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Agricultural Land Use Change in the Corn Belt

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THE CONVERSION of grass-like land to row crops (in our case, corn or soybeans) and general land use change in the Corn Belt region has important water quality implications. Additional agricultural production can increase nutrient runoff into the Upper Mississippi River Basin, thereby increasing the size of the Gulf of Mexico hypoxic zone. We use two data sources from the National Agricultural Statistical Services (NASS) to obtain detailed land use information in the Corn Belt from 2006 to 2014. We also identify and analyze any similarities and discrepancies between both data sources.

Focusing on the Corn Belt, we use NASS survey data and Cropland Data Layers (CDL) to obtain corn and soybean acres for twelve states: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota and Wisconsin. The NASS survey website provides county-level data for acres of both corn and soybeans planted from 2006 to 2014, and we convert CDL data to obtain comparable information at the same level.[1,2,3]

We utilize ten CDL categories for our land use comparison: corn, soybean, alfalfa, other hay/non alfalfa, switch grass, idle cropland, grass/pasture land, grassland herbaceous, grass/pasture, and pasture/hay. The corn and soybean categories are used to study changes in row crop acreage, and the remaining eight categories are aggregated into a grass-like category, used to study grass-like land changes. NASS survey does not provide county-level data on planted acres of alfalfa, hay, haylage and pastureland, thus as an alternative source for grass-like land data, we turn our attention to Conservation Reserve Program (CRP) acres. In particular, USDA Farm Service Agency offers CRP enrollment information at a county level.[4]

We first study land use change from 2006 to 2014 by computing total corn and soybean acreage in the Corn Belt. CDL reports roughly 122.2 and 137.5 million combined corn and soybean acres in 2006 and 2014, respectively. NASS survey data reports 128.5 and 135 million combined corn and soybean acres in 2006 and 2014, respectively. For row crop acreage, we observe a larger difference between data sources in 2006 than we do in 2014. In 2006, NASS survey data reports 6.3 million more acres than CDL, and NASS reports 2.5 million less acres than CDL in 2014. According to NASS survey data, total corn and soybean acreage increased by roughly five percent from 2006 to 2014, but CDL data shows roughly a 12 percent increase in the same period. While total acreage from both sources seems closer in 2014, the large difference in 2006 is reflected in the large percentage change differences from 2006 to 2014.

Focusing on land use change from each data source, we calculate the percentage change in corn and soybean acreage from 2006 to 2014. We illustrate the relative change in corn and soybean acreage in 2014 relative to 2006 in Figures 1 and 2.

NASS survey does not provide information on every county, as shown by the white areas in Figure 1. Major relative differences in acreage occur in the outer portions of each map, as shown by the darker areas. In particular, we notice larger increases in corn and soybean acreage in North and South Dakota in both maps, as shown by darker green areas. Moreover, CDL data shows a larger increase in Minnesota relative to NASS survey data, however, both show an increase in the northwestern part of the state. Overall, there is less variability in corn and soybean acreage in the inner portion of the map (e.g., Iowa, Illinois, Indiana, and portions of Wisconsin), as shown by lighter colors.

We expect CDL data to report more grass-like acres, as it includes land beyond that enrolled in CRP. In other words, we use CRP data as a proxy for grass-like land, but we are aware that it does not include all types of grass in the region. We compute the relative change in grass-like and CRP acreage in 2014 relative to 2006 following the same process as for corn and soybean acreages, as shown in Figures 3 and 4.

Figure 3 illustrates major decreases in grass-like land in Illinois, Indiana, and around the Minnesota/North Dakota border, consistent with

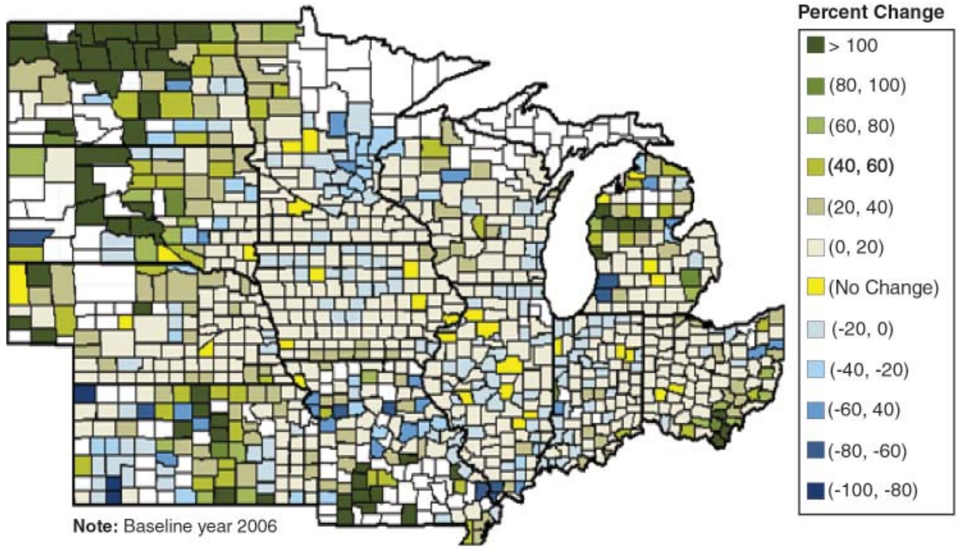

Figure 1. Corn and soybean acreage percentage changes in 2014 (Nass Survey)

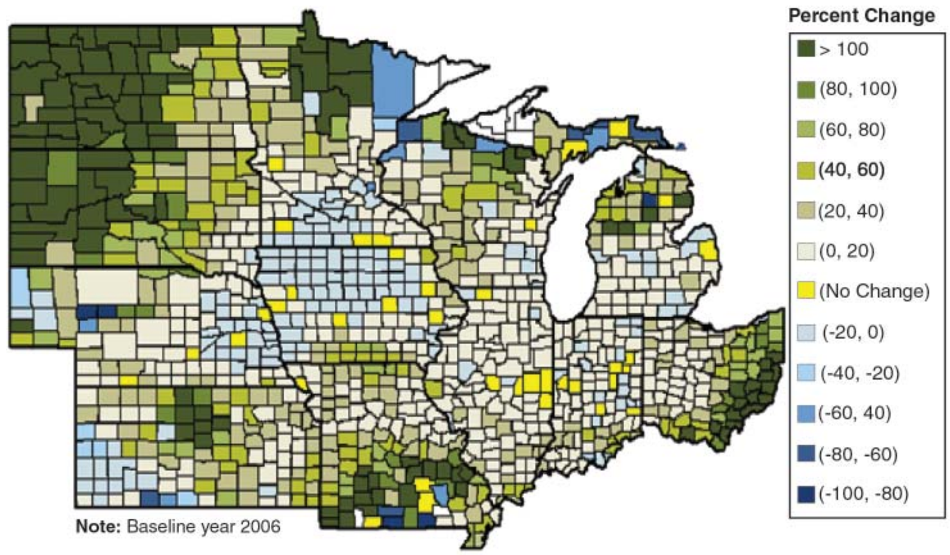

Figure 2. Corn and soybean acreage percentage changes in 2014 (CDL Survey)

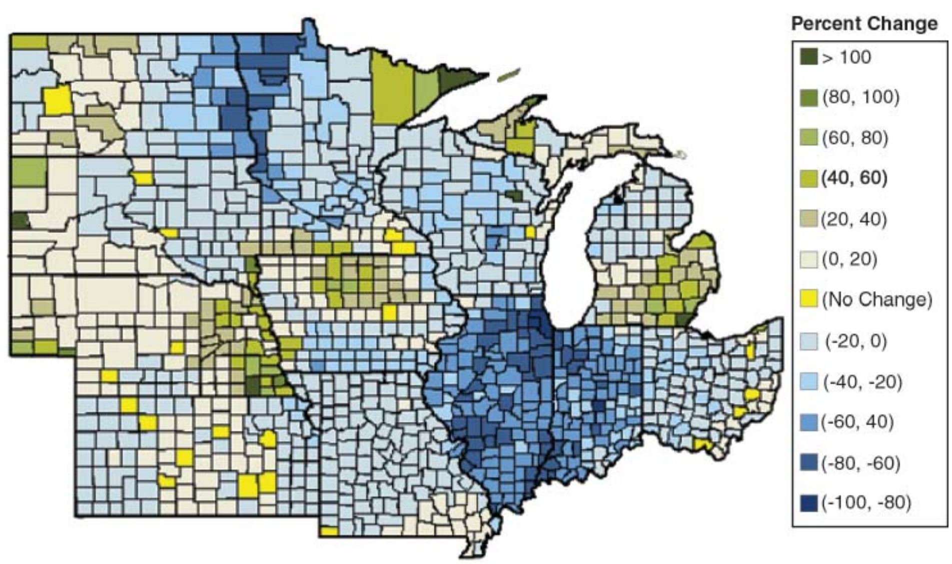

Figure 3. Grass-like acreage percentage changes in 2014 (CDL Survey)

Inside this issue

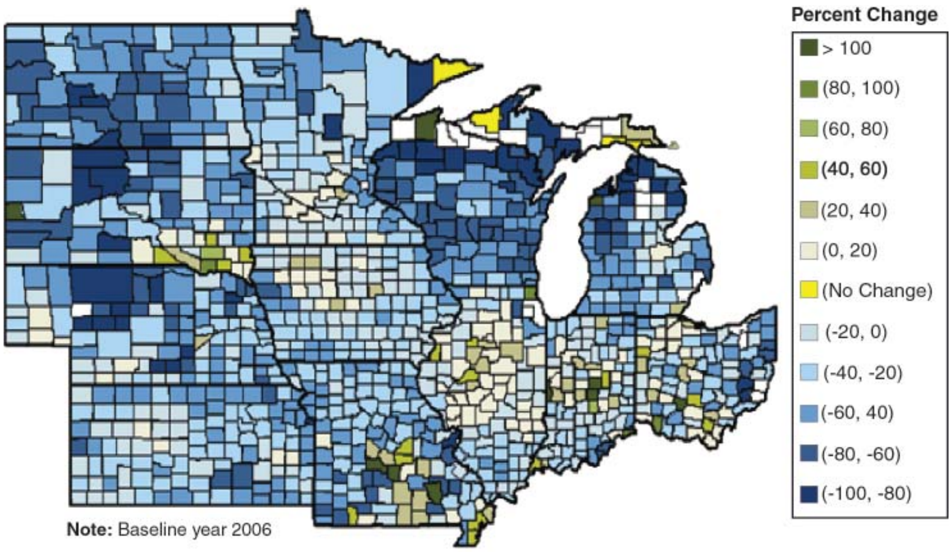

Figure 4. CRP acreage percentage changes in 2014 (USDA FSA)

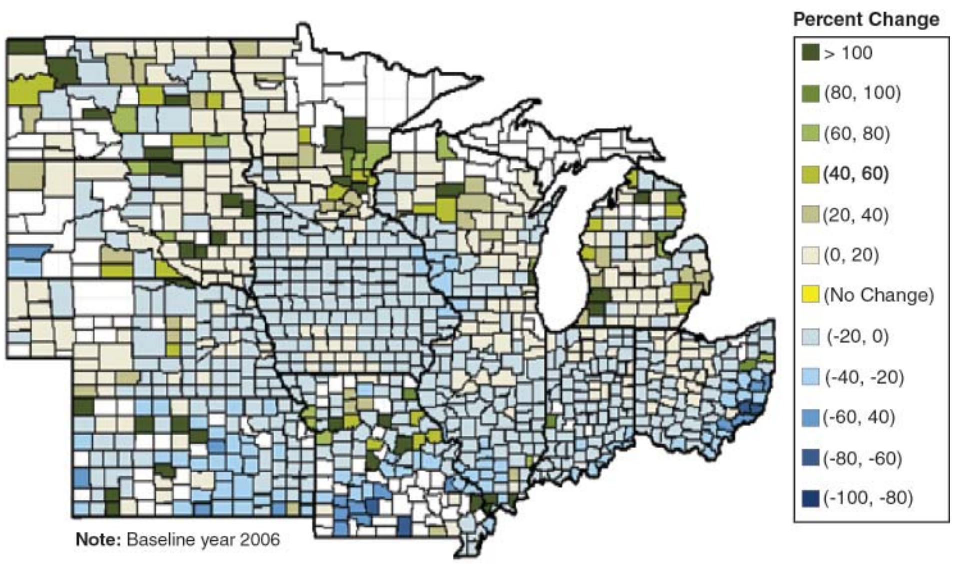

Figure 5. Spatial difference in corn and soybean acreage in 2014 (CDL versus NASS Surveys)

increases in corn and soybean acreage in those areas (see Figure 2). Missouri, Ohio, and Wisconsin show an overall decrease in grass-like acreage, also consistent with an increase in corn and soybean acres (see Figure 2). We also observe decreases in grass-like land in southern Iowa and northern Michigan. In Iowa, this coincides with an increase in corn and soybean acres (see Figure 2). In the Dakotas, we observe decreases in grass-like land primarily in the eastern portions of the states, which is again consistent with changes shown in Figure 2. The western portion of South Dakota shows an increase in grass-like acres (Figure 3) and in corn and soy bean acres (Figure 2).

Figure 4 shows that CRP acres have decreased in 2014 relative to 2006 in the majority of counties. We observe major changes in the Dakotas, Minnesota, Wisconsin, Michigan, Missouri, Kansas, and Nebraska. Overall, both NASS survey (Figure 1) and CDL (Figure 2) data show increases in corn and soybean acres that coincide with decreases in CRP acres (Figure 4). Some counties in Iowa, Illinois, Indiana, Ohio and the southern portion of Missouri show increases in CRP acres.

Both data sources show increases in grass-like land in Wisconsin, most counties in Minnesota and the Minnesota and North and South Dakota borders, and several counties in Kansas and Nebraska. Both maps suggest that Iowa has decreased grass-like land in the southern portion of the state. While CRP acres have decreased in most of the region, CDL data shows increases in grass-like land in the north-central part of Iowa, the majority of Nebraska, and several counties in the Dakotas, Kansas, and Michigan. In the northeastern part of Minnesota, CDL data shows a substantial increase in grass-like acres, while NASS survey shows an increase or no change in CRP acres.

We also compute the correlation between corn and soybean acreage in both datasets in 2014. The Pearson correlation is 0.98, suggesting that corn and soybean acreage are highly correlated between both data sources. Furthermore, we look at spatial differences in corn and soybean acreage between both data sources in 2014.

As shown in Figure 5, we observe smaller variations between data sets in Iowa, Illinois, Indiana, and most of Ohio, as depicted by lighter colors. We observe larger data discrepancies in the outer portions of the map, specifically, some counties in the Dakotas, Minnesota, Wisconsin, Michigan, Missouri, and Kansas, as depicted by darker green or darker blue colors. ■

Footnotes

[1] *http://quickstats.nass.usda.gov/.* We exclude data where location is denoted as "Other", since it cannot be linked to a specific county.

[2] *http://www.nass.usda.gov/research/Cropland/metadata/meta.htm* have meta information about state CDLs. For Michigan, CDL is available from 2007, not 2006.

[3] From CDL, we acquire counts of pixels attributed to certain land use types for 2006 and 2014 and convert these counts to area units according to the resolution in the raster CDL files.

[4] *http://www.apfo.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp-st*

Capturing Dynamic Linkages Between Agriculture and Energy in Biofuel Assessment: The Case of Iowa

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This article is based on the study "Integration of agricultural and energy system models for biofuel assessment," by Elobeid, A., S. Tokgoz, R. Dodder, T. Johnson, O. Kaplan, L. Kurkalova, and S. Secchi published in Environmental Modeling and Software, Volume 48, October 2013, Pages 1-16.

THE EXPANSION of biofuel production brought about a significant change in the dynamics between agriculture and energy. In the past, energy prices influenced the agricultural sector primarily through agricultural commodity production and transportation costs. Now, because of biofuels, the energy sector impacts the agricultural sector through feedstock demand and prices; and conversely, the agricultural sector now impacts energy prices through its competition in the transportation energy sector. In the past, studies analyzed the impact of biofuel production on agricultural and energy markets separately without accounting for sector feedback. However, in analyzing the impact of biofuels, the interconnectedness between the agricultural and energy sectors should not be ignored.

We present a modeling framework to capture the dynamics of this 'new' linkage between agriculture and energy. Our framework incorporates agricultural and energy market interactions at the macro level, as well as the assessment of farmers' production practices at the micro (field) level in Iowa. This is achieved by linking two macro models: the Center for Agricultural and Rural Development's (CARD) US agricultural markets model and the US Environmental Protection Agency's (EPA) MARKet ALlocation (MARKAL) energy systems model.[1] The models vary in that CARD's model treats energy variables, such as crude oil and natural gas prices, as exogenous, and treats agricultural variables such as corn prices as endogenous. The MARKAL model, on the other hand, treats energy prices as endogenous and agricultural variables such as corn prices as exogenous. The two models are first run separately to establish an initial baseline for each model; once the models are linked, a joint baseline that projects supply, utilization, and prices in the agricultural and energy markets up to the year 2024 is established. The joint baseline allows for feedback between the agricultural and energy sectors in the model, and then the results from the initial baseline and the integrated baseline are used in a micro model to assess the shifts in farming practices resulting from biofuel production.

We use a field-level, GIS-based micro model to assess the land use implications of changes in the agricultural and energy markets in Iowa on a micro level. The micro-level model uses 30-square-meter grids based on USDA remote sensing crop cover maps and budget analysis to simulate the expected land use and management choices of Iowa farmers on each grid unit. The model assumes that Iowa famers choose between continuous corn, corn-soybeans, and corn-corn-soybeans rotations. There are also three alternative tillage systems: conventional, mulch, and no-till. Additionally, farmers can choose between collecting and not collecting corn stover without major erosion control problems. For each of the rotation-tillage-stover collection choices, the model estimates the yearly average expected net returns. The expected profit-maximizing rotation-tillage-stover collection choice is the one that maximizes the yearly average expected net returns.

Table 1 shows the initial baseline results for marketing year 2020/21 for the CARD agricultural model (Column A) and the baseline results after the integration with MARKAL (Column B) when feedback between the two models is endogenized.[2] Pre-linkage, when the energy sector is exogenous in the CARD model, supply demand and prices for corn and ethanol are higher—gasoline prices are 18 percent higher relative to post-linkage levels. Corn ethanol demand is above mandated levels, which leads to higher demand for corn as a feedstock for ethanol production. The higher corn price results in more land planted to corn. Post-linkage CARD baseline results (Column B) show lower ethanol production (by 22 percent) and disappearance (by 12 percent) when compared with the pre-linkage CARD baseline. Consequently, corn planted area and production are lower. Thus, with biofuel production, not accounting for feedback between the agricultural and energy sectors tends to overestimate corn and ethanol supply, demand, and prices.

Both pre- and post-linkage results for crop area and prices from the CARD model and regional energy prices from MARKAL are incorporated into the micro model to see how land use and management decisions change with and without feedback effects. Figure 1 shows the micro-level results for the

Pre- and post-linkage baseline results in the CARD agricultural model for marketing year 2020/21

	Column A Initial (Pre-linkage) Baseline			Column B Post-linkage (Converged) Baseline		
	Corn	Soybeans	Wheat	Corn	Soybeans	Wheat
Planted area (million acres)	114	68	61	95	74	59
Production (million bushels)	18,916	3,164	2,358	15,818	3,349	2,417
Domestic use (million bushels)	16,259	2,441	1,356	13,164	2,416	1,327
Feed & residual[a]	6,155	2,247	214	5,389	2,234	168
Fuel alcohol	8,579			6,320		
HFCS	581			535		
Food & other	915		1,056	896		1,075
Seed	28	194	86	24	183	84
Exports (million bushels)	2,605	731	1,117	2,662	939	1,203
Ending stocks (million bushels)	1,212	221	332	1,493	250	631
Farm price ($/bushel)	4.37	10.81	5.86	4.28	9.96	6.37
Variable production expenses ($/acre)	301	140	126	320	141	134

	Initial Baseline Ethanol	Post-linkage Baseline Ethanol
Production (million gallons)	37,153	28,900
From corn	24,618	18,357
From other feedstocks[b]	35	0
From cellulosic	12,500	10,543
Domestic disappearance (million gallons)	40,527	35,572
Conventional	24,500	12,775
Other advanced ethanol	3,526	12,255
Cellulosic	12,500	10,543
Net imports (million gallons)	3,500	6,741
Ending stocks (million gallons)	2,028	1,268
Unleaded gasoline price, FOB Omaha ($/gallon)	2.71	2.30
Unleaded gasoline price, retail ($/gallon)	3.33	3.06
Conventional ethanol price, rack Omaha ($/gallon)	1.69	1.60

[a] For soybeans, this refers to crush.
[b] This represents ethanol from non-corn feedstocks, which were not included in the integrated version.

pre- and post-linkage baselines for Iowa cropland. The pre-linkage baseline shows larger corn acreage under continuous corn with stover removal when compared to the post-linkage baseline, which has more corn-soybean rotation.

Moving from the pre- to post-linkage baseline, over 2.3 million acres of cropland (less than 11 percent of Iowa's cropland) switches from continuous corn to corn-soybeans and from conventional to conservation tillage. This result has important implications for the environmental outcomes of biomass production—continuous corn rotation requires higher levels of nitrogen fertilizer and is associated with higher rates of conventional tillage as opposed to more environmentally benign conservation tillage. Figure 1 shows that, in the pre-linkage baseline, more intensified corn production is concentrated on Iowa's most productive land in the north-central part of the state. This result indicates that without the linkage between agriculture and energy, models may overestimate the extent

continued on page 10

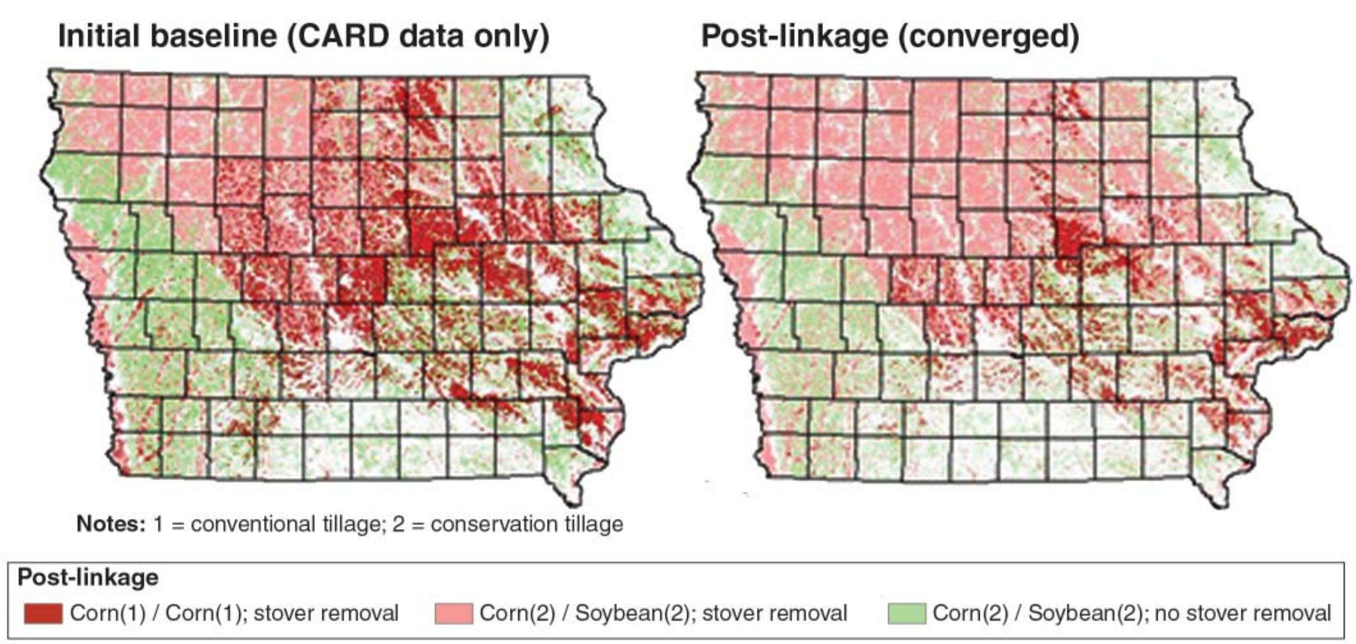

Figure 1. Crop rotations and management practices in Iowa pre-and post-linkages

Searching for Profitable Margins

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AGRICULTURE IS like any other business in that producers are searching for ways to achieve profitability. Their margins, the difference between revenues and costs, depend on many factors: weather, crop yields, livestock birthing rates, production costs, demand, etc. Within agriculture, crop and livestock margins tend to be countercyclical. When crop margins are high, livestock margins are usually low and vice versa. This relationship makes sense as high crop prices create strong revenues for crop producers, but high production costs for livestock producers; and the current pricing situation shows the opposite holds as well. Low crop prices create weak revenues for crop producers and lower production costs for livestock producers.

For the hog industry, 2015 has been a mixed year, but the positives have outweighed the negatives. Figure 1 shows the projected margins for producing hogs in Iowa based on current futures prices for lean hogs, corn, and soybean meal. For the livestock margin graphs shown, the margins are computed above the major variable production costs and feed and animal acquisition costs. For the details behind the hog margin projections, see our swine margins website at www2.econ.iastate.edu/margins/swinecrush.htm. A rough rule of thumb is that Iowa hogs are profitable when the computed margins are above $40 per head. While projected margins are below $40 per head currently, profits are expected this summer and fall and throughout the spring and summer of 2016. While hog prices have fallen from their lofty heights of last year, hog prices are projected to hold between $65 and $80 per hundredweight. Combined with lower feed costs, this results in a mostly profitable outlook over the next 18 months.

The hog industry has been in expansion mode for several months now. There were some early concerns that the industry would expand too quickly and supplies would drive prices down significantly. However, the latest USDA hog report showed the expansion was a bit smaller than anticipated, supporting a higher price picture. Also, with the passing of Memorial Day, the grilling season has started, providing support from the demand side of the market. Pork exports have also picked up recently, with the Chinese market starting to show some additional demand.

The profitability outlook for the cattle industry is also mixed, but it's not an issue of timing. The profitability picture is split by the role within the industry. Cow-calf operators are capturing high feeder cattle prices and strong profits. Finishing operations, for example, as shown in Figure 2, are paying those high feeder cattle prices and struggling to turn a profit. The figure shows the projected margins for finishing cattle in Iowa based on current futures prices for live cattle, feeder cattle, and corn. For the details behind the cattle margin projections, see our cattle margins website at www2.econ.iastate.edu/margins/cattlecrush.htm. For cattle, the rough rule of thumb is that Iowa cattle are profitable when the computed margins are above $150 per head. As the projections indicate, profitability does not seem to be in the cards over the short term for finishing cattle. While feed costs have declined, the historical high cost of purchasing feeder cattle is still overwhelming the margin outlook.

Over the projection period, live cattle futures are in the $150 per hundredweight range. Those are historical strong prices. However, with feeder cattle futures over $200 per hundredweight, the margins just aren't there. Beef supplies remain tight as beef production is lower in 2015. However, demand for beef holds strong. Retail beef prices have risen more than enough to offset the reduction in beef production. A weak spot in the beef demand picture is in the export arena. Between the strength of the US dollar, raising US beef prices worldwide, and the recent issues at US port facilities, beef exports have been reduced.

The profitability outlook for crops is similar to that for finishing cattle. Crop producers are searching for ways to reduce costs and improve margins. This is a dramatic turn from where the crop markets were just a year ago. Figure 3 tracks the projected crop margins for the 2015 corn and soybean crops in Iowa. For these crop margins, we have tracked corn and soybean futures prices, adjusted those prices to reflect Iowa cash prices for the crops, and compared those prices to estimated production costs for both crops. For 2015, the estimated production costs are $4.41 per bushel for corn and $10.96 per bushel for soybeans. These costs are slightly below the estimates for 2014, but the drop in crop prices has been larger. Last spring, crop prices were high enough to provide a positive margin projection. However, with the harvest of last year's record corn and soybean crops and a stalling of the growth in crop demand, crop prices have fallen and profitability disappeared.

Figure 1. Projected wean to finish crush margin, May 20, 2015

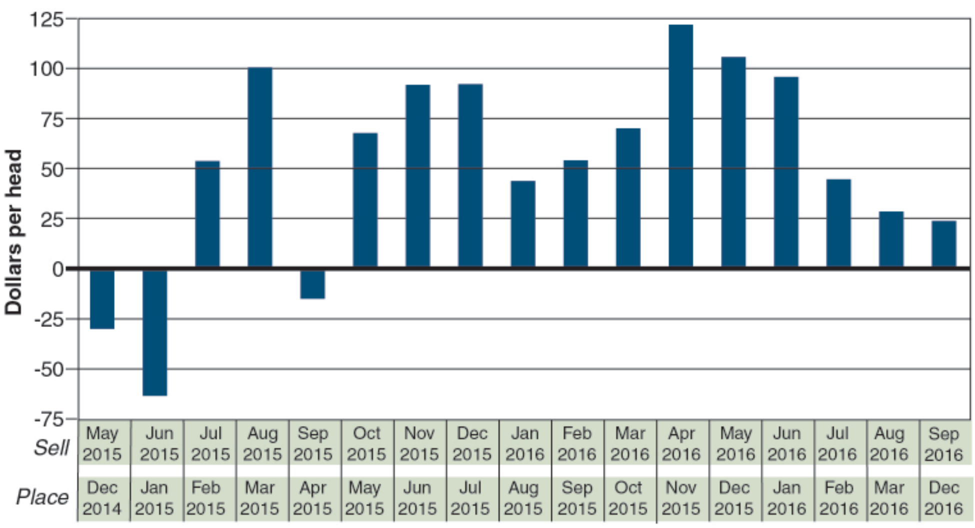


Figure 2. Projected yearling to finish crush margin, May 20, 2015

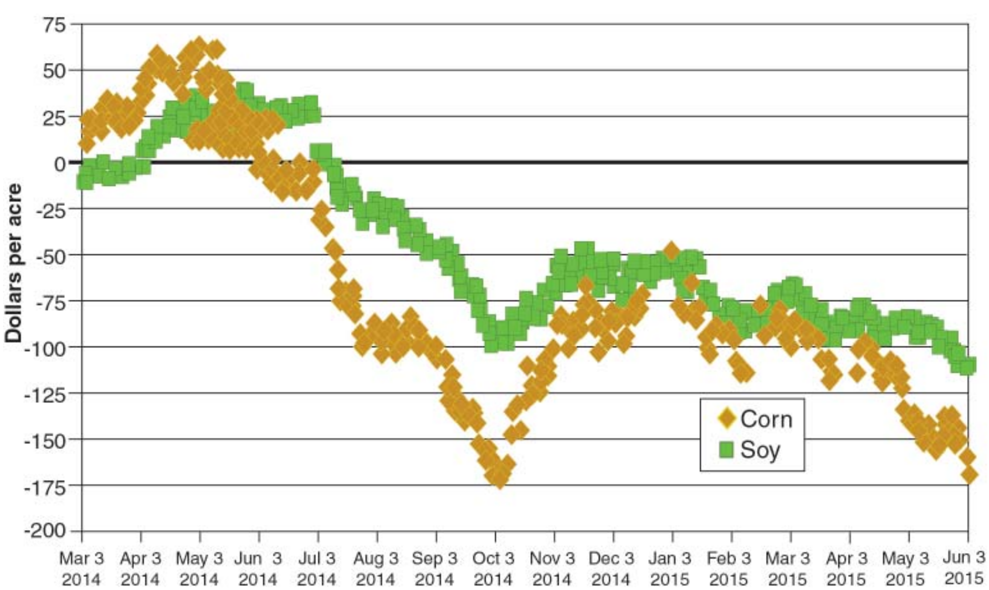
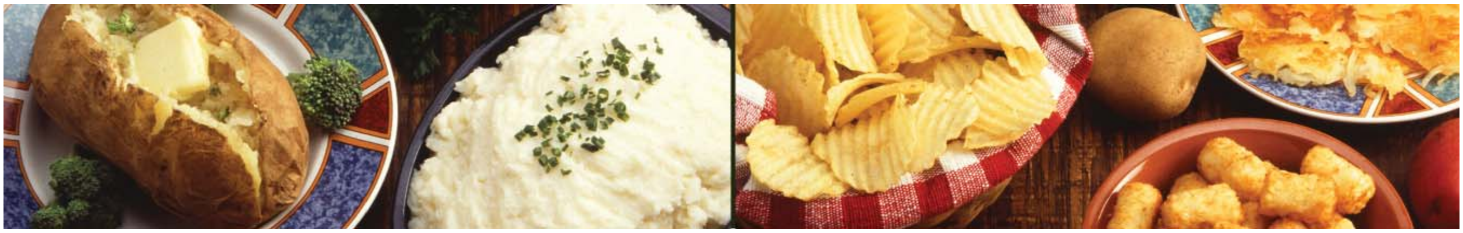


Figure 3. 2015 projected crop margins

Currently, both crops are displaying strongly negative margins, losses above $100 per acre if trend yields are achieved in 2015. Soybean margins have held up better than corn margins as the stalling in demand has been less for that crop. Soybean exports continue to set records and domestic crush demand has been on the rise as well. Meanwhile, for corn, demand is weakening as the US dollar is wearing down on exports and the lower oil prices over the past year has reduced the incentive for ethanol production. Projected crop supplies also remain quite high. In March, farmers indicated they would plant roughly 90 million acres to corn and 85 million acres to soybeans. Given trend yields, that would result in the third largest corn crop and the second largest soybean crop ever produced, so the crop markets are also feeling the pull of another round of large crop supplies entering the markets this fall.

Putting these profitability outlooks together, the US farm sector is definitely in a consolidation mode. National net farm income peaked in 2013 at $129 billion. The current projection for 2015 is $73.6 billion. During the last general economic downturn, agriculture recovered quickly and had some very strong years from 2010 to 2013. Now that the general economy has slowly been improving over the past couple of years, the agricultural economy has retreated. ■



Food Programs and the Potato

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THE SPECIAL Supplemental Nutrition Program for Women, Infants and Children (WIC) is one of USDA's major food assistance programs. WIC is authorized under the Healthy, Hunger-Free Kids Act of 2010. Major changes in the supplemental food packages were introduced in 2009 based on recommendations of a committee of the National Academies' Institute of Medicine (IOM). One of the innovative program changes implemented at that time was the introduction of a cash value voucher (CVV) to supplement the purchase of fruit and vegetables for qualifying participants. All fresh fruit and vegetables qualified for purchase with the CVV except "white potatoes." More specifically, white-fleshed potatoes. In 2014, Congress requested that USDA review the exclusion of potatoes; and at the request of USDA, a new IOM committee reviewed the regulation excluding white potatoes. Based on its review, the IOM committee issued a report in February 2015 that recommended that fresh white potatoes no longer be excluded from the food packages offered by WIC. Under the Consolidated and Further Continuing Appropriations Act, 2015, WIC agencies will begin to allow white potatoes no later than July 1, 2015. So why were white potatoes singled out for exclusion in 2009 and what changed? These questions highlight the role of efforts to align science and dietary guidance with effective program design. The challenge has been to make the guidance on dietary patterns better align with what foods people are eating and in what forms.

Introduced in 1974, the WIC program provides supplemental foods to meet the nutritional needs of low-income infants, young children and pregnant, breastfeeding, and postpartum women. In 2014 the program served 8.3 million low-income women, infants, and children under five years old at a total cost of $6.3 billion. Program benefits include a monthly allotment that can be redeemed at retail grocery stores for supplemental foods that are dense in nutrients lacking in the diets of eligible groups. The program also provides nutrition education, breastfeeding counseling, and referrals to health care and other social services for the target populations.

In 2009, USDA implemented major changes in program benefits; the Final Rule was published in March 2014. The revisions to the supplemental food packages were based on recommendations of an IOM committee report released in 2006. The supplemental foods include dairy products (milk, cheese, and yogurt), eggs, juice, iron fortified cereal, whole grain foods, dried or canned beans, peanut butter, and, for some, canned fish high in omega-3 fatty acids. For infants, the foods include infant cereals, meats, fruit and vegetables, and infant formula for formula-fed infants. Among the supplemental foods, the 2009 changes introduced a CVV of $10/month for women and $8/month for young children for the purchase of fresh fruit and vegetables. Some states also allow canned, dried, or frozen forms of fruit and vegetables (except those with added sugars, fats, or oils). There was one notable exclusion: the voucher could not be used for the purchase of white-fleshed potatoes.

The introduction of a CVV in 2009 was in line with findings that fruit and vegetables consumption was quite low for the target population, and thus included for the purpose of increasing the quantity and variety of fruits and vegetables consumed by participants. In 2006, when the recommendations on the CVV were developed, white potatoes were the most widely consumed vegetable and Americans, on average, met or exceeded the 2005 Dietary Guidelines for Americans (DGA) recommendation for how much starchy vegetables to include in the diet. The intent of the CVV was to increase diversity in fruit and vegetables intakes. By the time of the next Dietary Guidance review in 2010, USDA had revised its methods for setting the amounts of food groups in the recommended guidance to better account for actual consumption patterns of most Americans. The 2010 DGA recommends five cups per week of starchy vegetables, up from the three cups provided as the recommended guidance in 2005 . This change meant that currently, women and children in WIC now consume only 56 and 64 percent, respectively, of the recommended amount of starchy vegetables based on the 2010 DGA. In comparison, women and children consume 29 and 17 percent, respectively, of recommended amounts of dark green vegetables. The recognition of making the dietary guidance on the vegetables more in line with actual consumption patterns means that consumption of vegetables should be increased to be in line with recommended intakes.

During the last 15 years, other changes have occurred in the market that affect consumption patterns for potatoes. Per capita consumption of potatoes has been falling steadily for most types of potatoes. Today, per capita consumption (adjusted for losses in the system due to spoilage, and removal of inedible components in processing and other waste) is about 52 pounds per year, down from over 67 pounds per year in 1996. About half of potatoes consumed come from fresh potatoes; other consumption is in the form of processed products (e.g., frozen form, potato chips, dehydrated, and canned forms). Figures 1 and 2 show trends and share of consumption.

The shift in uses from the fresh market into processed products can be attributed to changes in consumer preferences, changes in retail markets including fast food service, and to processing and preservation technologies. The long-term decrease in potato consumption began well before the 2009 change in the WIC program benefits. Furthermore, 35 percent of potato consumption occurs outside of the home; and, a relatively large share of potatoes consumed in the home are purchased in forms likely not allowed by the WIC program CVV—as potato chips or frozen products with added fat. The change in the regulation to allow white potatoes is not likely to have a large effect on overall potato consumption. However, the change does favor a better image of the potato as part of a healthy diet. Furthermore, the inclusion will reduce the burden placed on retailers to identify and keep separate the white potato purchases from other allowed fruit and vegetables.

Inclusion of fruit and vegetables in the WIC food program has been viewed positively by participants, health professionals, and retail stores. Evidence is emerging that participants have changed their purchases to include more (additional) fruit and vegetables, especially fresh fruits. Although it is too early to tell whether inclusion of potatoes will shift these choices, what we know about demand behaviors suggests that consumers will not make large changes in purchasing more potatoes with the program vouchers, but other effects may be more significant. First, vendors will be able to include the potatoes at the time of sale with other WIC CVV transactions, lowering their burden on sorting these products in the transaction. Also, the change likely will reduce the potential for the potato to have a negative image in the minds of health conscious consumers—a concern of the potato industry. Finally, the change will allow program participants more choice among the fruit and vegetable selections. These changes are all likely to support the overall objective of increasing the WIC program benefits in a more efficient way. ■

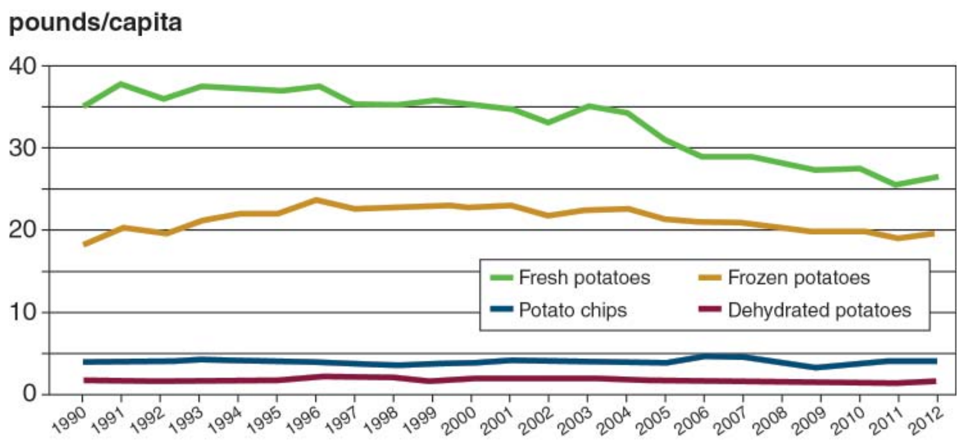

Figure 1. Per capita availability of potatoes 1990-2012

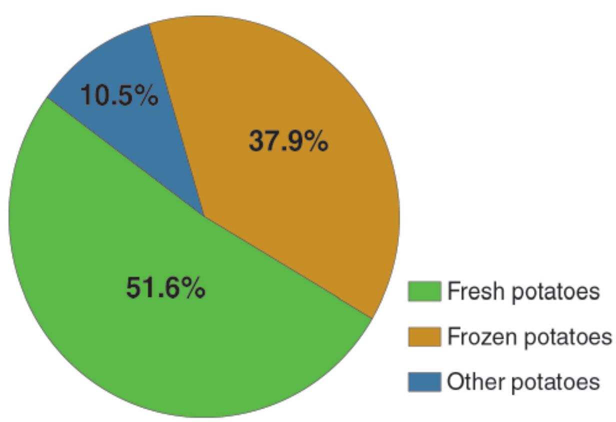

Figure 2. Share of potatoes available for consumption 2012

http://www.ers.usda.gov/data-products/food-availability-(per-capita)-data-system.aspx#26705

Source: USDA ERS, Per Capita Food Availability Adjusted for Loss

Capturing dynamic linkages between agriculture and energy in biofuel assessment continued from page 5

of continuous corn and the associated environmental impacts.

Our results show that, given the expansion of biomass feedstock production, the interplay between agriculture and energy affects land use and management decisions. As biofuel production continues to rely on land-based feedstocks, it becomes increasingly important to accurately assess the agricultural and environmental effects of these changes. Iowa is likely to experience significant intensification and extensification of production in terms of expanding land for biofuel production. Analyzing the impact of biofuels with limited attention to the linkages between agricultural and energy sectors, and how those coupled markets affect decisions at the field level, provides an inaccurate assessment. Thus, an integrated agricultural-energy market framework is necessary for accurate analysis and understanding the full ramifications of biofuel expansion. ■

Footnotes

[1]For the full description of the two models and how they are linked, see Elobeid et al. (2013).

[2] Comparison between the pre- and post-linkage results for the MARKAL model are available in Elobeid et al. (2013).

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