total bioenergy, 55 and 102 GJ ha^{-1}, for the single and double crops, respectively. This was likely due to the small relative DM yield of soybean grain compared to whole-plant crops such as silage. The soybean-wheat silage double-crop system resulted in lower potential energy yield , 214 GJ ha$^{-1,}$ than the corn for grain single crop system (223 GJ ha^{-1}) . The silage sorghum and wheat double crop yielded nearly as much bioenergy as the silage corn system on an average basis. The wheat alone contributed more gross energy to the system (130-195 GJ ha^{-1}) than the soybean single crop (55-120 GJ ha^{-1}).

In addition, the system gross energy yield was calculated because it was a valuable parameter to estimate the potential of these feedstocks for future biofuel production, which will improve in conversion efficiency. At the first planting date, there was a wide range of potential total energy yields: 92 GJ ha^{-1} for single-crop soybean and 223 GJ ha^{-1} for silage corn double-crop.

Second wheat harvest/planting date: At the second wheat harvest, the wheat was ensiled and in that form can serve as a valuable cellulosic ethanol product. As found in the first planting date, the wheat-silage crop combinations show higher gross energy yields, due to their high tonnage yields. The least productive system on a biofuel energy basis was the single-crop grain sorghum, yielding only 80 GJ ha^{-1}. Ensiled wheat double cropped with silage corn generated the highest biofuel yield of any system investigated in this study, 205 GJ ha^{-1}. Liquid biofuel yield for systems planted at the second harvest date were similar to the single-crop grain sorghum, which generated the least total bioenergy while the silage corn double crop generated the most. The three double-crop sorghum systems (grain, silage and sweet) yielded very similar total bioenergy (range= 124-179 GJ ha^{-1}), despite the fact that the stover was not included in the measurement from the grain sorghum.

Third wheat harvest/planting date: The third planting date came following winter wheat grain and straw harvest. The total bioenergy yields of the five systems were numerically similar, with a range of only 55-205 GJ ha^{-1}. This planting date was less productive in general than the second planting date on an energy production standpoint, likely due to the lack of grain crops tested in this treatment group. The range in energy potential is from 277 GJ ha^{-1} for double-crop soybeans with wheat to 411 GJ ha^{-1} for silage sorghum and wheat double-cropped. The sweet sorghum systems had less GE production than the silage sorghums, despite being more energy-dense. There were numerous agronomic problems (lodging and incomplete dry-down) associated with sweet sorghum production, which were particularly pronounced with the systems from the third planting date. The soybean-wheat double crop system had the least potential energy of the five systems at this planting date. The total plant biomass was not measured form the soybean and so this is underestimating the actual yield. The silage sorghums produce the most GE at this planting date (298 GJ ha^{-1}). Despite the differences found in economic yield, the total bioenergy yields of the five systems were numerically similar. This planting date was less productive in general than the second planting date on an energy production standpoint, likely due to the lack of grain crops tested in this treatment group.

Overall Conclusions of Crops for Ethanol Production: The total range of potential bioenergy yield ranged from 55 GJ ha^{-1} for single-crop soybean planted at the first planting date to 332 GJ ha^{-1} for the wheat silage plus silage corn double-crop system at the second planting date. The silage sorghum planted into tall wheat stubble with 194 GJ ha^{-1} average production. The straw value was not discounted for leaving taller stubble, and so the wheat straw ethanol yield potential is overestimated in these calculations. The soybean double crop was the least productive, with 102-120 GJ ha^{-1}. The relative liquid energy yields of the five double crop systems tested were similar. Soybean double crop produced the least energy. The silage sorghum double crop systems produced the most potential biofuel energy.

Table 4. General trends of potential profit, biodiesel yield, gross energy, gross energy cost and bioenergy of soybeans planted at wheat stage (1st-Boot), wheat maturity stage (2nd), after harvest either in bareground of wheat stubble at 7 cm at West Lafayette, Indiana, averaging years 2009-10.

	Soybean			
Planting Environment	No-till Bareground	Wheat Stubble 7 cm	Wheat Stubble 7 cm	Wheat Stubble 7 cm
Planting Schedule	1st- Harvest at Boot Stage	1st- Harvest at Boot Stage	2nd-Harvest at Head Stage	3rd-Harvest after Grain
	Dry Matter Basis			
Soybean Total Costs ($/ha)	$1,090	$841	$770	$707
Soybean Gross Energy (GJ/ha)	92	84	82	54.3
System Gross Energy [b] (GJ/ha)	92	214	277	204
Gross Energy Cost=Soybean Total Costs/System Gross Energy (($/ha)/(GJ/ha))= $/ha	$12	$4	$3	$3
Soybean Conversion for Gross Energy [c] (GJ/Mg)	22.7	22.7	22.7	22.7
Soybean Conversion for Ethanol [d] (Mg ETOH/Mg)	0.36	0.36	0.36	0.32
Ethanol (ETOH) Fuel Yield[e] (Mg/ha)	0	1.93	2.65	2.53
Biodiesel Fuel Yield (Mg/ha)	1.45	1.33	1.29	0.66
Total Bioenergy[f] (GJ/ha)	55	102	120	92.7

[a] All calculations were based on the enterprise budgets previously completed by Navarro (2009).

[b] Wheat gross energy + soybean gross energy.

[c] Carretto et al. (2004) cited for conversion unit

[d] USDA (2006) and Li (2010) cited for conversion unit.

[e] Total ETOH fuel yield = wheat ETOH yield + sorghum crop ETOH yield.

[f] Total bioenergy is total ETOH(Mg) *26.7 (GJ) + biodiesel (Mg)*37.8 (GJ) from: NC State Extension (2008); Goshadrou et al. (2011).

From the potential liquid biofuel production perspective, the silage crops were highly competitive with the grain crops, even exceeding grain crops in some cases. Current infrastructure in Indiana is designed to handle grain only, but these indicate that diversifying liquid biofuel production may warrant further investigation. These analyses used the DM yield of the forage crops for calculation, though undoubtedly there will be considerable costs associated with drying the biomass for transport. Advances in lignocellulosic ethanol technology will increase the fuel productivity of whole plant biomass. The second planting date generated on average the most potential for liquid biofuel. Gross energy content of these double-crop systems represents the potential of the biomass as fuel feedstocks, pending improvement of conversion technologies. These calculations do not include energy mass balance, which would provide the energy costs of production, harvest and handling to determine if these systems produce additional energy which could be used as fuel. Therefore this works to serve, as a preliminary data references for future work along these lines.

ACKNOWLEDGMENTS

We would like to thank our research funding for SARE Graduate-Student Grant and Purdue University Mission Funds.

REFERENCES

Alexander, R.A., J.F. Hentges, Jr., W.K. Robertson, G.A. Barden and J.T. McCall. 1963. Composition and digestibility of corn silage as affected by fertilizer rate and plant population. J. Anim. Sci. 22:5-8.

Amthor, J.S., R.J. Mitchell, G.B. Runion, H.H.Rogers, S.A. Prior and C.W. Wood. 1994. Energy content, construction cost and phytomass accumulation of Glycine max (L.) Merr. and Sorghum bicolor (L.) Moench grown in elevated CO2 in the field. New Phytologist. 128(3):443-450.

Barry, T.N. 1975. Effect of treatment with formaldehyde, formic acid, and formaldehyde-acid mixtures on the chemical composition and nutritive value of silage. N.Z. J. Agric. Res. 18(3):285-294.

Chen, Y., R. R. Sharma-Shivappa and C.Chen. 2007. Ensiling Agricultural Residues for Bioethanol Production. Appl. Biochem. Biotech. 143:80-92.

Carraretto, C., A. Major, A. Mirandola, A, Stoppato and S. Tonon. 2004. Biodiesel as alternative fuel: Experimental analysis and energetic evaluations. Energy, 29(12), 2195–2211.

Demirbas, A. 2008. Conversion of corn stover to chemicals and fuels. Energy Sources, Part A. 30:788-796.

Goshadrou, A., K. Karimi and M.J. Taherzadeh. 2011. Bioethanol production from sweet sorghum bagasse my *Mucor hiemalis*. Industrial Crops Products. 34:1219-1225.

Huang, H-J, S. Ramaswamy, W. Al-Dajani, U. Tschirner and R. A. Cairncross. 2009. Effect of biomass species and plant size on cellulosic ethanol: A comparative process and economic analysis. ScienceDirect. 33:234-246.

Indiana Corn Marketing Council (ICMC). 2010. Economic impact of the ethanol industry on Indiana's economy. Compiled by: Informa Economics. Online. http://www.incorn.org/EthanolEconomicImpactJune25.pdf.

Jørgensen, J.R., L.C. Deleuran, and B. Wollenweber. 2007. Prospects of whole grain crops of wheat, rye and triticale under different fertilizer regimes for energy production. Biomass and Bioenergy 31:308-317.

Lafitte, H.R. and R.S. Loomis. 1988. Calculation of growth yield, growth respiration and heat content of grain sorghum from elemental and proximal analysis. Ann. Bot. 62:353-361.

Li, B.Z., V. Balan, Y.J. Yuan and B.E. Dale 2010. Process Optimization to convert forage and sweet sorghum bagasse to ethanol based on ammonia fiber expansion (AFEX) pretreatment. Bioresour. Tech. 101(4):1285-1292.

Lorenz, A.J., R.P. Anex, A. Isci, J.G. Coors, N. de Leon and P.J. Weimer. 2009. Forage quality and composition measurements as predictors of ethanol yield from maize (*Zea mays* L.) stover. Biotechnology for Biofuels. 2:5.

Moe, P.W., H.F. Tyrell and N.W. Hooven, Jr. 1973. Physical form and energy value of grain corn. J. Dairy Sci. 56 (10):1298-1304.

Morris, B.D., J.W. Richardson, B.J. Frosch, J.L. Outlaw and W.L. Rooney. 2009. Economic Feasibility of Ethanol Production from Sweet Sorghum Juice in Texas. Selected Paper at Southern Agricultural Economics Association Annual Meetings, Atlanta, Georgia, January31-February 3.

NC State Extension. 2008. Conversion Factors for Bioenergy. Online. Available: http://www.ces.ncsu.edu/forestry/biomass/pubs/WB008.pdf.

Navarro, J.I. 2010. Economic Analysis of Double Cropping Systems in Central Indiana: Winter Wheat, Corn, Sorghum, Sweet Sorghum, and Soybeans, M.S. Thesis, Purdue University.

Navarro, J.I., S. Shoaf, L.J. Unruh Snyder, C. Dobbins and H. Ohm. 2012. *Economic analysis of biomass production utilizing winter wheat double-cropping*. Journal of the American Society of Farm Managers & Rural Appraisers 75(1): 89-97.

Owen, F.G. and J.W. Kuhlman. 1967. Effect of maturity on digestibility of forage sorghum silages. J. Dairy Sci.

50(4):527-530.

Pimentel D. and T.W. Patzek. 2005. Ethanol Production using Corn, Switchgrass and Wood; Biodiesel Production Using Soybean and Sunflower. Natural Resources Research. 14(1): 65-75.

Shoaf. S. 2012. Winter Wheat Management And Wheat-Row Crop Combinations For Grain, Silage And Biomass Production. Dissertation, Purdue University.

USDA. 2006. The economic feasibility of ethanol production from sugar in the United States. Online. http://www.usda.gov/oce/reports/energy/EthanolSugarFeasibilityReport3.pdf

Xu, J., M.H. Thomsen and A. B. Thomsen. 2010. Feasibility of Hydrothermal Pretreatment on Maize Silage for Bioethanol Production. Applied Biochemistry Biotechnology. 162:33-42.