The Economic Value of Soybean Meal and Hull Microbial Fermentation

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Abstract

Aspergillus oryzae and *Bacillus* spp. have been successfully used to ferment soybean meal and hull for nutritional enhancement and potentially increased economic value. Crude protein content of soybean hulls increased 5.25% after fermentation with *Aspergillus oryzae* and 6.43% with *Bacillus* spp. Also, crude protein content of soybean meal increased 9.93% after fermentation with *Aspergillus oryzae* and 10.6% with *Bacillus* spp. Stachyose and raffinose content decreased from 4.48% in soybean meal and 0.44% in soybean hull to non-detectable levels after both *Aspergillus oryzae* and *Bacillus* spp. fermentation. If protein gains from these microbial fermentation processes were applied to aggregate USDA U.S. soybean processing results over the last 10 marketing years, the value of soybean hull and meal production would be projected to have increased $43.58-$53.38 and $27.11-$33.20 per ton, respectively. Processed soybean value is projected to have increased $0.08-$0.30 per bushel for microbial fermentation of soybean hulls and $0.05-$0.06 per bushel for soybean meal.

Introduction

Recent research results have shown that that fermentation of soybean hulls and meal with two microorganisms - *Aspergillus oryzae* and *Bacillus* spp. - degrade soybean hull fiber, increase soybean hull protein content, degrade oligosaccharides in soybean meal, and degrade soybean meal protein peptide sizes (Vadlani, et al, 2011). This companion economic analysis quantifies the increase in the economic value of soybean hulls that would have been possible if these fermentation processes had been in use over the last decade, i.e., from the 2000/01 through the 2010/11* marketing years. (*Note: this analysis extends through June 2011, with July and August remaining of MY 2010/11 for U.S. soybeans).

Review of Fermentation Impact on Soybean Meal & Hull Characteristics

Soybean hull contains about 85.7% carbohydrates, 9% protein, 4.3% ash, and 1% lipids, and is used as a fiber supplement in animal feed [Liu, 1997]. Despite the recognized value of soybean meal and hull, these components have some inherent disadvantages. The dietary energy value of uncooked soybean meal is relatively low because ingredients are encapsuled by carbohydrates and hard to digest by enzymes. Galacto-oligosacchrides (GOS) generally represent approximately 4 to 6% of soybean dry matter. Oligosaccharides in the carbohydrate fraction, particularly raffinose and stachyose, could lead to flatulence and abdominal discomfort for monogastric animals [Krause et al, 1994; Zhang et al, 2003].

Aspergillus oryzae has the ability to produce enzymes such as hemicelluloses, hydrolases, pectinases, lipases, and tannases [Brijwani et al., 2010]. *Bacillus* spp. was isolated at Kansas State University and has successfully enhanced the protein content of the Dried Distillers' Grains and Solubles (DDGS) by utilizing the residual corn fiber as substrate in an industry-sponsored proprietary project [Robb et al, 2007].

Microbial bioprocessing of soybean hulls and meal, along with protein enhancement and removal of anti-nutritional factors, will result in nutritional enhancement of soybean hulls and meal, and enhance the competitive standing of these feedstuffs relative to increasingly available DDGS in the United States.

Review of Analysis of Fermentation Affects

Soybean carbohydrates make up approximately 40% of soybean meal dry matter and 87% soybean hull dry matter [Karr-Lilienthal et al., 2005]. *Bacillus* spp. and *Aspergillus oryzae* could use these carbohydrates for growth and enhance the protein content of fermented soybean meal and hull, with the additional benefit of decreasing the fiber content in soybean hulls. Brijwani [2010] used the soybean hull as the substrate for *Aspergillus oryzae* fermentation to produce cellulolytic enzyme system and found the presence of five kinds of cellullolytic enzyme activities. Robb [2007] used *Bacillus* spp. fermentation to increase the protein content of corn chalk.

After fermentation with *Bacillus* spp., the protein content of soybean meal was increased by 10.6%, and soybean hull by 6.43% (Table 1). The fiber content of soybean meal was increased by 0.24% and that of soybean hull was decreased by 18.34%. Similarly, the protein content of soybean meal was increased by 9.93% and soybean hull by 5.25% after fermentation with *Aspergillus oryzae* (Table 2). The crude fiber content of soybean meal was increased by 1.54 while that of soybean hull was decreased by 3.85%. Soybean hull is usually used as the low value product additive for ruminant feed, but has no market in non-ruminant usage. The protein enhancement after fermentation found by Vadlani, et al (2011) added protein content to processed soybean hulls, which may enhance their competitive value as a feedstuff.

Summarized results of changes in stachyose and raffinose content resulting from *Bacillus* spp. and *Aspergillus oryzae* fermentation are shown in Table 3. Prior to fermentation, stachyose and raffinose content was 4.48% in soybean meal and 0.44% in soybean hull. After *Bacillus* spp. and *Aspergillus oryzae* fermentation, their content decreased to undetectable levels.

Removal of oligosaccharides in soybean meal such as stachyose and raffinose would avoid causing flatulence to non-ruminants as well as enhancing nutrient digestibilities and energy availability of soybean meal. Such oligosaccharides are considered indigestible in non-ruminants' small intestines because these animals lack alpha-galactosidase. GOS are digested to some extent in the small intestine (76 to 88% for stachyose, 31 to 65% for raffinose, and 32 to 55% for verbascose) [Karr-Lilienthal et al, 2005] through fermentation by bacterial populations. Fermentation of GOS results in the production of carbon dioxide and hydrogen, potentially resulting in increased flatulence. Carbon dioxide and hydrogen can cause flatulence, nausea, and discomfort in swine [Krause et al, 1994]. Weanling pigs fed a GOS-free diet supplemented with 2% stachyose or fed a diet containing soybean meal had increased incidence of diarrhea compared with pigs fed a control diet [Zhang et al, 2003]. Additionally, fermentation of GOS has been implicated to have negative effects on nutrient digestibilities and energy availability of soybean meal. Parsons et al. [2000] found that roosters fed soybean meal with low oligosaccharide concentrations had higher total net metabolizable energy values (2931 kcal/kg DM) than those fed conventional soybean meal (2739 kcal/kg DM).

Fermentation degraded protein in soybean meal enhances protein digestibility in swine diets. An *in vivo* experiment confirmed the results by showing that feeding piglets fermented soybean meal significantly increased average daily gain and average daily feed intake and improved feed conversion

efficiency compared with feeding piglets unfermented soybean meal [Feng et al, 2007b; Min et al, 2009]. With regard to the soybean allergy, Liu, X. [2007] showed that fermentation of soybean meal decreased immune response to soybean protein in piglets. This result is also consistent with Hong (2004) who showed that *Aspergillus oryzae* fermented soybean meal contained more small peptides (<20 kDa) than soybean meal, and that fermented soybean meal contained less large peptides (>60 kDa).

Table 1. Fermentation of soybean meal & hull using *Bacillus* spp. Microbial culture

Sample	Crude Protein %	Protein Increase %	Crude Fiber %	Crude Fiber Change %
Soybean meal control*	46.88%		4.19%	
Soybean meal**	57.48%	+10.60%	4.43%	+0.24%
Soybean hull control***	12.06%		50.80%	
Soybean hull****	18.49%	+6.43%	32.46%	(18.34%)

* 15 g soy meal + 4.8 g ammonium sulphate + 0.3 g potassium phosphate in 100 ml H_2O, pH 6.5
** soy meal after 48 hours of fermentation using *Bacillus* spp. Inoculum.
*** 15 g soy hull+4.8 g ammonium sulphate + 0.3 g potassium phosphate in 100 ml H_2O, pH 6.5.
**** soy hull after 48 hours of fermentation using *Bacillus* spp. innoculum

Table 2. Fermentation of soybean meal & hull using *Aspergillis oryzae* Microbial culture

Sample	Crude Protein %	Protein Increase %	Crude Fiber %	Crude Fiber Change %
Soybean meal control*	45.81%		3.74%	
Soybean meal**	55.74%	+9.93%	5.28%	+1.54%
Soybean hull control***	12.06%		32.97%	
Soybean hull****	17.31%	+5.25%	29.12%	(3.85%)

* 15 g soy meal + 4.8 g ammonium sulphate + 0.3 g potassium phosphate in 100 ml H_2O, pH 6.5
** soy meal after 96 hours of fermentation using *Aspergillus oryzae* inoculum.
*** 15 g soy hull+4.8 g ammonium sulphate + 0.3 g potassium phosphate in 100 ml H_2O, pH 6.5.
**** 15 g soy hull after 96 hours of fermentation using *Aspergillus oryzae* innoculum

Table 3. Stachyose and raffinose content

	Soybean Meal (SBM)	Soybean Hulls (Soyhulls)	*Bacillus* spp.		*Aspergillus oryzae*	
Item (% w/w)	control	control	SBM	Soyhulls	SBM	Soyhulls
Stachyose & raffinose	4.48	0.44	ND	ND	ND	ND

ND: non detectable

Economic Analysis of Soybean Hull Protein Improvements

Historic Soybean Processing Value Relationships: Since MY 2001/02 on average soybean oil has made up 38.6%, soybean meal 61.4% and soybean hulls 1.7% of the estimated processing value of U.S. soybeans (Table 4). The average market price of soybean hulls during this period was $91.32 on a per ton basis, ranging from $61.33 in MY 2001/02 to a September 2010 through July 2011

preliminary average of $157.03 per ton in MY 2010/11. The average market price of soybean meal during this period was $247.82 on a per ton basis, ranging from $166.56 in MY 2001/02 to a September 2010 through July 2011 preliminary average of $344.17 per ton in MY 2010/11.

Figures 1 through 8 depict trends and inter-relationships in U.S. soybean processor aggregate data over time, and can be found in an appendix at the end of this report.

Figure 1 - Yield of processed soybean components on a marketing year average basis

Figure 2 - Yield of processed soybean components on a monthly average basis

Figure 3 – Prices of soybean oil, meal & hulls on a marketing year average basis

Figure 4 – Prices of soybean oil, meal & hulls on a monthly average basis

Figure 5 – Dollar Revenue from soybean oil, meal & hulls on a marketing year average basis

Figure 6 – Percent Revenue from soybean oil, meal & hulls on a marketing year average basis

Figure 7 – Dollar Revenue from soybean oil, meal & hulls on a monthly average basis

Figure 8 – Spread between soybean processed value and market price on a marketing year basis

Table 5 shows derived values for protein in soybean hulls and meal on both a per pound of protein and per 1% of protein basis. This method of implicitly valuing soybean meal and hull protein follows that developed by Hill (1994). For the MY 2001/02 through MY 2010/11 period, the implicit value of soybean hull protein on a per pound and per percentage basis has been higher than for soybean meal. Assuming 11% protein, soybean hull protein averaged $0.42 per pound and $8.30 per percent of protein for MY 2001/02-2010/11. Assuming 48% protein, soybean meal protein averaged $0.26 per pound and $5.16 per percent of protein for MY 2001/02-2010/11.

Although the relationship between soybean hull and meal protein implicit values varied considerably (11% standard deviation), soybean meal value protein per pound averaged 63.9% of that for soybean hulls during the most recent 10 year period. The value per bushel of soybeans of soybean hulls produced averaged only 2.9% of soybean meal value. These measures of protein value on a per unit basis will be used later to estimate the value of increased soybean hull protein from application of microbial fermentation processes as developed by Vadlani, et al (2011).

Quantified protein and fiber standards for soybean meal from the National Oilseed Processors Association (NOPA) are provided in Table 6. Minimum protein and maximum fiber standards will be useful in evaluating the economic impact of microbial fermentation upon soybean hulls and meal later in the analysis.

Results for *Bacillus* spp.: To measure the impact on protein and fiber content of soybean hulls and meal of microbial fermentation with *Bacillus* spp., the protein and fiber control and treatment measurements in Table 1 from Vadlani, et al (2011) are applied to historical USDA soybean components data in Table 4 (see Table 7a). A 6.43% increase in protein from *Bacillus* spp. fermentation processes results in an average 0.22 pound per bushel of soybeans increase in marketable soybean hull protein if projected over the MY 2001/02 – MY 2010/11 period. An 18.34% decrease in fiber from *Bacillus* spp. fermentation processes results in an average 0.63 pound decrease in soybean hull fiber per bushel of soybeans processed if projected over the MY 2001/02 – MY 2010/11 period. The application of this microbial fermentation process would raise soybean hull protein contents

markedly above minimum NOPA standards (whereas they were approximately equal to these standards before at 0.40 pounds), and would lower fiber content below NOPA maximum fiber content levels (below 1.3-1.4 pounds) as opposed to being above these criteria originally (see NOPA standard measures in Table 6).

Soybean meal protein meal contents also improved from *Bacillus* spp. fermentation, increasing 10.60% or 4.67 pounds per processed bushel of soybeans. Soybean meal fiber content increased 0.24% or 0.11 pounds per bushel of soybeans processed. These changes raise soybean meal protein markedly above NOPA protein standards but are still comfortably below maximum fiber standards.

Using soybean hull protein values, these increases in protein from *Bacillus* spp. fermentation are projected to have increased the processed value of soybeans by $0.30 per processed bushel if they had been used over the MY 2001/02 – 2010/11 period, ceteris paribus (i.e., all else being equal) (Table 8a). The increased protein content in soybean hulls would have increased soybean hull processed value by $53.38 per ton.

Similarly, using soybean meal protein values, these increases in protein from *Bacillus* spp. fermentation are projected to have increased the processed value of soybeans by $0.06 per processed bushel if this process had been used over the MY 2001/02 – 2010/11 period, ceteris paribus (Table 8a). The increased protein content in soybean meal would have increased soybean meal processed value by an average of $33.20 per ton over the most recent 10 year time period.

Results for *Aspergillus oryzae*: To measure the impact on protein and fiber content of soybean hulls and meal of microbial fermentation with *Aspergillus oryzae*, the protein and fiber control and treatment measurements in Table 2 from Vadlani, et al (2011) are applied to the historical USDA soybean components data in Table 4 (see Table 7b). A 5.25% increase in protein from *Aspergillus oryzae* spp. fermentation processes results in an average 0.18 pound per bushel of soybeans increase in marketable soybean hull protein if projected over the MY 2001/02 – MY 2010/11 period. A 3.85% decrease in fiber from *Bacillus* spp. fermentation processes results in an average 0.13 pound decrease in soybean hull fiber per bushel of soybeans processed if projected over the same time frame. The application of this microbial fermentation process would raise soybean hull protein contents markedly above minimum NOPA standards (whereas they were approximately equal to these standards before at 0.40 pounds), and would lower fiber content further below NOPA maximum fiber content levels (below 1.3-1.4 pounds) (see NOPA standard measures in Table 6).

Soybean meal protein contents also improved from *Aspergillus oryzae* fermentation, increasing 9.93% or 4.41 pounds per processed bushel of soybeans. Soybean meal fiber content increased 1.54% or 0.68 pounds per bushel of soybeans processed. These changes raise soybean meal protein markedly above NOPA protein standards but are still comfortably below maximum fiber standards.

Using soybean hull protein values, these increases in protein from *Aspergillus oryzae* fermentation are projected to have increased the processed value of soybeans by $0.08 per processed bushel if they had been used over the MY 2001/02 – 2010/11 period, ceteris paribus (Table 8b). The increased protein content in soybean hulls would have increased soybean hull processed value by $43.58 per ton.

Similarly, using soybean meal protein values, these increases in protein from *Aspergillus oryzae* fermentation are projected to have increased the processed value of soybeans by $0.05 per processed bushel if they had been used over the MY 2001/02 – 2010/11 period, ceteris paribus (Table 8b). The increased protein content in soybean meal would have increased soybean meal processed value by and average of $27.11 per ton over the same period.

Discussion of Results

These results are favorable economically for the use of microbial fermentation of soybean hulls and meal. However, key assumptions have been made in this analysis that merit serious consideration.

Whereas this analysis assumes that changes in soybean hull and meal protein and fiber nutritional characteristics are enhanced separately (i.e., ceteris paribus), it is common practice for soybean hulls to be mixed with soybean meal for final feedstuff sales. Although the enhancement of both products would have positive impacts on their competitive marketability, enhanced levels of protein in soybean meal and hulls, and diminished levels of fiber in soybean hulls would likely cause changes in sales and distribution marketing approaches for the nutritionally enhanced versions of their products (as opposed to current marketing practices).

An enhanced version of a model developed by Brumm and Hurburgh (1990) to be released in the near future (observation based on communications with Hurburgh) could be used to assess the impact of these nutritional enhancements on the total value of processed soybeans. A key issue that such a model could address is whether – after nutritionally enhancing soybean meal - it would still be profitable to mix nutritionally enhanced soybean hulls to meet NOPA soybean meal standards.

Another assumption in this analysis is that the nutritional enhancements from microbial fermentation would take place over time without compensating readjustments in the soybean meal and hull markets (i.e., again “ceteris paribus”). It is likely that if the nutritional properties of both soybean meal and hulls had been enhance by these microbial fermentation processes over the last decade, then the prices of the products themselves would have reflected it. The use of implicit protein values in the accompanying analysis amount to an effort to economically quantify the monetary impact of these nutritional enhancements. However, in a competitive feedstuff market these nutritional enhancements for soybean meal and hulls could possibly have repositioned these products relative to competitive alternatives, and further affected meal and hull prices and revenues in unforeseen ways.

As far as it goes, this analysis anticipates “stage one” changes from nutritional enhancements in soybean hulls and meal, but does not address possible “stage two” market dynamics that would likely have occurred had such product changes been in existence throughout the last decade.

Conclusions

The nutritional enhancement of soybean hulls and soybean meal has the potential to improve the processed value of soybeans in an economically significant manner. Increased protein content in meal and hulls, and decreased fiber content in hulls are likely to have a positive effect on the market value of these products. However, the final decision by soybean processors on whether to adopt these or

similar microbial fermentation processes or not will depend on benefit-cost analysis. In other words, the decision to invest in these microbial fermentation processes will depend on weighing the cost of instituting such processes in their processing plants against the anticipated gains in sales revenue from the nutritionally enhanced soybean hull and meal product production. Finally, it is likely that the adoption of these microbial fermentation processes will change the marketing of these products as well as the manner in soybean hulls were commonly mixed with soybean meal by soybean processors in the past to meet NOPA soybean meal specifications.

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Table 4: Estimated Processing Value of Soybeans*

	Value of Soybean Processing Products per bushel										Percent of Total Soybean Crush Processed Value			No. 1 yellow Illinois @ processor	Price Spread Product value Less soybean price
	Soybean oil			Soybean meal			Soybean hulls			Total					
	Yield	Price 1/	Value	Yield	Price 2/	Value	Yield	Price 3/	Value	Value	Oil	Meal 4/	Hulls 4/		
Mktg Year	Lbs.	Cents	$	Lbs.	-----Dollars-----		Lbs.	$/ton	$	-----Dollars-----	-----Percent-----			-----Dollars-----	
1990/91	11.23	21.31	$2.39	47.47	$168.49	$4.00				$6.39	37.4%	62.6%		$5.90	$0.49
1991/92	11.42	19.31	$2.20	47.51	$177.70	$4.22				$6.43	34.3%	65.7%		$5.84	$0.59
1992/93	10.85	21.01	$2.28	47.54	$180.80	$4.30				$6.58	34.6%	65.4%		$5.95	$0.63
1993/94	10.87	26.74	$2.91	47.62	$182.65	$4.35				$7.25	40.1%	59.9%		$6.59	$0.66
1994/95	11.08	27.50	$3.05	47.33	$151.77	$3.59				$6.64	45.9%	54.1%		$5.73	$0.91
1995/96	11.15	24.90	$2.78	47.69	$217.27	$5.18				$7.96	34.9%	65.1%		$7.39	$0.57
1996/97	10.91	22.60	$2.47	47.36	$260.38	$6.17				$8.63	28.6%	71.4%		$7.80	$0.83
1997/98	11.25	25.65	$2.89	47.41	$186.55	$4.42				$7.31	39.5%	60.5%		$6.64	$0.67
1998/99	11.30	20.49	$2.31	47.25	$130.56	$3.08				$5.40	42.9%	57.1%		$5.00	$0.40
1999/2000	11.34	15.81	$1.79	47.76	$158.04	$3.77				$5.57	67.8%	32.2%		$4.90	$0.66
2000/01	11.24	13.99	$1.57	48.06	$165.60	$3.98				$5.55	28.3%	71.7%		$4.77	$0.78
2001/02	11.14	16.05	$1.79	44.27	$166.56	$3.69	3.33	$61.33	$0.10	$5.58	32.1%	66.1%	1.8%	$4.79	$0.79
2002/03	11.39	21.80	$2.48	43.90	$178.87	$3.93	3.27	$66.00	$0.11	$6.52	38.1%	60.2%	1.7%	$5.90	$0.62
2003/04	11.20	29.74	$3.33	44.32	$259.59	$5.75	3.37	$77.34	$0.13	$9.21	36.2%	62.4%	1.4%	$8.22	$0.99
2004/05	11.33	23.24	$2.63	44.26	$182.91	$4.05	3.41	$56.53	$0.10	$6.78	38.9%	59.7%	1.4%	$5.98	$0.79
2005/06	11.64	23.38	$2.72	43.83	$174.71	$3.83	3.38	$68.99	$0.12	$6.67	40.8%	57.4%	1.7%	$5.70	$0.97
2006/07	11.34	29.91	$3.39	44.03	$198.31	$4.37	3.45	$96.72	$0.17	$7.92	42.8%	55.1%	2.1%	$7.04	$0.89
2007/08	11.54	51.26	$5.92	43.95	$327.75	$7.20	3.49	$133.45	$0.23	$13.35	44.3%	53.9%	1.7%	$12.32	$1.03
2008/09	11.36	33.42	$3.80	43.93	$328.92	$7.22	3.49	$107.16	$0.19	$11.21	33.9%	64.5%	1.7%	$10.26	$0.95
2009/10	11.12	35.26	$3.92	43.81	$316.44	$6.93	3.37	$88.60	$0.15	$11.00	35.6%	63.0%	1.4%	$9.91	$1.09
2010/11*	**11.52**	**51.64**	**$5.95**	**44.39**	**$344.17**	**$7.64**	**3.59**	**$157.03**	**$0.28**	$13.87	42.9%	55.1%	2.0%	$13.08	$0.79
10 Year Avg	**11.36**	**31.57**	**$3.59**	**44.07**	**$247.82**	**$5.46**	**3.42**	**$91.32**	**$0.16**	**$9.21**	**38.6%**	**59.7%**	**1.7%**	**$8.32**	**$0.89**
Std Deviation	0.16	11.34	$1.32	0.21	$71.04	$1.57	0.09	$31.35	$0.06	$2.84	3.9%	4.0%	4.0%	$2.78	$0.13
Coeff of Var	0.01	0.36	0.37	0.00	0.29	0.29	0.03	0.34	0.37	0.31	0.10	0.07	0.14	0.33	0.15
10 Yr Trend	0.02	3.17	$0.37	(0.01)	$20.40	$0.45	0.02	$8.65	$0.02	$0.83	0.5%	(0.5%)	0.0%	$0.81	$0.02

*Data Sources: USDA Oil Crops Yearbook, Table 9 (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1290); USDA Agricultural Market Service Data Portal (http://marketnews.usda.gov/portal/lg); and U.S. Census Bureau report M311J - Fats and Oils: Oilseed Crushings (http://www.census.gov/manufacturing/cir/historical_data/m311j/index.html).

1/ Crude, tanks, f.o.b. central Illinois. 2/ 44 percent (solvent), Decatur, based on Sept.- Aug. year. Beginning 2001/02, 48 percent solvent.

2/ 44 percent (solvent), Decatur, based on Sept.- Aug. year. Beginning 2001/02, 48 percent solvent.

3/ Central Illinois, bulk.

4/ USDA reported soybean meal and hulls together as a percent of total soybean crush processed value from the 1990/91 through the 2000/01 marketing years. However, soybean meal and hulls have been reported separately since MY 2001/02.

Table 5: Derived Protein Values for Soybean Hulls & Meal

Mktg Year	Soybean Meal Protein Value [2] 44% thru 2000/01 48% from 2001/02 $/lb SBM Protein	Soybean Meal Protein Value [2] 44% thru 2000/01 48% from 2001/02 $/1% SBM Protein	Soybean Hull Protein Value 11% Protein $/lb Soybean Hull Protein	Soybean Hull Protein Value 11% Protein $/1% Soybean Hull Protein	Ratio of Soyhull to SBM Protein Values %Meal/Hulls	Ratio of Soyhull to SBM $Revenue per Bu of Soybean $SBM/$Soyhulls	Oil vs Meal Driven Mkts "Oil": SBM<=62.5% "Meal": SBM>=67.5% "Neutral": Not Oil or Meal Oil, Meal, Neutral	Total Pounds of Soybean Oil, Soybean Meal & Soybean Hulls Total Pounds
1990/91	$0.19	$3.83					Neutral	58.70
1991/92	$0.20	$4.04					Neutral	58.92
1992/93	$0.21	$4.11					Neutral	58.38
1993/94	$0.21	$4.15					Oil	58.48
1994/95	$0.17	$3.45					Oil	58.41
1995/96	$0.25	$4.94					Neutral	58.85
1996/97	$0.30	$5.92					Meal	58.27
1997/98	$0.21	$4.24					Oil	58.66
1998/99	$0.15	$2.97					Oil	58.55
1999/2000	$0.18	$3.59					Oil	59.10
2000/01	$0.19	$3.76					Meal	59.30
2001/02	$0.17	$3.47	$0.28	$5.58	62.2%	2.8%	Meal	58.75
2002/03	$0.19	$3.73	$0.30	$6.00	62.1%	2.7%	Oil	58.56
2003/04	$0.27	$5.41	$0.35	$7.03	76.9%	2.3%	Neutral	58.89
2004/05	$0.19	$3.81	$0.26	$5.14	74.1%	2.4%	Oil	59.01
2005/06	$0.18	$3.64	$0.31	$6.27	58.0%	3.0%	Oil	58.85
2006/07	$0.21	$4.13	$0.44	$8.79	47.0%	3.8%	Oil	58.82
2007/08	$0.34	$6.83	$0.61	$12.13	56.3%	3.2%	Oil	58.98
2008/09	$0.34	$6.85	$0.49	$9.74	70.3%	2.6%	Neutral	58.78
2009/10	$0.33	$6.59	$0.40	$8.05	81.8%	2.2%	Neutral	58.30
2010/11*	$0.36	$7.17	$0.71	$14.28	50.2%	3.7%	Oil	59.51
10 Yr Avg	**$0.26**	**$5.16**	**$0.42**	**$8.30**	**63.9%**	**2.9%**	**Neutral**	**58.85**
Std Deviation	$0.07	$1.48	$0.14	$2.85	11.0%	0.5%		0.30
Coeff of Var	0.29	0.29	0.34	0.34	0.17	0.19		0.01
10 Yr Trend	$0.02	$0.43	$0.04	$0.79	-0.4%	0.1%		0.03

Table 6. NOPA Composition Standards & Tolerances for Soybean Hulls & Soybean Meal*

	Soybean Meal Composition - 44% Protein				Soybean Meal Composition - 48% Protein				Soybean Hulls Composition - 11% Protein	
	Protein Standard Minimum	**Protein Adj.** Tolerance Minimum	**Fiber** Standard Maximum	**Fiber Adj.** Tolerance Maximum	**Protein** Standard Minimum	**Protein Adj. Tolerance Minimum**	**Fiber** Standard Maximum	**Fiber Adj. Tolerance Maximum**	**Protein** Standard Average	**Fiber** Standard Average
	44.00%	43.50%	7.00%	7.50%	47.50%	**47.00%**	3.30%	**3.80%**	11.00%	39.60%
Mktg Year	Pounds	Pounds	Pounds	Pounds	Pounds	**Pounds**	Pounds	**Pounds**	Pounds	Pounds
1990/91	20.9	20.7	3.3	3.6						
1991/92	20.9	20.7	3.3	3.6						
1992/93	20.9	20.7	3.3	3.6						
1993/94	21.0	20.7	3.3	3.6						
1994/95	20.8	20.6	3.3	3.5						
1995/96	21.0	20.7	3.3	3.6						
1996/97	20.8	20.6	3.3	3.6						
1997/98	20.9	20.6	3.3	3.6						
1998/99	20.8	20.6	3.3	3.5						
1999/2000	21.0	20.8	3.3	3.6						
2000/01	21.1	20.9	3.4	3.6						
2001/02					21.0	**20.8**	1.5	**1.7**	0.4	1.3
2002/03					20.9	**20.6**	1.4	**1.7**	0.4	1.3
2003/04					21.1	**20.8**	1.5	**1.7**	0.4	1.3
2004/05					21.0	**20.8**	1.5	**1.7**	0.4	1.4
2005/06					20.8	**20.6**	1.4	**1.7**	0.4	1.3
2006/07					20.9	**20.7**	1.5	**1.7**	0.4	1.4
2007/08					20.9	**20.7**	1.5	**1.7**	0.4	1.4
2008/09					20.9	**20.6**	1.4	**1.7**	0.4	1.4
2009/10					20.8	**20.6**	1.4	**1.7**	0.4	1.3
2010/11*					21.1	**20.9**	1.5	**1.7**	0.4	1.4

NOPA: National Oilseed Processors Association (http://www.nopa.org/)

Table 7a. Projected Results of KSU *Bacillus* spp. Microbial Fermentation on Soybean Hulls & Meal Protein & Fiber Content

Extrapolation of soybean meal & hull fermentation *Bacillus* spp. microbial culture research impacts for MY 2001/12 – 2010/11

	Soybean Meal						Soybean Hulls					
	Control Protein	Bioprocessed Protein	Difference Protein	Control Fiber	Bioprocessed Fiber	Difference Fiber	Control Protein	Bioprocessed Protein	Difference Protein	Control Fiber	Bioprocessed Fiber	Difference Fiber
	46.88%	57.48%	10.60%	4.19%	4.43%	0.24%	12.06%	18.49%	6.43%	50.80%	32.46%	(18.34%)
Mktg Year	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu
2001/02	20.75	25.45	4.69	1.85	1.96	0.11	0.40	0.62	0.21	1.69	1.08	(0.61)
2002/03	20.58	25.23	4.65	1.84	1.94	0.11	0.39	0.60	0.21	1.66	1.06	(0.60)
2003/04	20.78	25.47	4.70	1.86	1.96	0.11	0.41	0.62	0.22	1.71	1.09	(0.62)
2004/05	20.75	25.44	4.69	1.85	1.96	0.11	0.41	0.63	0.22	1.73	1.11	(0.63)
2005/06	20.55	25.20	4.65	1.84	1.94	0.11	0.41	0.62	0.22	1.72	1.10	(0.62)
2006/07	20.64	25.31	4.67	1.84	1.95	0.11	0.42	0.64	0.22	1.75	1.12	(0.63)
2007/08	20.60	25.26	4.66	1.84	1.95	0.11	0.42	0.65	0.22	1.78	1.13	(0.64)
2008/09	20.59	25.25	4.66	1.84	1.95	0.11	0.42	0.65	0.22	1.77	1.13	(0.64)
2009/10	20.54	25.18	4.64	1.84	1.94	0.11	0.41	0.62	0.22	1.71	1.09	(0.62)
2010/11*	20.81	25.52	4.71	1.86	1.97	0.11	0.43	0.66	0.23	1.82	1.17	(0.66)
10 Yr Avg.	**20.66**	**25.33**	**4.67**	**1.85**	**1.95**	**0.11**	**0.41**	**0.63**	**0.22**	**1.74**	**1.11**	**(0.63)**

Table 7b. Projected Results of KSU *Aspergillus* oryzae Microbial Fermentation on Soybean Hulls & Meal Protein & Fiber Content

Extrapolation of soybean meal & hull fermentation *Aspergillus oryzae* microbrial culture research for MY 2001/02 – 2010/11

	Soybean Meal						Soybean Hulls					
	Control Protein	Bioprocessed Protein	Difference Protein	Control Fiber	Bioprocessed Fiber	Difference Fiber	Control Protein	Bioprocessed Protein	Difference Protein	Control Fiber	Bioprocessed Fiber	Difference Fiber
	45.81%	55.74%	9.93%	3.74%	5.28%	1.54%	12.06%	17.31%	5.25%	32.97%	29.12%	(3.85%)
Mktg Year	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu	Lbs/bu
2001/02	20.28	24.68	4.40	1.66	2.34	0.68	0.40	0.58	0.18	1.10	0.97	(0.13)
2002/03	20.11	24.47	4.36	1.64	2.32	0.68	0.39	0.57	0.17	1.08	0.95	(0.13)
2003/04	20.30	24.70	4.40	1.66	2.34	0.68	0.41	0.58	0.18	1.11	0.98	(0.13)
2004/05	20.28	24.67	4.40	1.66	2.34	0.68	0.41	0.59	0.18	1.13	0.99	(0.13)
2005/06	20.08	24.43	4.35	1.64	2.31	0.68	0.41	0.58	0.18	1.11	0.98	(0.13)
2006/07	20.17	24.54	4.37	1.65	2.32	0.68	0.42	0.60	0.18	1.14	1.01	(0.13)
2007/08	20.13	24.50	4.36	1.64	2.32	0.68	0.42	0.60	0.18	1.15	1.02	(0.13)
2008/09	20.12	24.49	4.36	1.64	2.32	0.68	0.42	0.60	0.18	1.15	1.02	(0.13)
2009/10	20.07	24.42	4.35	1.64	2.31	0.67	0.41	0.58	0.18	1.11	0.98	(0.13)
2010/11*	20.34	24.74	4.41	1.66	2.34	0.68	0.43	0.62	0.19	1.18	1.05	(0.14)
10 Yr Avg.	**20.19**	**24.56**	**4.38**	**1.65**	**2.33**	**0.68**	**0.41**	**0.59**	**0.18**	**1.13**	**0.99**	**(0.13)**

Table 8a. Market Value of Added Protein in Soybean Hulls & Meal from *Bacillus* spp. Microbial Fermentation

Estimate of added value from soybean hull fermentation using Bacillus spp. microbial culture research on soybean processing values for MY 2001/12 – 2010/11

	Soybean Meal Protein Value 48% Protein	Soybean Hull Protein Value 11% Protein	Industry Production of Soybean Hulls per bu of Soybeans	Added Industry % Protein via **KSU Bacillus** Bioprocessing **6.43%**	SBM Protein $ Added Value of Protein via **KSU Bacillus** Bioprocessing	SBM Protein $ Added Value of Protein via **KSU Bacillus** Bioprocessing	Soyhull Protein $ Added Value of Protein via **KSU Bacillus** Bioprocessing	Soyhull Protein $ Added Value of Protein via **KSU Bacillus** Bioprocessing
Marketing Year	$/lb SBM Protein	$/lb SoyHull Protein	Pounds per bu of soybeans	Added Protein Lbs.	$/bu of Soybeans	$/ton of Soyhulls	$/bu of Soybeans	$/ton of Soyhulls
2001/02	$0.17	$0.28	3.33	0.214	$0.04	$22.31	$0.06	$35.85
2002/03	$0.19	$0.30	3.27	0.210	$0.04	$23.96	$0.21	$38.58
2003/04	$0.27	$0.35	3.37	0.217	$0.06	$34.77	$0.26	$45.21
2004/05	$0.19	$0.26	3.41	0.219	$0.04	$24.50	$0.19	$33.05
2005/06	$0.18	$0.31	3.38	0.217	$0.04	$23.40	$0.23	$40.33
2006/07	$0.21	$0.44	3.45	0.222	$0.05	$26.57	$0.34	$56.54
2007/08	$0.34	$0.61	3.49	0.225	$0.08	$43.90	$0.48	$78.01
2008/09	$0.34	$0.49	3.49	0.224	$0.08	$44.06	$0.38	$62.64
2009/10	$0.33	$0.40	3.37	0.217	$0.07	$42.39	$0.29	$51.79
2010/11*	$0.36	$0.71	3.59	0.231	$0.08	$46.10	$0.59	$91.79
10 year average	**$0.26**	**$0.42**	**3.42**	**0.220**	**$0.06**	**$33.20**	**$0.30**	**$53.38**

Table 8b. Market Value of Added Protein in Soybean Hulls & Meal from *Aspergillus oryzae* Microbial Fermentation

Estimate of added value from soybean hull fermentation using Aspergillus oryzae microbial culture research on soybean processing values for MY 2001/12 – 2010/11

	Soybean Meal Protein Value 48% Protein	Soybean Hull Protein Value 11% Protein	Industry Production of Soybean Hulls per bu of Soybeans	Added Industry % Protein via **KSU Aspergillus** Bioprocessing **5.25%**	SBM Protein $ Added Value of Protein via **KSU Aspergillus** Bioprocessing	SBM Protein $ Added Value of Protein via **KSU Aspergillus** Bioprocessing	Soyhull Protein $ Added Value of Protein via **KSU Aspergillus** Bioprocessing	Soyhull Protein $ Added Value of Protein via **KSU Aspergillus** Bioprocessing
Marketing Year	$/lb SBM Protein	$/lb SoyHull Protein	Pounds per bu of soybeans	Added Protein Lbs.	$/bu of Soybeans	$/ton of Soyhulls	$/bu of Soybeans	$/ton of Soyhulls
2001/02	$0.17	$0.28	3.33	0.175	$0.03	$18.22	$0.05	$29.27
2002/03	$0.19	$0.30	3.27	0.172	$0.03	$19.56	$0.05	$31.50
2003/04	$0.27	$0.35	3.37	0.177	$0.05	$28.36	$0.06	$36.91
2004/05	$0.19	$0.26	3.41	0.179	$0.03	$20.01	$0.05	$26.98
2005/06	$0.18	$0.31	3.38	0.177	$0.03	$19.11	$0.06	$32.93
2006/07	$0.21	$0.44	3.45	0.181	$0.04	$21.69	$0.08	$46.16
2007/08	$0.34	$0.61	3.49	0.183	$0.06	$35.85	$0.11	$63.69
2008/09	$0.34	$0.49	3.49	0.183	$0.06	$35.98	$0.09	$51.15
2009/10	$0.33	$0.40	3.37	0.177	$0.06	$34.61	$0.07	$42.29
2010/11*	$0.36	$0.71	3.59	0.189	$0.07	$37.64	$0.13	$74.95
10 year average	**$0.26**	**$0.42**	**3.42**	**0.179**	**$0.05**	**$27.11**	**$0.08**	**$43.58**

Appendix

Appendices figures 1 through 8 depict trends and inter-relationships in U.S. soybean processor aggregate data.

Appendix Figure 1 shows the yield of processed soybean components on a marketing year average basis – illustrating the consistency of soybean oil, meal and hull production efficiency since the 2001/02 marketing year. However, the total combined pounds of soybean oil, meal and hulls in MY 2011/12 to date (59.51 pounds) for a 60 pound bushel of soybeans is the higher production efficiency estimate since the beginning of the 10 year period. Total average soybean product output of 59.01 pounds in MY 2004/05 is the only other year with implicit soybean product production over 59 pounds per bushel. **Appendix Figure 2** presents monthly average soybean processing component yields for September 2005 through June 2011 – with the same trends as in the aggregate marketing year average data in Figure 1.

Appendix Figure 3 shows the marketing year average prices of processed soybean components on a uniform basis (i.e., cents per pound) Figure 3 shows the higher per pound value of soybean oil than either soybean meal or hulls, and also the higher market value of soybean meal relative to hulls since the 2001/02 marketing year. In MY 2010/11 to date, the price of soybean oil (i.e., $0.52 per pound) is $0.35 higher than for soybean meal ($0.17 per pound) and $0.44 higher than for soybean hulls ($0.08 per pound). **Appendix Figure 4** presents monthly average soybean component prices for September 2005 through July 2011 – with the same trends as in the aggregate marketing year average data in Figure 4.

Appendix Figure 5 shows the marketing year average value or revenue of processed soybean components on a $ per bushel basis. Figure 5 shows the marked increase in processed soybean values since MY 207/08, caused by increases in all three soybean components. Soybean oil processed values ranged from $1.79 to $3.39 per bushel of soybeans during the MY 2001/02 to MY 2006/07 period, but increased to a range of $3.80 to $5.95 during MY 2007/08 through MY 2010/11. Soybean meal processed values ranged from $3.69 to $5.75 per bushel of soybeans during the MY 2001/02 to MY 2006/07 period, but increased to a range of $6.93 to $7.64 during MY 2007/08 through MY 2010/11. Soybean hull processed values ranged from $0.10 to $0.13 per bushel of soybeans during the MY 2001/02 to MY 2005/06 period, but increased to a range of $0.15 to $0.28 during MY 2006/07.

Appendix Figure 6 shows the marketing year average percent of total processed soybean value from the separate components on a percent of total soybean value basis. The 2.0% value of soybean hulls of total soybean processed value for MY 2010/11 is second only to 2.1% in MY 2006/07. In no other years did soybean hull values account for over 2.0% of total processed soybean value. **Appendix Figure 7** presents monthly average soybean component values for September 2005 through July 2011 – with the same trends as in the aggregate marketing year average data in Figure 5.

Appendix Figure 8 shows the relationships between marketing year average soybean processing values and soybean market prices as represented by soybean processing spread for the MY 1990/91 through MY 2010/11 period. Figure 8 shows that soybean processing spreads have generally trended

higher since MY 1990/91, but also that the processing spread of $0.79 per bushel for MY 2010/11 to date is equal to the lowest processing margin since MY 2004/05.

Figure 1. Yields of Processed Soybean Components - Marketing Year Avg.
MY 2001/02 through MY 2011/12*

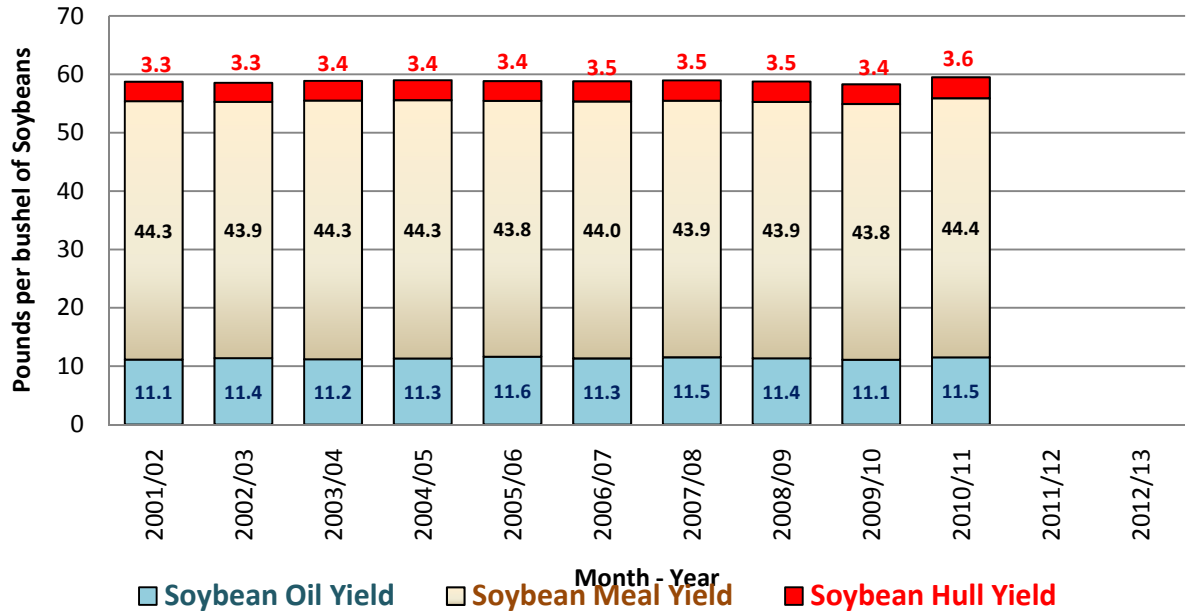
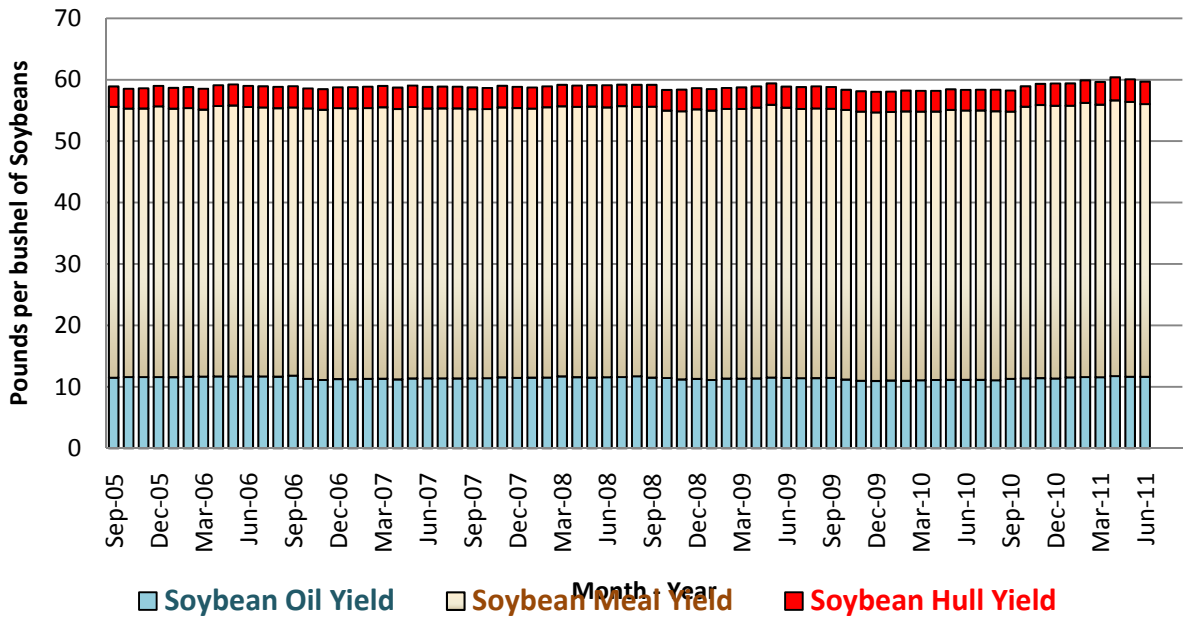


Figure 2. Yields of Processed Soybean Components - Monthly Avg.
September 2005 through June 2011



Appendix (continued)

Figure 3. Prices for Soybean Oil, Meal & Hulls - Marketing Year Average
MY 2001/02 through MY 2011/12*

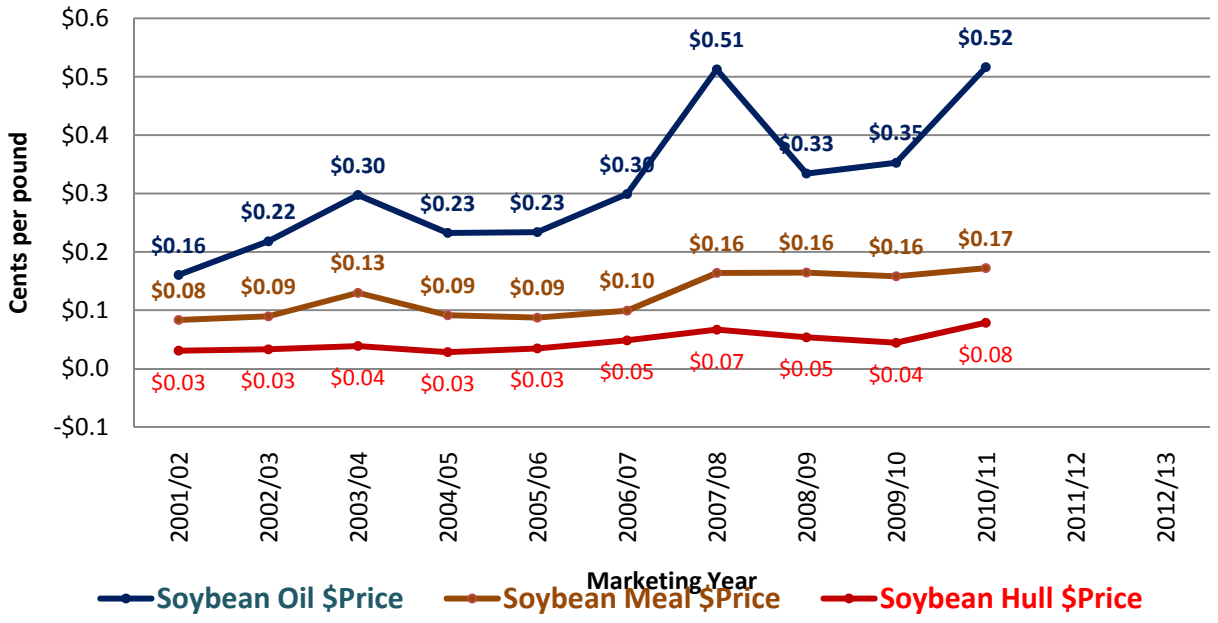
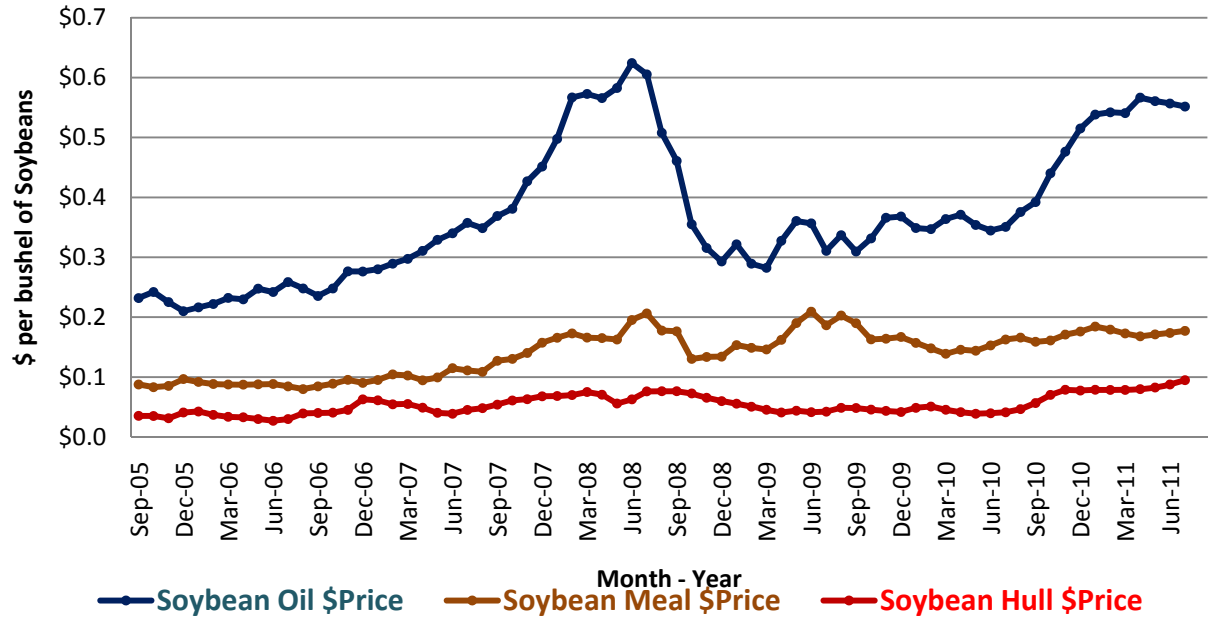


Figure 4. Prices for Soybean Oil, Meal & Hulls - Monthly Average
September 2005 through July 2011



Appendix (continued)

Figure 5. Value of Processed Soybeans Components - Marketing Year Avg.
MY 2001/02 through MY 2011/12*

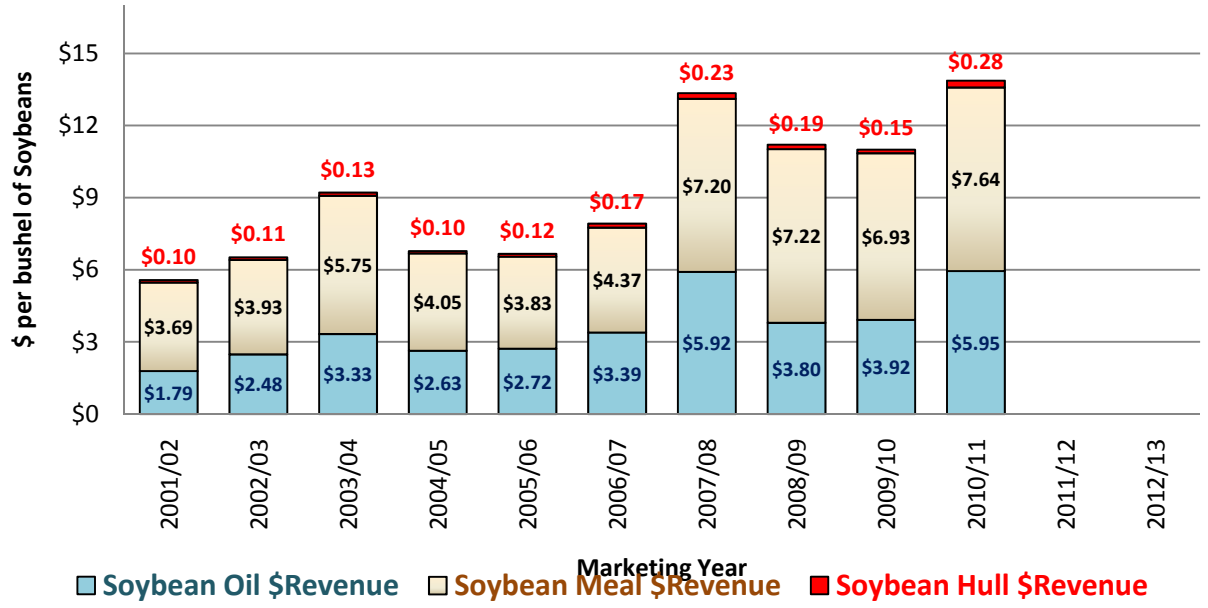
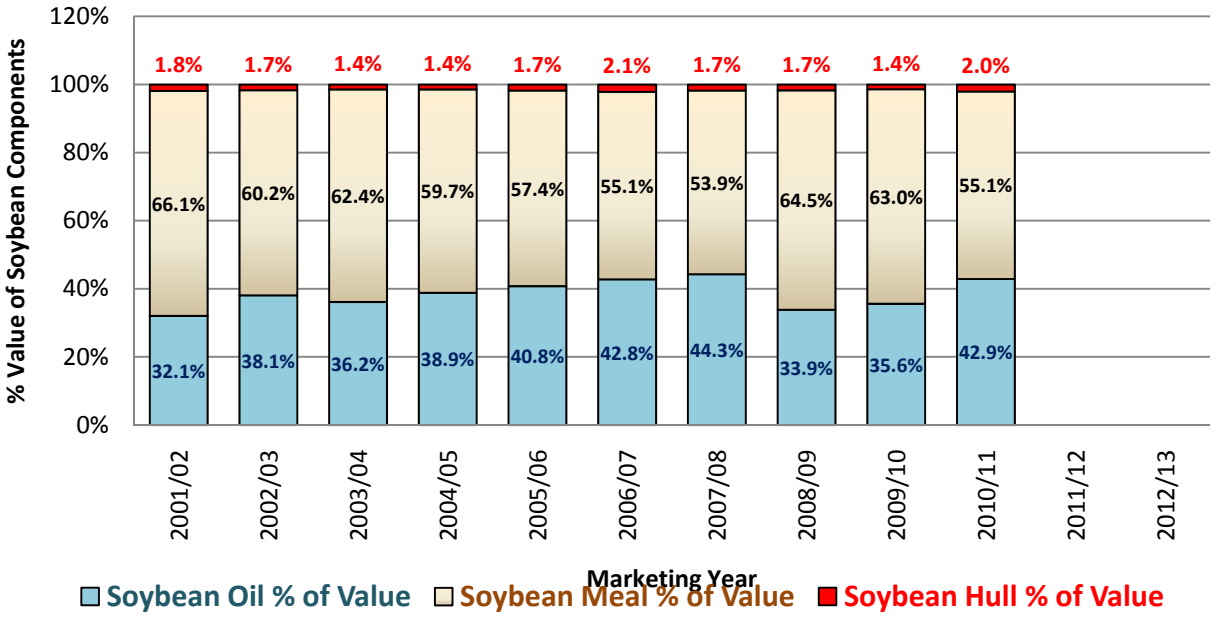


Figure 6. Percent Value of Processed Soybean Components
MY 2001/02 through MY 2011/12*



Appendix (continued)

Figure 7. Value of Processed Soybean Components - Monthly Average
September 2005 through June 2011

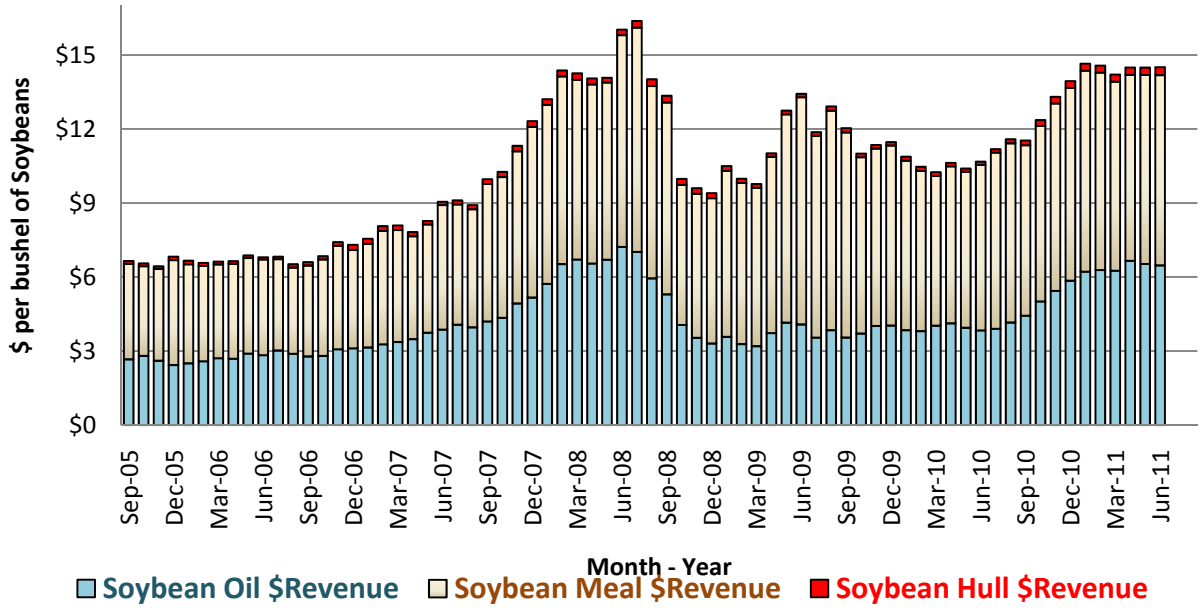


Figure 8. Spread Between Value of Products & Soybean Price
MY 1990/91 through MY 2011/12*