RFA
RENEWABLE FUELS ASSOCIATION

Ethanol's Contribution to Land Use Change

An Analysis of Acreage Shifts Caused by Increased Ethanol Production

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Introduction

Higby Barrett was selected by the Renewable Fuels Association to determine the extent to which corn used to produce ethanol used toward the Renewable Fuel Standard has come from land expansion (extensification) versus higher yields (intensification). Land use is impacted by many factors that must be considered when accounting for acreage shifts, particularly in the major crop exporting countries like the U.S. and Brazil. Also, new demand sources do not always generate new acres but rather take market share from other crops or other sources of demand such as exports or feeding. This report examines the factors that impact land use change and analyzes the land use change or lack of change that was associated with increased ethanol production in the U.S.

Ethanol production expansion was the result of the Renewable Fuel Standard (RFS), which supported the growth of the ethanol sector. The construction of the ethanol plants that followed is an example of infrastructure developments and capital investments that supported local farm economies. Ethanol can be made from a variety of crops, but the crop commonly used in the U.S. is corn, due to its agronomic and economic viability in the U.S. However, there were already existing land use trends in place before the ethanol boom that cannot be ignored. This report presents the case for each of these factors, exploring the expected trends and the actual trends that occurred.

Land use can be affected by changes in crop production. However, farmland has become more productive over time. This can be from specific farming practices, increased inputs, or other technological improvements that allow for either greater yields or less crop loss during harvest. This distinction is often referred to as land's intensification versus extensification.

Intensification generally refers to higher yields, which can result from the use of more inputs per acre, while extensification refers to more output from more acres being planted. Other examples of intensification that increase yields that do not involve higher inputs per acre are seed technology, precision agriculture and infrastructure improvements. These land use issues are explored within this study to determine the role intensification and extensification played in the increase in ethanol production in the U.S.

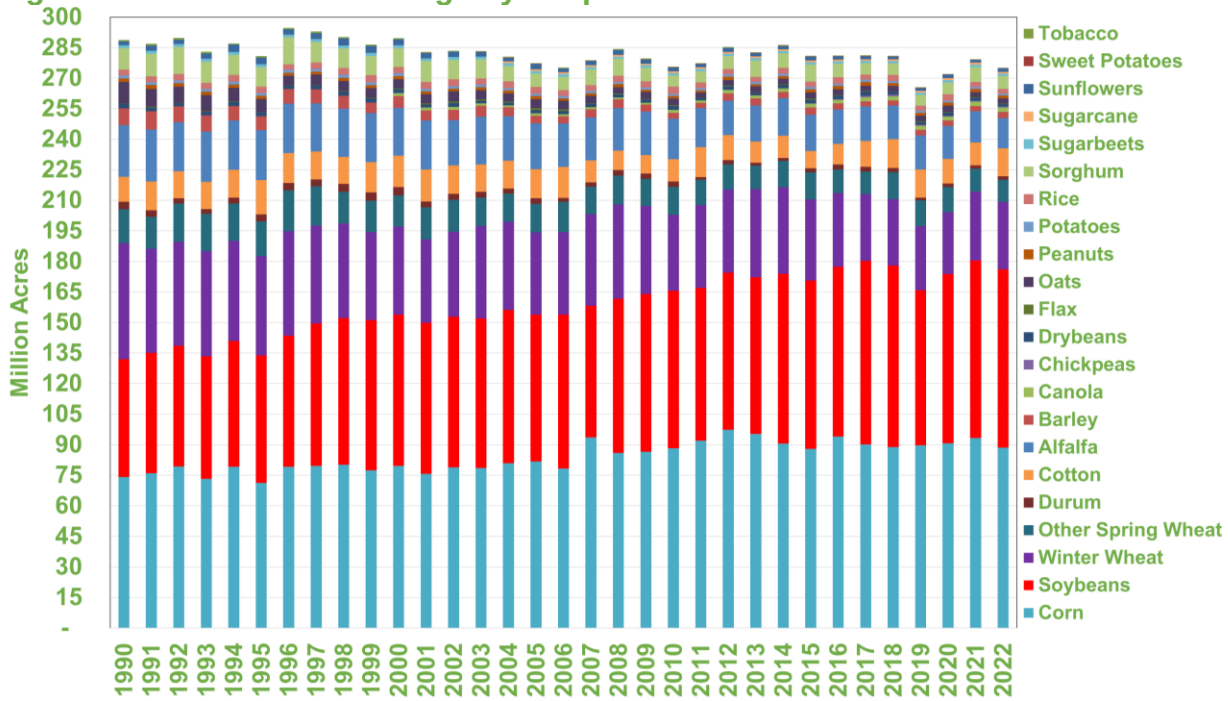
Executive Summary

U.S. Agricultural Land and Primary Crop Acreage

The 2022 Census of Agriculture showed a continuing decline in agricultural land. Total agricultural land has fallen by over 74 million acres since 1992.

According to USDA-NASS, total planted acreage for the 22 primary row crops grown in the U.S. declined from 288.8 million acres in 1990 to 275.1 million acres in 2022, a decrease of 13.7 million acres. Removing alfalfa from the mix, U.S. total planted acreage declined from 263.4 million acres in 1990 to 260.1 million acres in 2022, a decrease of 3.2 million acres. In 1990, the U.S. dataset did not include acres from canola, chickpeas, sugarcane, and sweet potatoes, but in 2022 those crops accounted for 3.6 million acres. Excluding these crops from the 2022 totals to make a more valid comparison, the reduction in U.S total planted acreage since 1990 would have been 17.4 million acres, or 6.9 million acres without alfalfa included.

Figure 1: U.S. Planted Acreage by Crop



Source: USDA and Higby Barrett

Crude oil prices were a major factor in the agricultural sector and the overall U.S. economy in the mid-2000s. Because energy is the largest commodity in the world, skyrocketing energy costs rippled through the supply chain for agriculture and food. Nitrogen fertilizer uses natural gas as a feedstock. Higher energy prices increase chemical costs, farm fuel costs, and delivery costs. Corn drying costs are directly tied to propane or natural gas. When generators are used for irrigation, they primarily run on diesel. This increases crop costs, which also raises meat costs.

Congress was eager to take steps to lower prices and regain energy independence. The RFS originated with the Energy Policy Act of 2005 and was expanded and extended by the Energy Independence and Security Act of 2007 (EISA).

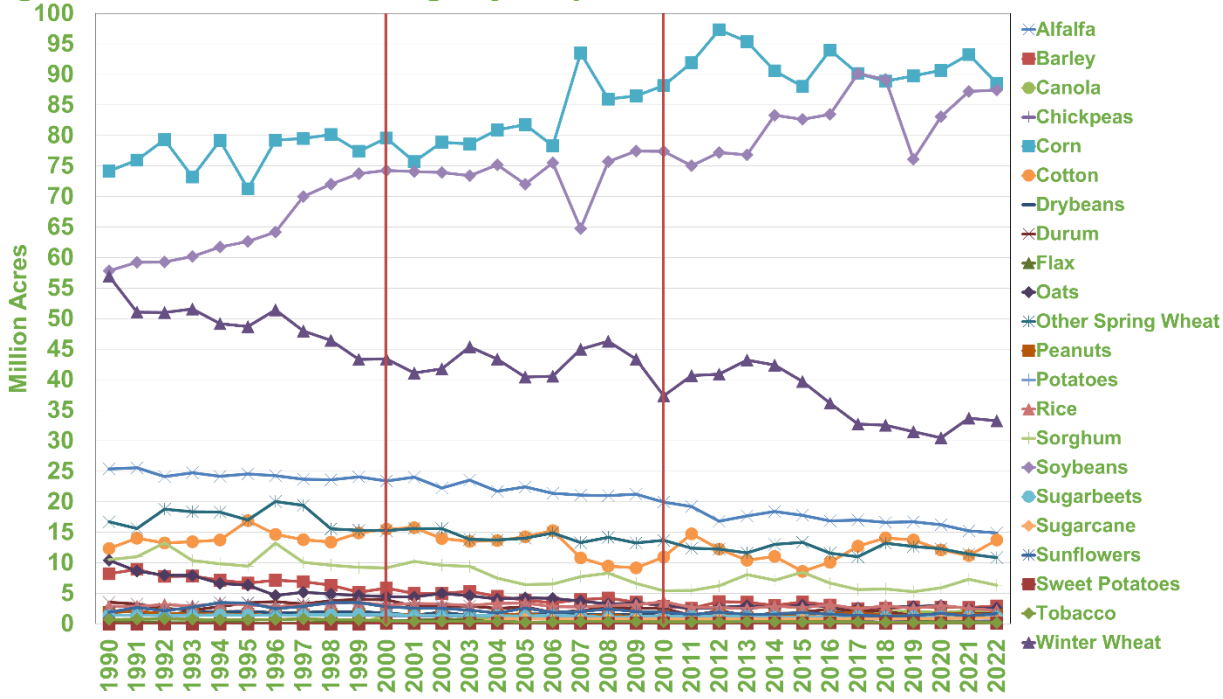
It is notable that U.S. corn planted acreage in 2006 was lower than in 2000. Even with the development of the ethanol industry, corn supplies remained abundant until 2007. At that point, conditions tightened, and more corn acres were needed. U.S. planted acreage in 2007 and 2008 was impacted by three primary factors: the increase in biofuel production under the RFS, multiyear worldwide wheat production issues, and the elimination of the U.S. Step 2 cotton export program. This is in addition to the ongoing trend of increasing Chinese imports of soybeans.

Wheat prices increased to $9.795 per bushel in 2007 and peaked at $12.825 per bushel in 2008 because of various wheat production issues across the globe. In 2007 and 2008, U.S. wheat planted area increased by 3.13 million acres and 3.16 million acres, respectively. This represented a major reversal, considering that from 1990 to 2006 wheat planted area declined from 77.24 million acres to 57.34 million acres, a decrease of 19.91 million acres. Wheat acres started declining well before the RFS was enacted in 2005.

U.S. cotton area plunged from 15.27 million acres in 2006 to 10.83 million acres in 2007. While the higher corn price attracted acres from cotton, the reason cotton acres declined was that the U.S. eliminated the Step 2 cotton export program in August 2006. U.S. cotton exports declined by 4.7 million bales in crop year 2006/07, resulting in already high ending stocks ballooning to 9.5 million bales. Even after a 4.45 million acre decline in cotton area in 2007, U.S. ending stocks increased to 10.1 million bales. In 2008, cotton planted area fell an additional 1.36 million acres, to 9.47 million.

As grain supplies tightened, corn planted area increased by 15.2 million acres in 2007, while soybean planted acres decreased by 10.78 million. This was largely reversed in 2008, when corn planted acres decreased by 7.55 million and soybean planted acres increased by 10.98 million.

Figure 2: U.S. Planted Acreage by Crop



Source: USDA and Higby Barrett

The primary buildout of ethanol production capacity occurred from 2000 to 2010. As EIA reported, "The use of ethanol as a gasoline additive increased in an accelerating fashion from 2000 to 2010. Its use was

spurred by the Clean Air Act amendments of 1990 (and subsequent laws)." However, during that decade, U.S. total planted area declined from 289.6 million acres to 275.7 million, a decrease of 13.9 million acres. The crop experiencing the largest decline was winter wheat, which lost 6.1 million acres.

U.S. total area planted to primary row crops increased by 3.7 million acres in 2007 and 5.4 million acres in 2008 to reach 284 million acres. However, this was still approximately six million acres below the 2000 level.

In 2022, total planted area was 275.1 million acres, or back to the 2006 level. Since peaking in 2017, U.S. corn use for ethanol has declined by over 400 million bushels.

In addition to changes in the crop mix, there has been conversion of pasture to cropland, although it is difficult to tease out the number of acres involved. The primary drivers for pastureland being converted to cropland are higher yielding seed varieties in regions that have shorter growing seasons and lower precipitation totals, expanded corn demand due to ethanol, and low cow calf profitability.

For certain areas, the ethanol buildout greatly widened the gap between the value of cropland and pastureland. To illustrate the point, cropland and pastureland values were compared for Nebraska and Oklahoma. The ethanol buildout added many ethanol plants to eastern Nebraska versus almost none for Oklahoma. From 2000 to 2010, the cropland premium to pastureland value decreased in Oklahoma by $42 per acre. However, in Nebraska, the farmland value premium increased by $1,071 per acre.

Regional Crop Acreage Patterns

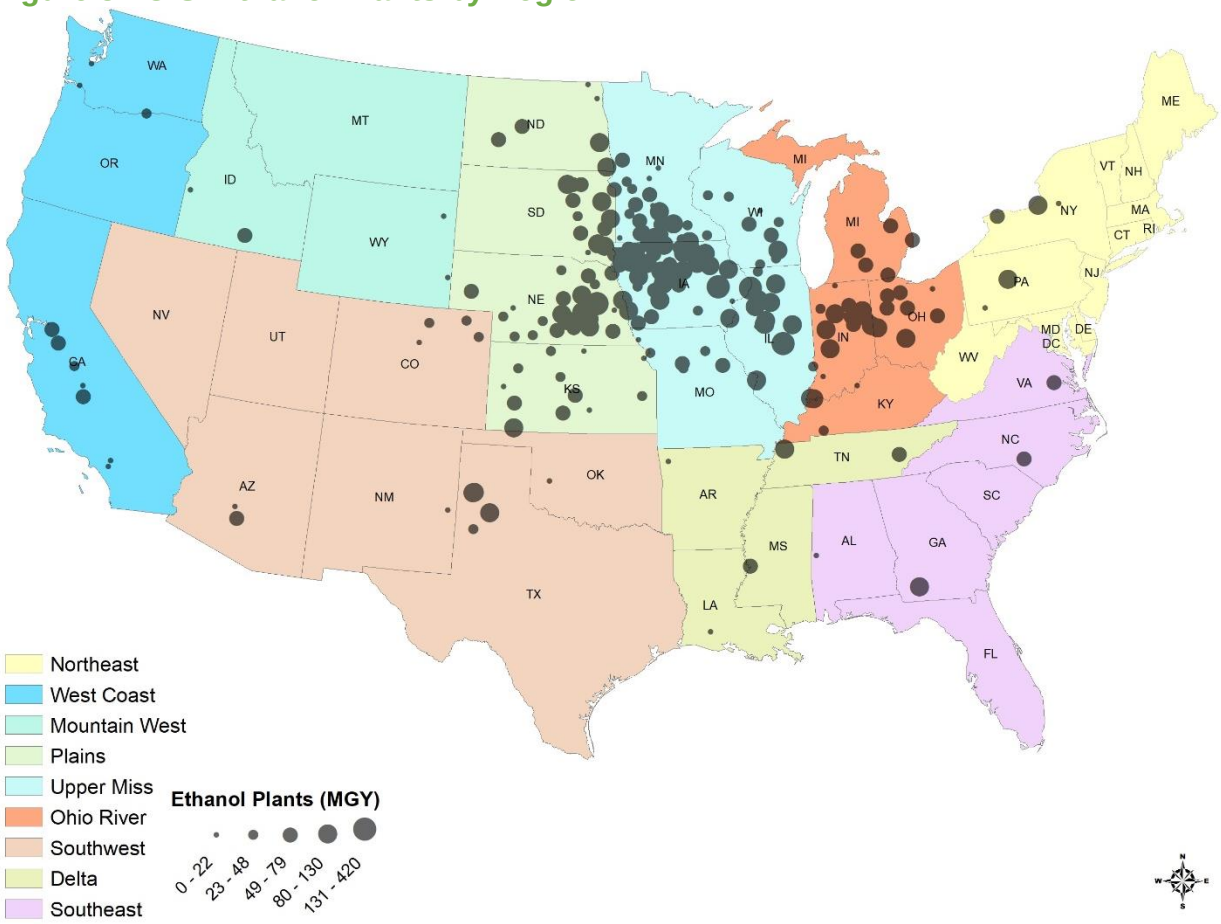
Between 1990 and 2022, planted acres decreased in all regions except the Plains. During the ethanol buildout from 2000 to 2010, crop acreage decreased in all regions except the Northeast and Mountain West; planted area expanded by 140,000 acres in the Northeast and 370,000 acres in the Mountain West.

In the Plains States, corn acres were increasing before the ethanol buildout started and continued to increase after it ended, which means ethanol was not the only reason for the expansion. Before the 1996 farm bill, known as Freedom to Farm, farmers were locked into growing their base acres and forced to set aside acreage. After the bill was passed, Plains State farmers were free to grow new varieties of soybeans and corn.

From 1990 to 2022, Plains States planted area increased from 71 million acres to 75.9 million acres, an increase of 4.8 million acres. (In 2021, planted area reached 79 million, 8 million higher than 1990.) However, given that canola area was first reported in 2010 at 1.3 million acres, the actual increase in total planted area through 2022 could be lower by that amount, at 3.5 million acres. Freedom to Farm had not been passed in 1990, so the number of canola acres at the time was likely close to zero.

However, most of the acreage expansion occurred in the years right after Freedom to Farm rather than during the ethanol buildout. From 1990 to 2000, crop area increased 4.1 million acres. During the buildout from 2000 to 2010, total Plains States planted area decreased 1.5 million acres (even as corn and soybean acres increased 3.3 million and 3.9 million, respectively).

Figure 3: U.S. Ethanol Plants by Region



Source: Ethanol Magazine, Higby Barrett

Intensification of U.S. Food and Feed Crop Production

Focusing on the primary food and feed crops, excluding cotton, exemplifies how long cropland acreage has been declining and yields have been increasing. A portion of corn and soybean acreage increase came from switching out of cotton and alfalfa acres, which would not involve new cropland. Corn is the highest yielding crop, and more importantly the gap in yields between corn and other crops has increased, which means farmers have had an incentive to plant more corn.

Long term acreage trends can be seen in USDA Production, Supply and Distribution (PSD) data, which starts in the mid-1960s. Since 1964/65, approximately 77 percent of crop production growth, or 281.2 million metric tons (MMT), has come from yield increases, versus at most 23 percent, or 85.2 MMT, from increasing grain and oilseed planted area. It should be remembered that 17 percent of the increase in grain and oilseed acreage came from cotton, which while not a food crop is still a row crop. Also, a switch from alfalfa to food crops accounted for 37 percent. Given that extensification refers to new agricultural land in production, since 1964/65 approximately 89 percent of production growth, or 327.4 MMT, has come from yield increases and cropland switching from nonfood crops to food crops or intensification versus 11 percent, or 39 MMT, from extensification.

Brazil Crop Acreage and Production

From 1990 to 2022, Brazil added almost 65 million acres of cropland. The Central West crop region has added over 40 million acres, an increase of 365 percent, accounting for over 60 percent of the country's total cropland expansion.

Figure 4: Brazil State Map and Crop Regions

Source: USDA ERS

The North crop region is primarily the Amazon, which is designated as being off limits to crop expansion, though land keeps entering crop production. Since 1990, land in production (not double cropped) in the North crop region has expanded by 7 million acres, or an increase of 662 percent. This represents 11 percent of national cropland expansion.

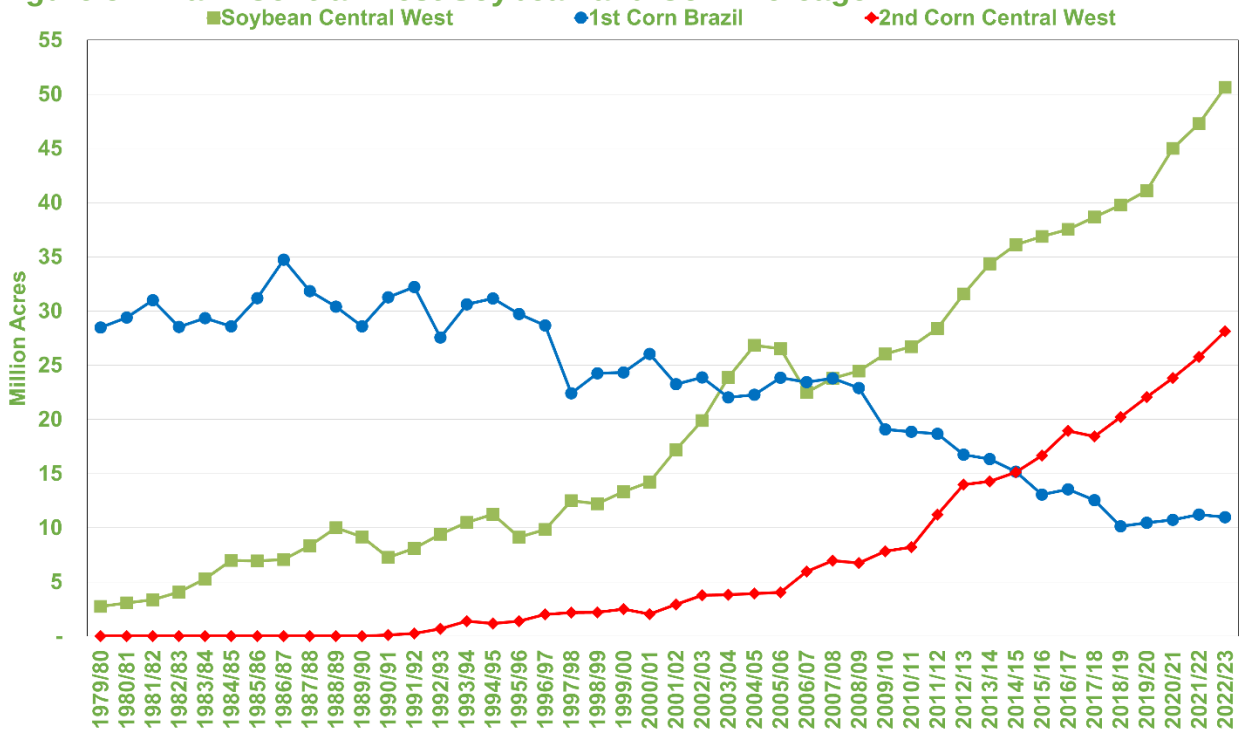
Since 1990, the South crop region has expanded by 10 million acres, an increase of 38 percent, while the Northeast crop region expanded under 6 million acres, or 77 percent. The Southeast crop region had the smallest expansion of under 2 million acres, or 17 percent.

In terms of the crops involved, soybean and second crop corn acres expanded, while first crop corn acres declined. It should be noted that the soybean acreage increase started before the U.S. RFS was expanded. After severe disease issues, continuous planting of soybeans was outlawed, which put an emphasis on double crop corn.

In the Central West, expansion of corn and soybean acreage has occurred in lock step. Since second crop corn is produced far from export ports, the low local price reflects high transportation costs. For local meat producers, the second crop provides a competitive advantage.

Over the long term, corn yields in Brazil have increased from being on par with other crops to being the second highest yielding crop behind rice. The yield differential for corn over sorghum, rye, barley, and wheat suggests farmers should replace those crops with corn. It should be noted that corn is increasingly being planted in areas where many people thought it could never be grown profitably. Soybean yields have also increased, rising 287 percent since 1977.

Figure 5: Brazil Central West Soybean and Corn Acreage



Source: CONAB

From 1964/65 to 2020, approximately 40 percent of crop production growth, or 94.2 MMT, has come from yield increases and double cropping, or intensification, versus 60 percent, or 135.4 MMT, from extensification, or increase in land area.

Much of the acreage expansion has occurred in regions covered with forests and native grasses. For farmers inland, grazing cattle was an enterprise that monetized owning grassland. When grassland was converted to soybeans, feed demand was created for corn to replace the lost pastureland. The availability of soybean meal and corn enabled the hog and poultry industries to expand.

World Food and Feed Crop Production

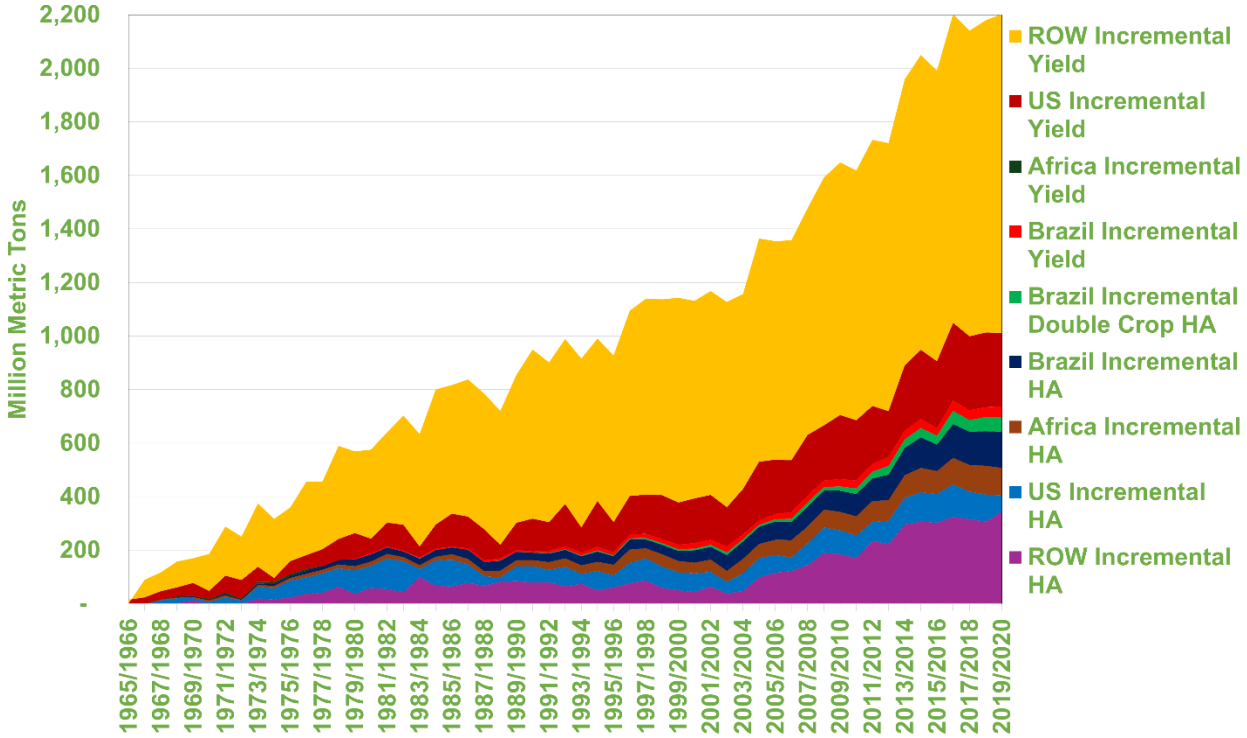
Comparing the incremental harvested acreage impact on world production versus incremental yield impact since 1964/65 demonstrates how improving yields are the driving force behind world production increases. Approximately 70 percent of the extra food crop production results from yield increases versus 30 percent from additional cropland entering production.

In this estimate, Brazil's second crop corn production was included along with incremental yield since double cropping is a more intensive use of the land. The data on double crop acreage in other countries is limited, so some of the estimated incremental harvested acreage impact on world production could likely be attributed instead to double cropped acreage.

Of the crops covered in this report, barley, millet, mixed grains, oats, rye, sorghum, and wheat collectively lost 59.5 million hectares. Corn, rice, rapeseed, and soybeans gained 265.2 million hectares.

Since the mid-1960s, double cropping in Brazil has accounted for three percent of total incremental world food and feed crop production, yield increases in Brazil have accounted for two percent, U.S. yield improvement has accounted for 12 percent, Africa yield has accounted for two percent, and rest of world yield has accounted for for 52 percent. On the other hand, crop production on Brazil's additional harvested acres has accounted for six percent of total incremental production, while the U.S. has accounted for three percent, Africa has accounted for five percent, and rest of world has accounted for 16 percent. Since around 2002, the impact from harvested acres has increased.

Figure 6: World Production Change Broken Out from 1964/65



Note: Crops Included, Barley, Corn, Millet, Mixed Grain, Oats, Rapeseed, Soybeans, Rice, Rye, Sorghum, Wheat
Source: USDA PSD, Higby Barrett

Conclusions

The RFS continues to play a significant role in U.S. agriculture. Higby Barrett's goal was to examine the subject at a level of granularity that produced tangible findings.

1. Farmers are the decision makers for land use allocation. Planting decisions are made in response to a variety of variables that are not always price related.
2. The RFS supported existing U.S. acreage trend towards more corn and soybeans. Ethanol is not the only reason why corn acres have increased. New technologies and farm policies resulted in increased corn and soybean acres.
3. Ethanol plants provide the nearby farmer with an extra marketing option that encourages more corn acres. Ethanol plants were primarily built in corn surplus areas.
4. In the report we detail our analysis of what really shifted acreage in the U.S. While ethanol is part of this narrative it is not the sole cause of the changing crop mix. For example:

   a. Before, during, and after the 2000-2010 ethanol buildout, wheat acreage was declining, and corn and soybean acres were increasing.
   b. Only a third of the area formerly in cotton was replaced by corn and soybeans. This means that other factors were causing the decline in cotton acreage.
   c. A large portion of the conversion of pasture occurred before 2000 and after 2010.
   d. U.S. total cropland continued to decrease from 2000 to 2010.
5. The financial incentive from higher land prices when land is converted to a higher and better use of farming versus grazing was a driving force for pasture conversion. Ethanol played a role in driving crop margins that encouraged these decisions by landowners in the U.S.
6. Ethanol was one driver behind additional planted acreage in the Plains States, but much of the acreage expansion occurred in the years before the ethanol buildout. A farm bill that gave growers freedom to allocate their acreage, along with other government programs, urbanization, and loss of acres elsewhere also drove additional acres in certain areas.
7. Soybeans were the driving force for new acres in Brazil. Crop rotations and soybean economics in Brazil had the effect of driving corn acreage higher. The corn acreage increase was not driven by ethanol, but rather corn's place in the crop rotation with soybeans.
8. While pastureland has been converted into corn and soybean acres, overall cropland totals are down, which does not indicate there has been extensification in the U.S.
9. Ethanol is one of many factors that has driven corn intensification, but since corn is already one of the biggest crops in the U.S. new technologies and practices to increase yields were already being targeted.
10. In the U.S., from 1964/65 until 2020, approximately 89 percent of production growth, or 327.4 MMT, has come from yield increases and crop switching (intensification) versus 11 percent, or 39 MMT, from extensification.

Crop Planting Decision Factors

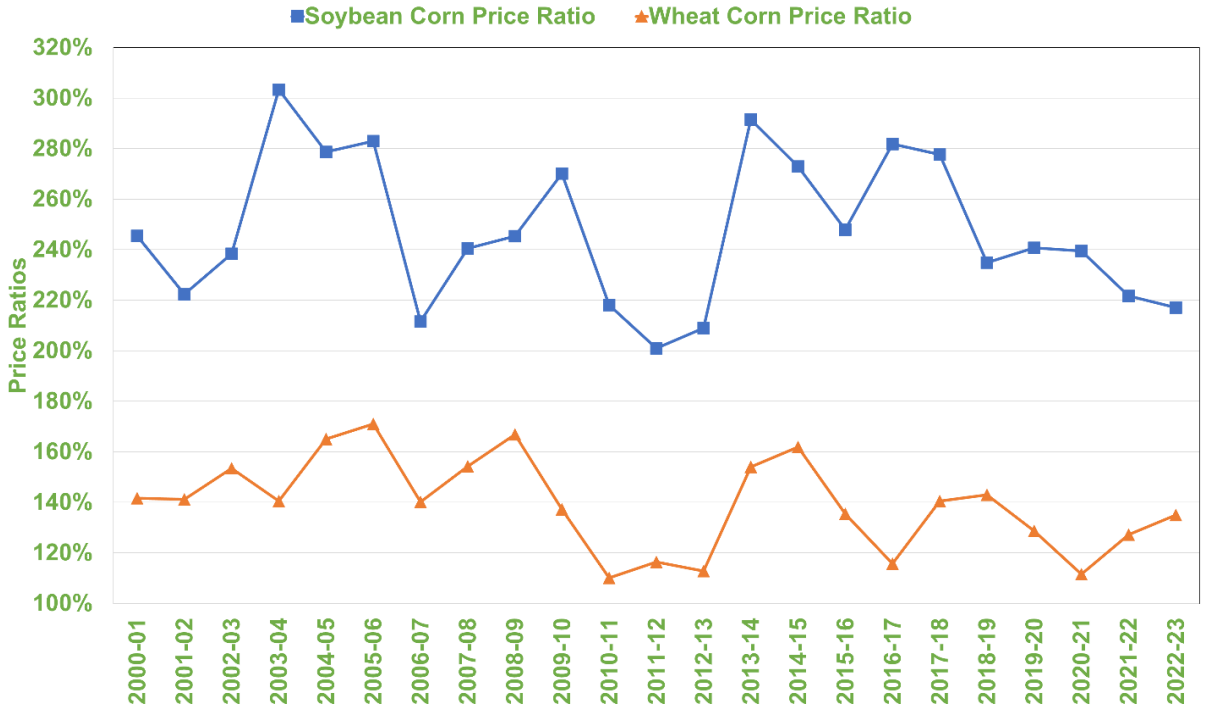
A major challenge in predicting crop acreage is that farmers base planting decisions on their individual situation. In other words, planting decisions are made at the farm level. The variability across farms is immense and always changing. Also, the decision factors are intertwined.

The viability of a farm is dependent on market access, input access, weather, and a price that covers costs. Most countries emphasize a safe and ample food supply as an important national security goal. To ensure that goal is met, governments offer programs that are designed to help the farmer mitigate the risks of operating a farm. Trade policies concerning agriculture change as countries' situations change in terms of agriculture and local politics. Planting decisions are influenced by government programs.

Prices

One common tool to estimate the next year's acreage is price ratios. Price ratios are a method to compare relative prices of crops. The idea is a better price for one crop versus another will entice the farmer to switch acres to the crop with a higher price.

Figure 7: Crop Price Ratios (September through August Marketing Year)



Source: USDA

The U.S. price ratios indicate that price relationships should have increased corn acres in 2003, 2005, 2007, 2011, 2012, 2015, 2016, 2019, 2022 and 2023. For corn, eight out of the 10 years selected acreage increased and two years decreased. The price ratios indicate soybean acreage should increase in 2002, 2004, 2006, 2008, 2009, 2010, 2013, 2014, 2017, 2018, 2020 and 2021. For soybeans, eight out of 12 years selected acreage increased and four years decreased. For wheat, acres should have increased in 2003, 2005, 2006, 2007, 2008, 2012, 2014, 2015, 2018, 2019, 2020, 2022 and 2023. For wheat, eight out

of 13 years selected acreage increased and five years decreased. The increase in wheat prices in 2007 increased wheat acres despite the positive increase for corn in the corn wheat price relationship.

This begs the question, "Why are the relationships between planted acreage and price not tighter?" USDA Prospective Plantings issues statistical acreage estimates for several crops. The Prospective Plantings report is a beginning point, but the first USDA World Supply and Demand report that has an objective survey carries more market credibility. This is because the ability to correctly estimate crop acreage with statistics is limited. For example, over the last couple of years, one of the driving themes of oilseed prices has been the growth of renewable diesel production capacity and the resulting sharp rise in biomass-based diesel feedstock prices. In March 2023, USDA reported that farmers planned to increase U.S. corn acreage by four percent (3.4 million acres) to 92 million acres. In addition, USDA's Prospective Plantings report indicated that farmers did not plan to change soybean acreage substantially from the 87.5 million acres planted in 2022. It was expected that the biofuel policy would increase soybean acreage. By the time the farmers put the planters away, the soybean planted area had dropped nearly four million acres from 2022 and USDA's Prospective Plantings estimate. Despite indications that farmers would only increase U.S. corn acreage marginally in 2023, supportive planting weather allowed farmers to make substantial changes to plant more acreage than March intentions. In June, USDA reported that farmers increased U.S. corn area by 5.5 million acres to 94.1 million, which ultimately increased to 94.9 million acres, an increase of 6.3 million acres from 88.6 million in 2022. The U.S. planted corn acreage was the largest since 2012.

The takeaway is statistical models assumes the only planting variable that changes is price. Many would argue that weather conditions and seed availability during planting are the primary factors. Two reasons to plant the crop as early as possible are better yields and not knowing if the weather will remain favorable.

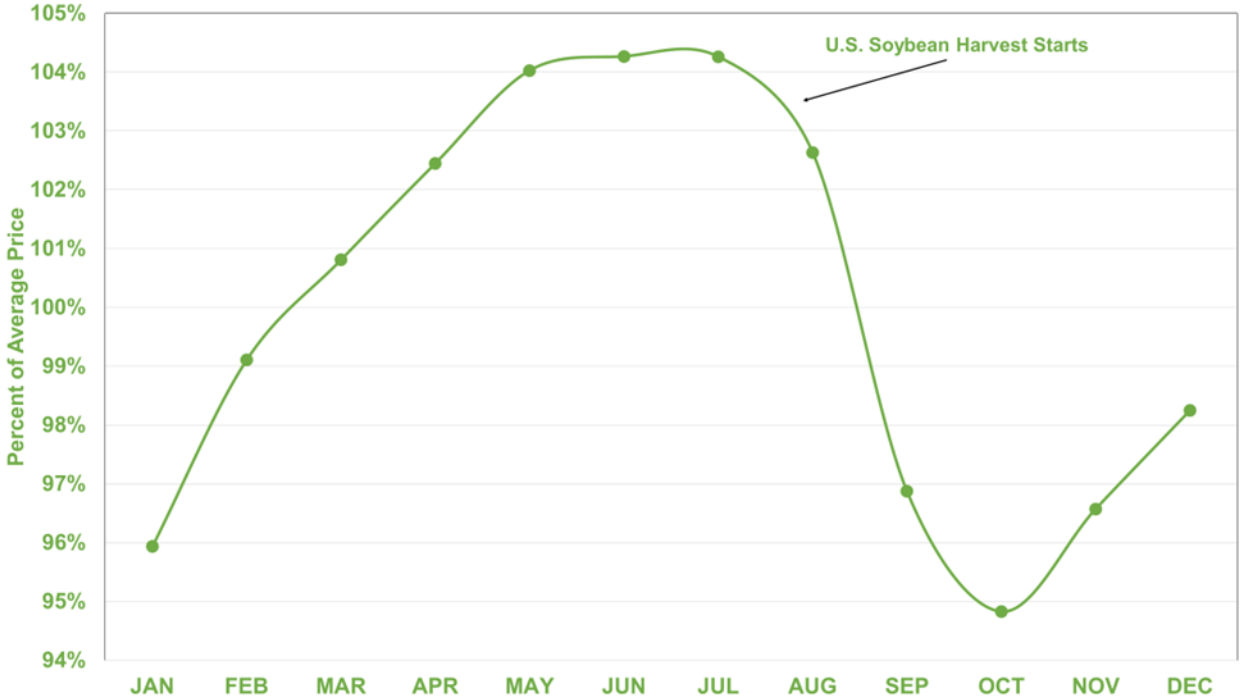
Data Concerns

Large economic models require resources to maintain. Statistics do not always reflect what is occurring. Newly introduced short season varieties of soybeans enable soybeans to be planted in regions with short growing seasons. Farmers reported that yield improvement is the reason for planting more soybean acres. The farmer comments are often assumed to mean the average soybean yield improved versus the average wheat yield. The short season soybean variety yields lower than the full season variety. For example, farmers in South Dakota said the short-season drought resistant soybean varieties enabled them to add the crop to their rotation. Because South Dakota state soybean yields from 2000 to 2010 increased 8.5 percent while wheat yields increased 14.1 percent, using state level statistics indicates wheat acreage should not have shifted to soybeans. Farmers in South Dakota traditionally have raised wheat because of its ability to handle a dry climate with harsh weather conditions. Soybeans were a new crop for many farmers. The lack of a soybean baseline makes the yield comparison misleading. It is reasonable to assume that before the new varieties the yields were so low that planting soybeans was not an option.

Farmers receive different prices depending on when the crop is sold and where the crop is sold, especially if currency fluctuations are considered. To assume one price for countries as large as the U.S., Brazil, and China, means there will be significant modeling error before the analysis begins. For example, from July until October, the seasonal corn and soybean cash price declines, which puts a strong downward pressure on future prices. In June and July, the holders of corn and soybean stocks begin to feel the pressure to move crops to create elevator space for the following crop. As the U.S. soybean harvest begins in August, the harvest price pressure increases. Farmers in early harvesting states (Bootheel of Missouri and south) know if they store the crop, the cash price is going to decline over the next two months. So, the primary reason for storage is to aid the harvesting operations and the best marketing option is to immediately push the crops into the marketing channel. How much flows directly to the market depends on the quantity

required to fill the global export pipeline which largely depends on the South American crops. Farmers in the Southern U.S. that can harvest early will receive a price premium that varies depending on the world supply and demand situation. Another example of constraints are farmers in the Northern Plains States who are captive to the railroads to export products out the Pacific Northwest while farmers close to the Inland Mississippi River System have access to barge transportation. The main takeaway from these constraints is that the USDA average crop farm price is an estimate based on surveys across a wide time span and geographical area and does not tell the whole story when looking at regional crop marketing decisions.

Figure 8: U.S. Soybean Cash Seasonal (2010 to 2023)



Source: USDA, NASS

Infrastructure

Estimating how the changing infrastructure will impact crop acreage is challenging. Typically, a new processing plant will cause the local price to increase relative to futures markets, such as the Chicago Board of Trade, and more importantly provide another marketing option. The difference between the local cash price and the futures price is referred to as “basis”. In this example the basis will increase or strengthen. The same effect occurs when other infrastructure is added to a farming region, such as the addition of shuttle trains, river ports, export elevators, and new roads. This is true for farmers in other countries, especially in Mato Grasso, Brazil.

Production Contracts

Farmer production contracts directly impact crop decisions. The impact of production contracts is more pronounced in countries that control the further processing. For example, a rice farmer that has a good relationship with a rice processor will want to maintain that relationship. The same is true for farmers that own further processing facilities, such as cotton gins, and sugar beet refineries.

Seed Technologies

The promise of new seed technology improvements always has a learning curve. Although the technologies have been tested, the ultimate test is at the individual farm level. Crop rotations are impacted by new seed varieties. The emergence of new soybean and corn varieties that increase the ability of corn and soybeans to handle cold and drought has expanded the Corn Belt west and north.

Farm Investments

Longer term and medium-term farm investment decisions will impact planting decisions. For example, buying a $1.2 million cotton picker commits the farmer to growing enough cotton to pay the note. Tiling and irrigation are expenses that increase yields and reduce the impact of excessive rainfall and droughts. It is easier to cover the increased production cost with a higher yielding crop, such as corn.

Crop Expertise and Set-up

Farmers have expertise in certain crops and do not want to commit to growing a new crop for a one-year price move. New crops require a learning curve for each farm. Also required is the equipment to grow the crop and a market. For example, with the recent high wheat prices, many farmers contemplated growing wheat but could not access the correct equipment.

Crop Rotations

Farmers use proven crop rotations that provide the greatest benefit. How committed a farmer is to a preferred crop rotation and estimating the benefits of the crop rotation is a challenge. The same farmer on the same land will have a different price ratio threshold depending on where they are in the crop rotation cycle. The result is farmers tend to default back to the ideal agronomic crop rotation. There are many rotations used by farmers, but if we use a simple corn and soybean example, economics favor corn-soybean crop rotations versus continuous corn for three reasons.

1. To minimize corn yield losses requires more fertilizer, herbicides and insecticides which increases input costs.
2. Corn yield still declines despite the extra inputs.
3. Every year the field is not in soybeans the soybean yield receives a “bump.”

At some point the farmer will plant soybeans to capture the soybean yield increase and reduce weed and insect pressures for next year’s corn crop. Farmers begin with an agronomic plan which can be influenced by price, but achieving a yield and having a market are the driving forces behind which crops are planted.

Countries’ Agricultural and Trade Policies

Changing agricultural policies from the U.S. and other counties directly impacts planting decisions. When Freedom to Farm was implemented in 1996, more farmers immediately began switching wheat acres to soybean acres and experimenting with new crop rotations. Corn is a great rotation crop with soybeans, which increased demand for drought resistant varieties of corn.

USDA reported, “The Federal Agriculture Improvement and Reform Act of 1996 (1996 Act) was signed into law in April 1996, providing new farm sector law for 1996-2002. The 1996 Act is a milestone in the evolution of U.S. agricultural policy because it fundamentally redesigns income support programs and discontinues supply management programs for producers of wheat, corn, grain sorghum, barley, oats, rice, and upland cotton. The 1996 Act expands planting flexibility and lets authority expire for Acreage Reduction Programs.”

The Act is commonly known as Freedom to Farm and allowed farmers to choose which crops to grow versus having to plant program base acres to qualify for government payments. It also ended the government ordering farmers to set aside acres to reduce ending stocks.

Policy changes alter long-term decisions. For example, when China allowed soybean imports to increase, Brazil increased soybean acreage to meet growing world demand, especially in Asia. Brazil's second corn crop is not planted at an ideal time because it is double cropped behind soybeans. Even though the corn yields are low, the second crop revenue covers operational costs and contributes to the gross margin. Because the soybean crop has already paid for most of the fixed costs and some of the operational costs, farmers plant corn to maximize profits per acre. The driving force behind planting more corn is the decision to plant soybeans. Because adding land into production is a long-term proposition, the decision is based on the belief that China was going to allow soybean imports to continue to increase.

Equilibrium

When discussing commodity prices, a favorite saying of Dr. Willard Sparks was “High prices cure high prices and low prices solve low prices.” In economic terms, it means the market players will react to prices and over time will pull or push supply and demand towards equilibrium or balance. Investopedia defines “equilibrium as the state in which market supply and demand balance each other, and as a result prices become stable. Generally, an over-supply of goods or services causes prices to go down, which results in higher quantities being consumed—while an under-supply or shortage causes prices to go up resulting in less quantities being consumed.”

Due to many of the factors discussed in the Crop Planting Decision Factors section, commodity markets are always in a state of disequilibrium. Every year weather conditions will result in countries reaping above average yields or below average yields. Because the weather conditions vary, shipments originations and destinations will change from one year to the next. Price is a variable that influences where the commodities flow. This assumes government policies allow the market to operate efficiently.

Governments have a responsibility to protect their citizens. Energy and food are the two most important commodities. Governments want to have domestic stocks in case of an emergency and a domestic production base. To protect domestic producers from more efficient foreign production, tariffs and other non-tariff regulations are implemented to prevent imports and increase the domestic price. The higher domestic price results in more acreage and incentive for farmers to apply more inputs to maximize yields. On the flipside, an exporting country like the U.S. will take advantage of the lower crop price to develop value added products, such as meat and ethanol.

As crop yields improved, the excess supply of crops in exporting countries increased. To protect its farmers, governments implemented programs to promote agriculture through export enhancement programs, increase domestic consumption by helping the poor afford groceries and school lunch programs, Conservation Reserve Program reducing acreage, and development of additional markets, such as renewable fuels.

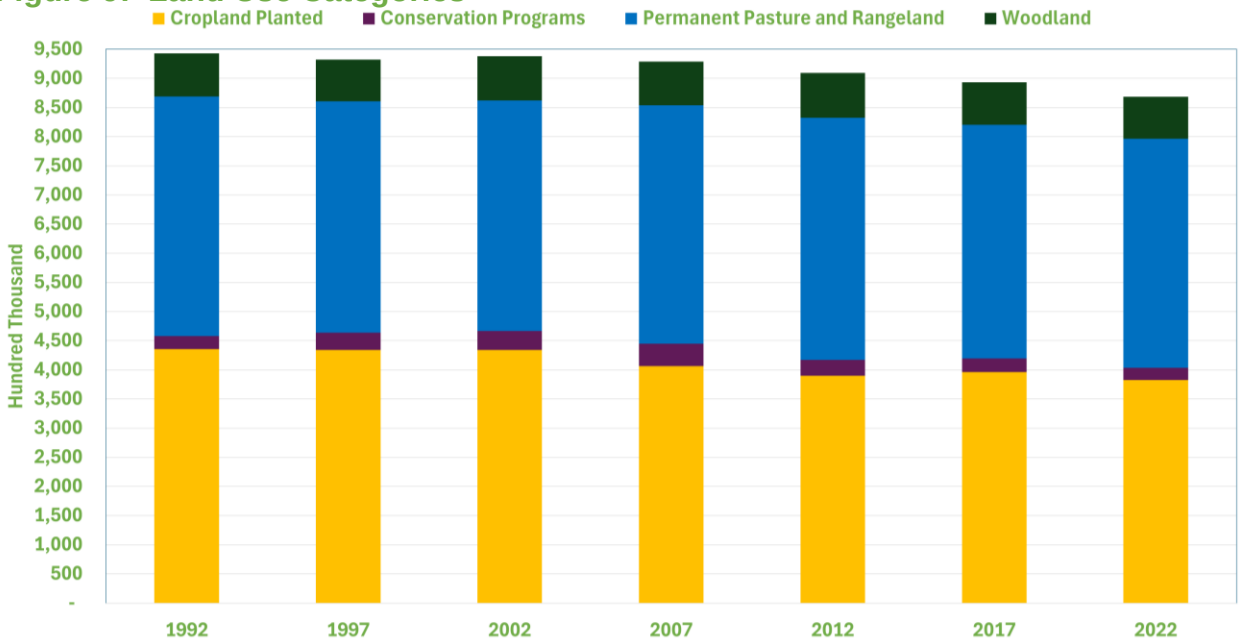
The U.S. was energy deficit and ethanol production reduced dependence on foreign crude oil and created a market for the excess crop production. As corn was pulled into ethanol production, price increased to ration corn consumption and increase more corn production. The policy also created downstream markets for the distillers dried grain (DDGS), which is approximately a third of every bushel. Because DDGS has a different nutritional composition than corn, animal nutritionists had to develop new feed rations. Now that nutritionists have experience working with DDGS, this feed ingredient is more readily pushed into feed rations.

Over time, entrepreneurs will take advantage of an available supply, such as new access to DDGS for feed, and create consumption, such as adding DDGS to cattle rations. If successful, and using the cattle example, the cattle feeding operation will create a local demand source and this new source of local demand may grow in the future.

U.S. Total Acreage

The 2022 Census of Agriculture reported land use numbers. The numbers illustrate a continual decline the agricultural land use. Total agricultural land has declined over 74 million since 1992. Cropland Planted has experienced the largest decline of 53 million acres since 1992. Permanent Pasture and Rangeland acreage declined by more than 17 million and Woodland and Conservation Programs acreage declined by over one million.

Figure 9: Land Use Categories

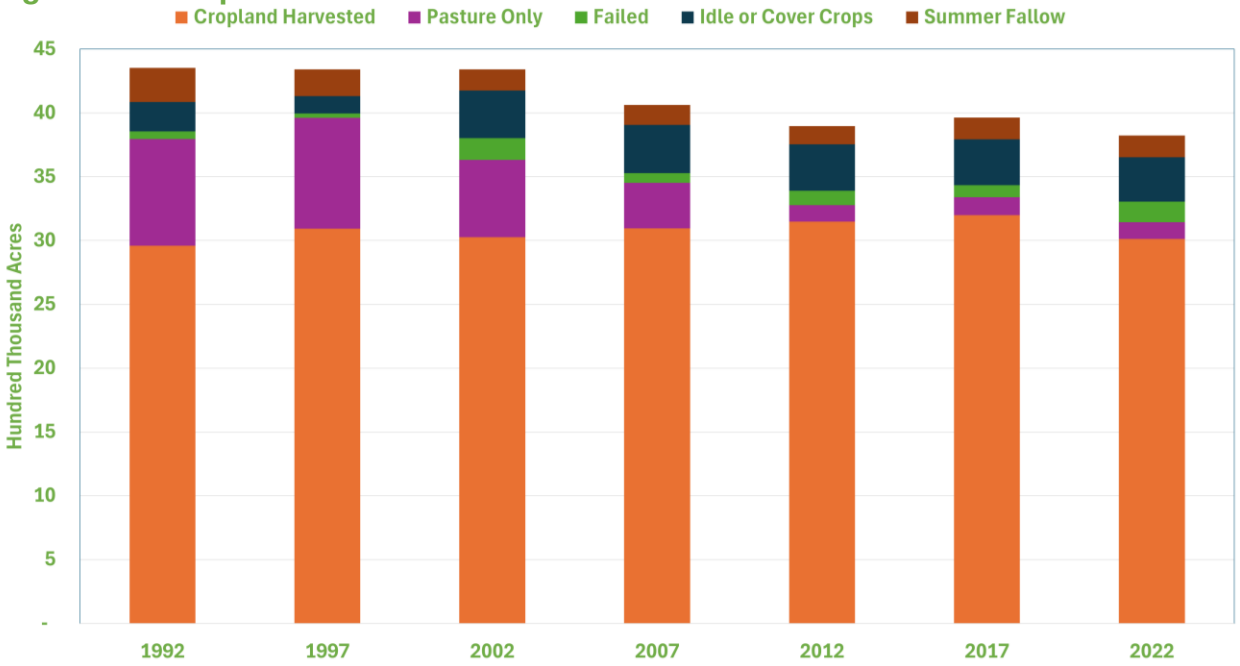


Source: Census of Agriculture

"Cropland Planted" comprises of what is machine harvested. This category includes cropland harvested, other pasture and grazing land that could have been used for crops without additional improvements, cropland on which all crops failed or were abandoned, cropland in cultivated summer fallow, and cropland idle or used for cover crops or soil improvement but not harvested and not pastured or grazed.

From 2000 to 2022, the only cropland subcategory to increase was "Summer Fallow" by half a million acres. Census of Agriculture includes many crops that were outside the impact of the ethanol buildout, such as horticulture and Christmas trees. Higby Barrett focused on crops that directly compete with corn for acres.

Figure 10: Cropland Planted Breakdown



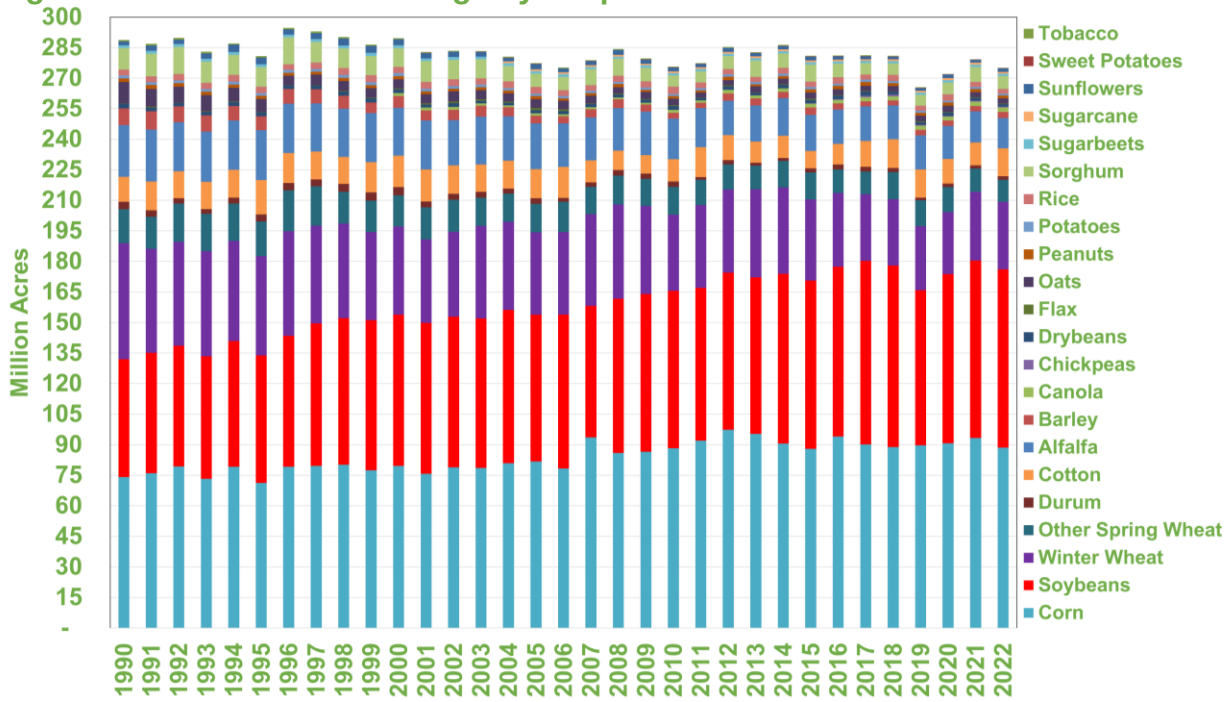
Source: Census of Agriculture

For the 22 primary row crops in the U.S., total planted acreage decreased from 288,781,110 acres in 1990 to 275,055,860 in 2022 or a decrease of 13,725,250 acres. Removing alfalfa from the mix, U.S. total planted acreage decreased from 263,388,110 acres in 1990 to 260,142,860 acres in 2022 or a decrease of 3,245,250 acres. In 1990, the U.S. dataset did not include acres from canola, chickpeas, sugarcane, and sweet potatoes. In 2022, those crops account for 3,629,300 acres. If the totals are adjusted by removing these crops from the 2022 acreage totals, U.S total planted acreage decreases 17,354,550 acres and without alfalfa included, decreases 6,874,550 acres. Due to budgetary concerns small acreage states were added and subtracted over the period. The largest reduction in states covered occurred in 2019, resulting in a reduced total acreage by 595 thousand acres or 0.2 percent.

The primary ethanol buildout was from 2000 to 2010. From 2000 to 2010, U.S. total planted acreage decreased from 289,554,010 to 275,679,221 or a decrease of 13,874,874 acres. Alfalfa planted acres declined by 3,445,000 because the ethanol buildout provided a local market for corn and low profitability of cow calf operations. The primary reason for the planted acreage decline was winter wheat losing 6,058,000 acres.

The lack of variability in total acres speaks to the effectiveness of the U.S. safety net for row crops. Acres that qualify for the farm programs typically stay in production unless the land is developed into residential use. New cropland primarily enters production by plowing up pastureland and return of acres that were in fallow, such as conservation reserve program (CRP) acres, which are discussed later in this report.

Figure 11: U.S. Planted Acreage by Crop



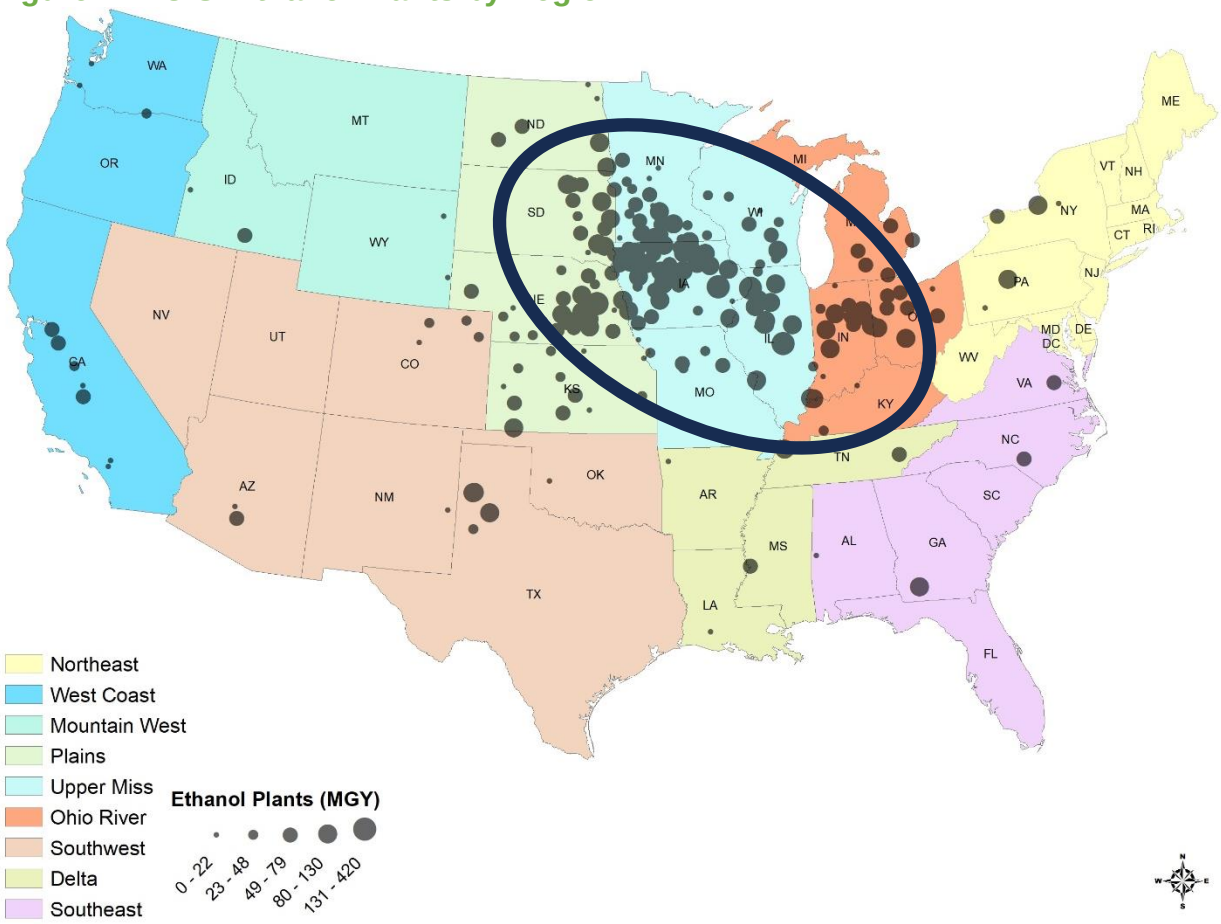
Source: USDA and Higby Barrett

Pasture Versus Cropland Value.

The primary drivers for pastureland being converted to cropland are higher yielding seed varieties in regions that have shorter growing seasons and lower precipitation totals, ethanol plants and low cow calf profitability.

Not surprisingly, the ethanol buildout occurred in the Corn Belt. The ethanol plants created extra demand for local corn which improved the local price the farmer received and improved the ease of marketing corn.

Figure 12: U.S. Ethanol Plants by Region



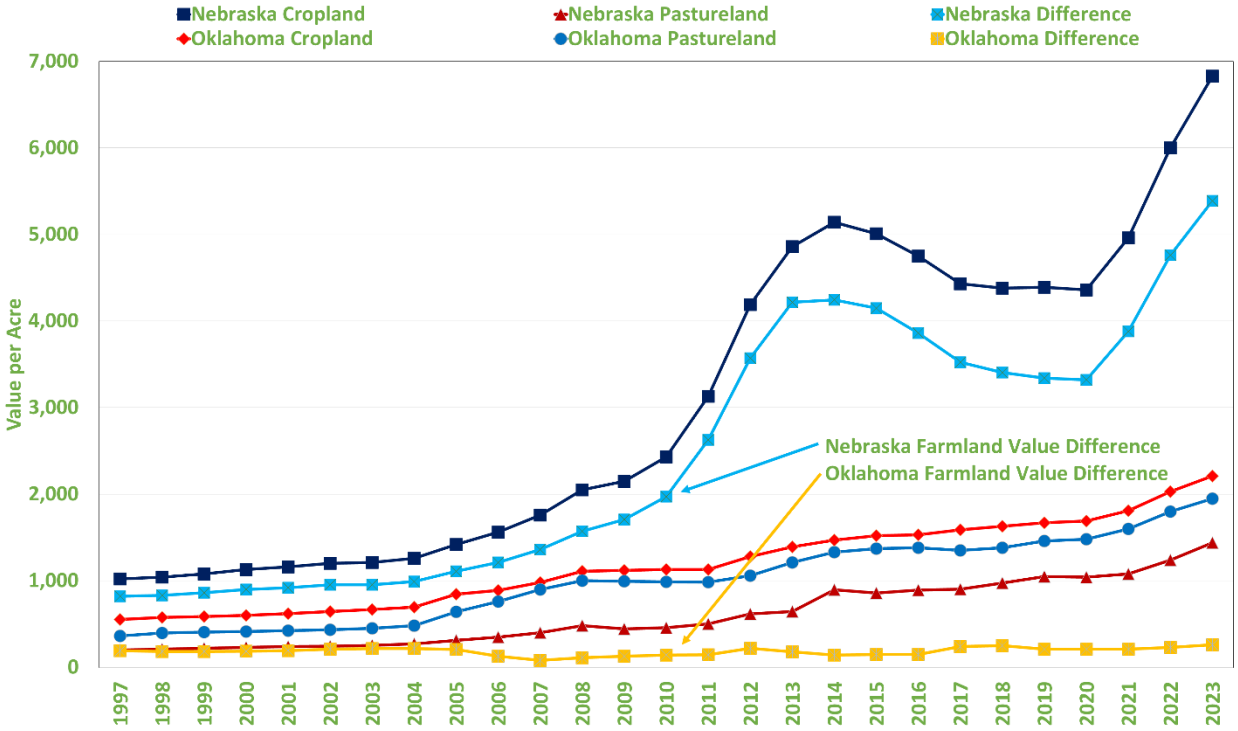
Source: Ethanol Magazine, Higby Barrett

Pastureland is often land that cannot grow crops profitably and/or small fields. For certain areas, the ethanol buildout greatly widened the gap between the value of cropland and pastureland.

To illustrate the point, the cropland and pastureland value was compared for Nebraska and Oklahoma. The ethanol buildout added many ethanol plants to Eastern Nebraska versus almost none for Oklahoma. The wider gap encouraged ranchers to switch pastureland into marginal cropland. Some ranchers reduced their cow herd while other ranchers devoted less land to the cow calf operation and bought extra feed to supplement the pasture that was lost. For ranchers in the eastern area of the Plains States, the row crop economics versus pasture became too advantageous to disregard.

The farmland value difference between cropland and pastureland decreased in Oklahoma from 2000 to 2010 by $42 per acre. During the same period, in Nebraska, the farmland difference increased by $1,071 per acre.

Figure 13: Nebraska Oklahoma Farmland Value Ethanol Response



Source: USDA Nass

Double Crop Acres

The USDA June Acreage report surveys farmers concerning how many soybean acres followed another crop. It is generally assumed that the crop it follows is winter wheat, but a closer examination of the data suggests farmers are including other crops. The key takeaway from this is that the winter wheat assumption overstates how many winter wheat acres are double cropped with soybeans. In 1990, approximately 6,361,850 soybean acres were double cropped versus 3,498,000 acres in 2022 or a decrease of 2,863,850 acres. Accounting for double cropped acreage, from 1990 to 2022 total farmed cropland, excluding alfalfa, declined by approximately 4 million acres.

It should be noted that even with the Russia Ukraine war dramatically increasing wheat prices, double cropped acreage declined in 2022, which speaks to the variety of factors that impact planting decisions. It also speaks to the difficulty of developing a price elasticity that is logical.

Figure 14: Hard Red Wheat (Weekly Nearby Contract)

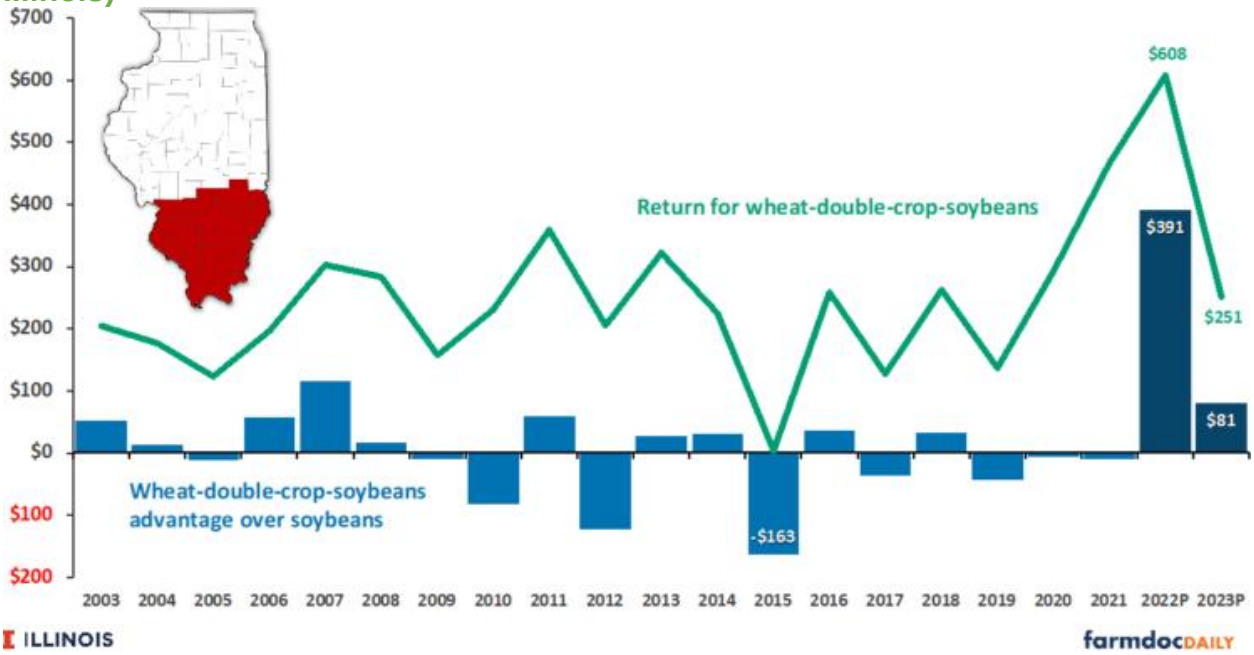
Source: CME Group and Bar Chart

For example, the primary factor that impacts the farmer's decision to double crop is the soybean yield. The winter wheat yield is not impacted. The soybean yields are negatively impacted by the winter wheat removing moisture from the soil and a much shorter growing season. The short-season soybean varieties do not yield as well as regular season soybean varieties. The extra time allows the plant to grow larger and produce more fruit.

A quick glance at the University of Illinois (farmdoc daily) double crop budgets would suggest all U.S. soybean acres should be double cropped versus the reported four percent. The source of the data for the budgets is farmers who can double crop soybeans and make a profit. The assumed soybean yields in Southern Illinois are 58 bushels for regular season varieties and 46 bushels for short season varieties or a yield decrease of 20 percent. Every enterprise budget is a guide that farmers must put in their data to make the budget relevant to their farming operation. Farmers have told Higby Barrett that their soybean yield loss is closer to 50 percent. Double cropping does carry a yield risk and risk tolerance depends on the individual farmer.

It should be noted that regular soybean acres produce yields that are 25 percent to 100 percent higher than double crop soybeans. Moving away from double cropping and replacing wheat acres with soybean acres reduces wheat output but this is partially offset by higher soybean production.

Figure 15: Operator and Land Returns Wheat-Double Crop Soybeans (Southern Illinois)

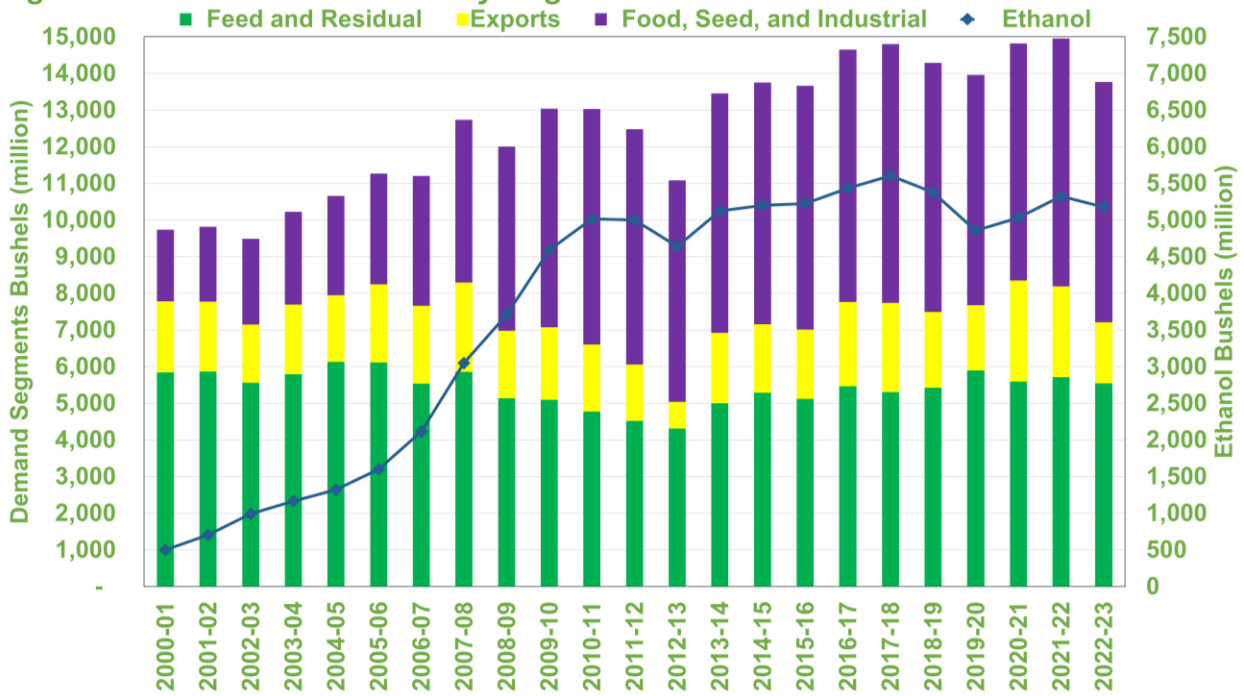


Renewable Fuel Standard

EIA reported, "The use of ethanol as a gasoline additive increased in an accelerating fashion from 2000 to 2010. Its use was spurred by the Clean Air Act amendments of 1990 (and subsequent laws), which mandated the sale of oxygenated fuels in areas with unhealthy levels of carbon monoxide. Starting in 2010, E10 (an ethanol-gasoline blend containing 10 percent ethanol) was sold in all 50 states to boost octane, meet air quality requirements, or satisfy the Renewable Fuel Standard. Increases in ethanol use are also attributed to more widespread availability of flex-fuel vehicles, which can use blends as high as E85 (containing up to 85 percent ethanol), and greater availability of E85 stations. Ethanol is also available as E15 for use in light-duty vehicles of model year 2001 and newer."

A quick look at the U.S. corn demand categories exemplifies the ethanol buildout occurred from 2000 to 2010. The infrastructure that was built is a major positive for farmers. From an economic standpoint, this should have led to a spike in corn acreage to take advantage of changing market conditions. U.S. corn planted acreage in 2006 was lower than 2000 corn planted acreage. Even with changes to the Clean Air Act in 1990, corn supply was still being pushed into the market until 2007. The reason was the U.S. had available bushels to meet the increases in corn demand.

Figure 16: U.S. Corn Demand by Segment

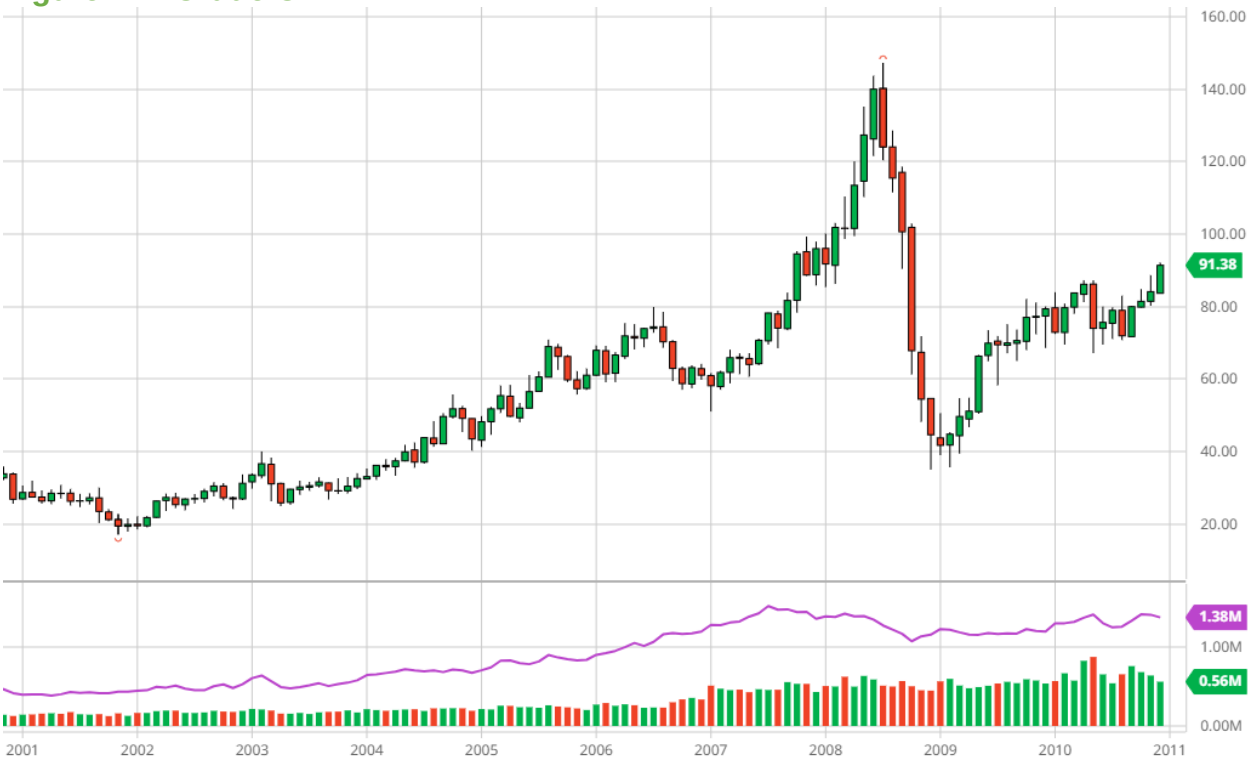


Source: USDA and Higby Barrett

Crude oil prices were an overarching driver of behavior during 2007 and 2008. Because energy is the largest commodity in the world, skyrocketing energy costs ripple through the entire supply chain. The increase in producer costs accumulates and results in much higher retail prices. Nitrogen fertilizer uses natural gas as a feedstock. Higher energy prices increase chemical costs, farm fuel costs, and delivery costs. Corn drying costs are directly tied to propane or natural gas. When generators are used for irrigation, they primarily run on diesel. The added cost increases crop costs which increase meat prices. The cool chain needs diesel to keep the refrigerated trucks cool. Retail operations must pay increased store cooling costs and increased freezer costs. The consumer must pay higher fuel costs to travel to and from the store. Much of the cumulative cost resulting from increased energy prices is included in other categories.

Another issue is players in the supply chain who will anticipate higher energy costs and will act by increasing the prices of their goods or services. This is a dangerous economic situation that can lead to an inflation spiral. Congress was eager to take steps to lower energy prices and regain energy independence. One step Congress took was increasing the Renewable Fuel Standard. Crude oil prices had already quadrupled from $20 per barrel to $80 per barrel. Despite steps Congress took, crude price increased to $144 per barrel around the time the economy entered the Great Recession.

Figure 17: Crude Oil WTI

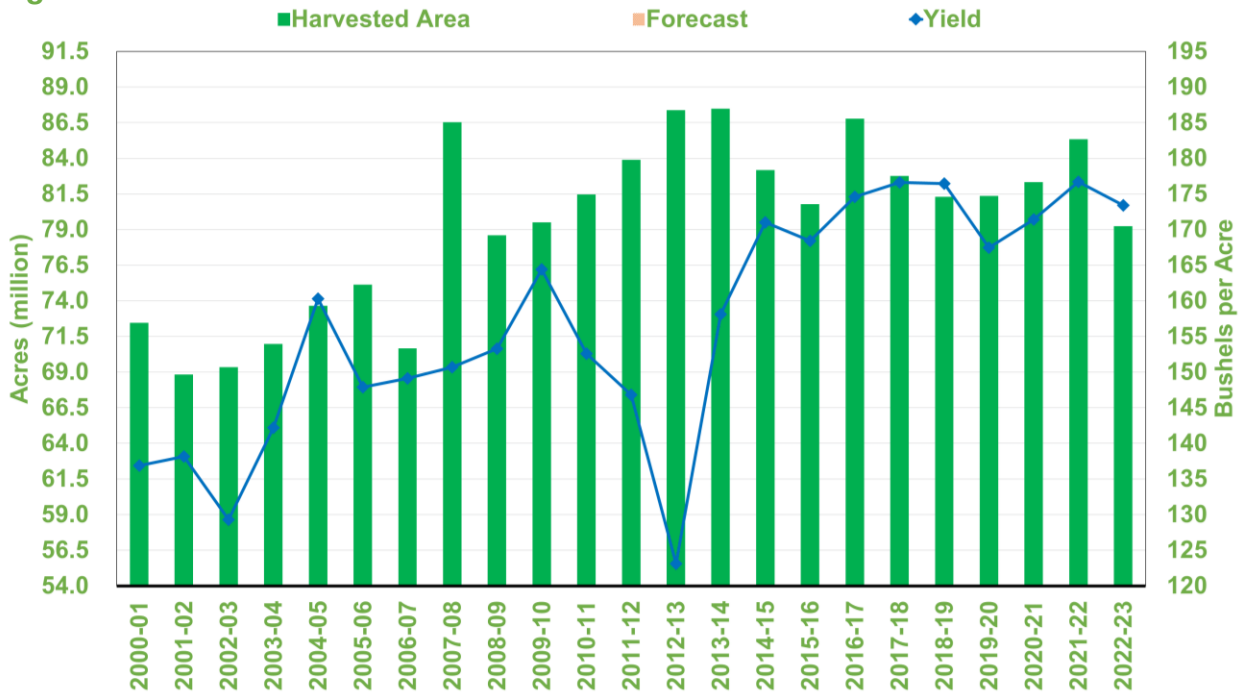


Source: ICE and Barchart

The Renewable Fuel Standard originated with the Energy Policy Act of 2005 and was expanded and extended by the Energy Independence and Security Act of 2007 (EISA). The new mandate volume required more corn acres.

Market players responded to the increased ethanol mandate by increasing corn price versus soybean price until farmers indicated they would alter the crop rotation to plant continuous corn (corn on corn) versus soybeans. Farmers who would typically have a 50 / 50 corn soybean crop rotation switched to 60 40 crop rotation to take advantage of the favorable price ratio. In 2007, soybean planted acres decreased 10.78 million and corn planted acres increased 15.2 million. In 2008, corn planted acres decreased by 7.55 million and soybean planted acres increased by 10.98 million.

Figure 18: U.S. Corn Harvested Area and Yield

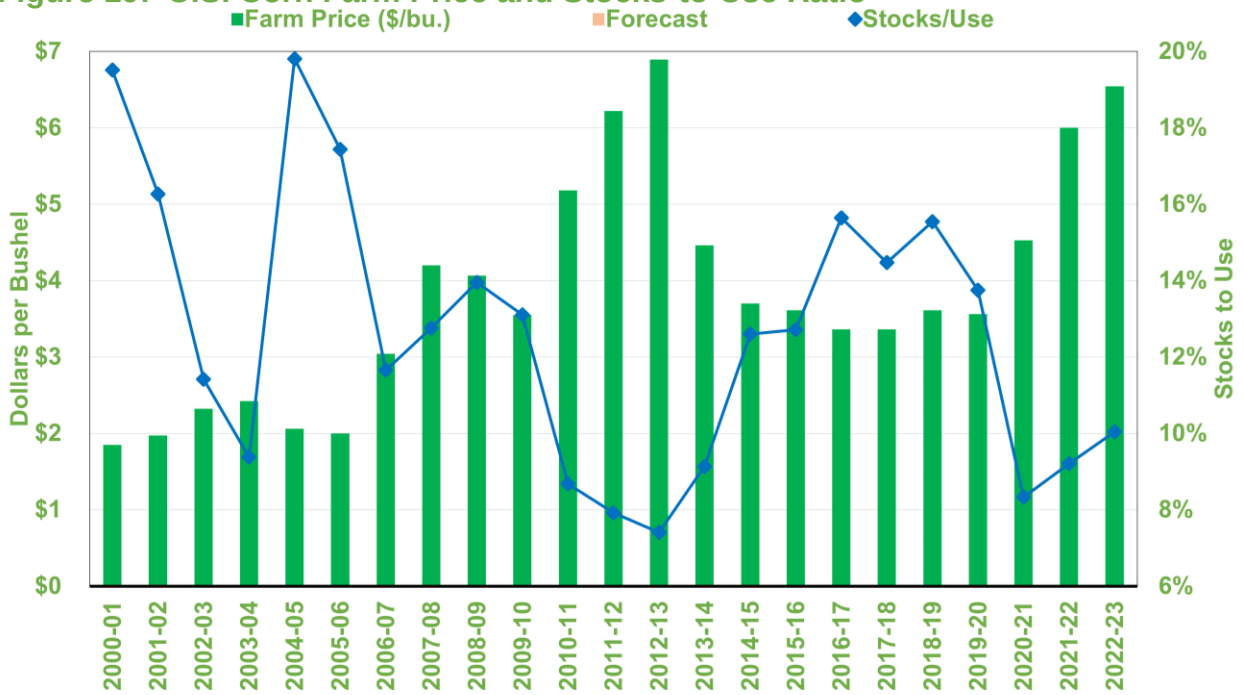


Source: USDA

The changes in crop production are the most significant driver in crop prices because it is the most volatile. While the change in corn ethanol consumption appears small compared to the change in corn production, the stocks-to-use ratio declined despite U.S. farm corn price increasing 50 percent from crop year 2005/06 to 2006/07. Since peaking in 2017, U.S. corn ethanol consumption has declined by over 400 million bushels.

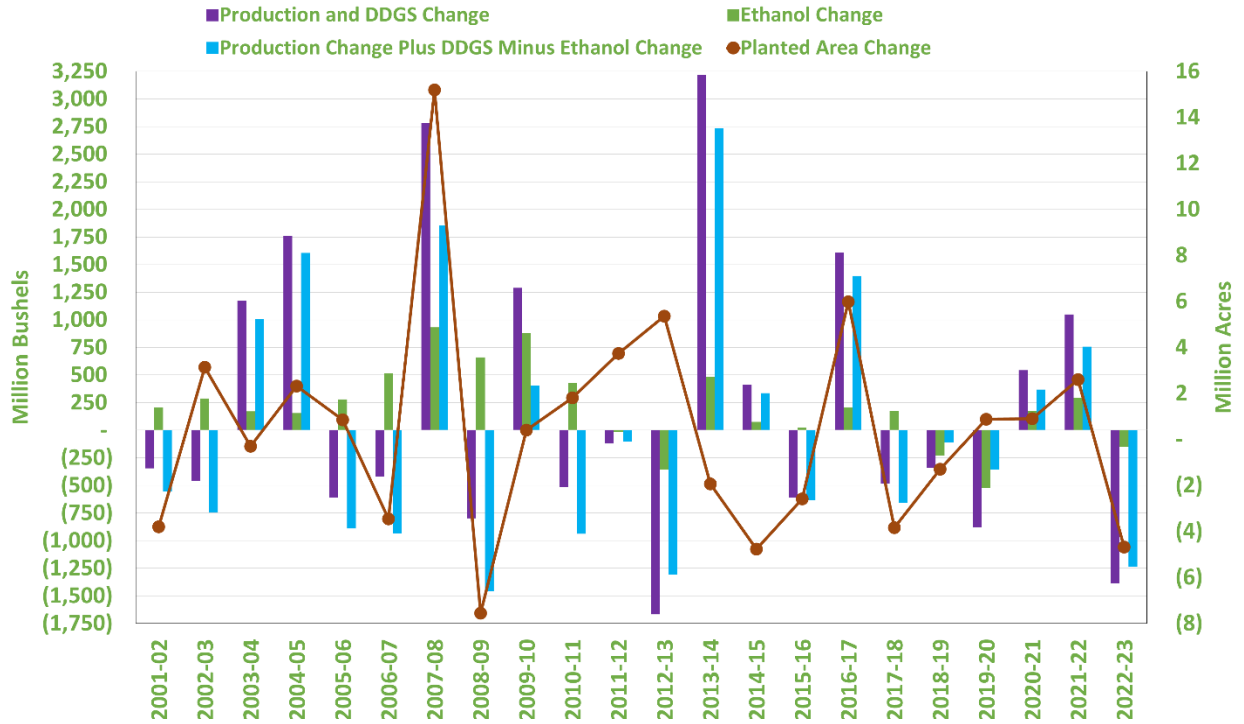
Since 2006/07, the factor that has the greatest impact on the price of corn are yields. The market players adjust to the other fundamentals but yields and in turn available supply can change very quickly. A sudden yield loss limits the options available to a buyer other than to outbid other buyers. For example, in 2012/13, a severe drought reduced yields and the U.S. corn price had to reach a level that rationed demand. If the world had greater available supply of corn, U.S. corn exports could have been switched to other suppliers and/or world stocks could have been pulled down at a lower price.

Figure 19: U.S. Corn Farm Price and Stocks-to-Use Ratio



Source: USDA

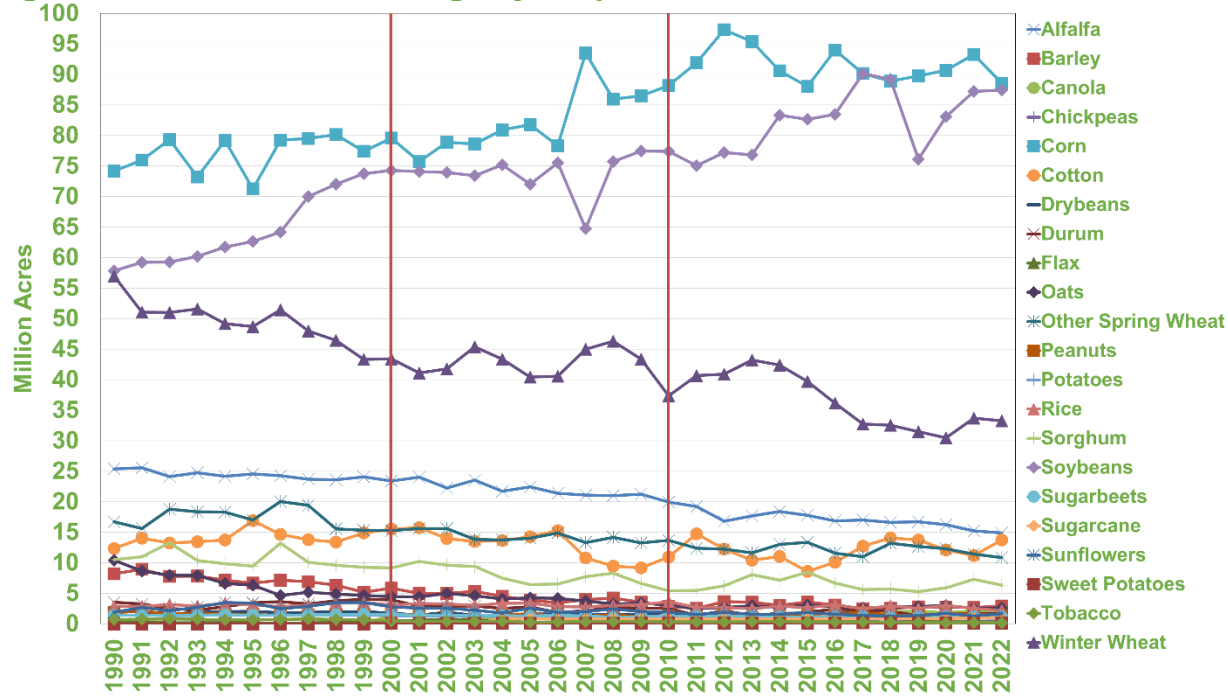
Figure 20: Corn Production Plus DDGS Change, Corn Ethanol Change, Production Change Plus DDGS Change Minus Ethanol Change, Corn Planted Area Change



Source: USDA

The primary ethanol buildout was from 2000 to 2010. From 2000 to 2010, U.S. total planted acreage decreased from 290 million to 276 million or a decrease of 14 million acres. U.S. total planted acreage increased by 3.68 million in 2007 and 5.44 million in 2008 to reach 284 million or still approximately six million below 2000. In 2022, total planted acres are at 275.06 or back to the 2006 level. U.S. planted acreage in 2007 and 2008 was impacted by three primary factors. First was the increase in the Renewable Fuel Standard, second was multiyear worldwide wheat production issues, and third was the elimination of the U.S. Step 2 cotton export program. It should be remembered this is in addition to China ramping up soybean import volumes and new seed varieties stretching the bounds of where corn and soybeans can be grown.

Figure 21: U.S. Planted Acreage by Crop

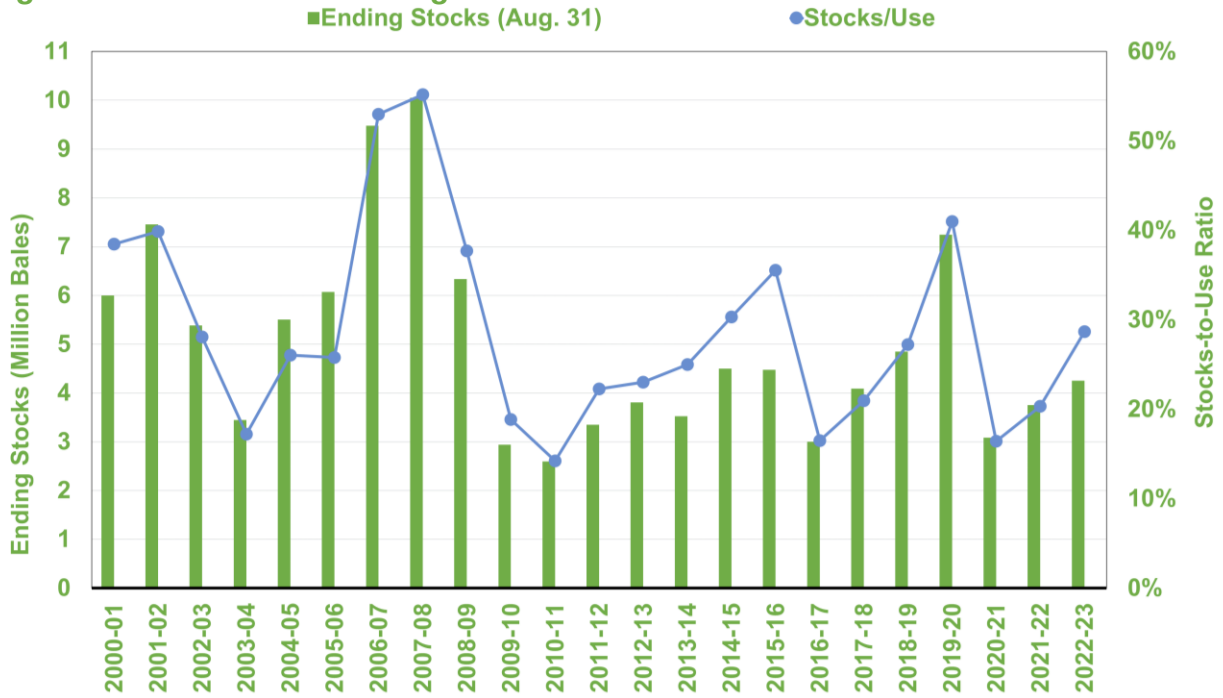


Source: USDA and Higby Barrett

Wheat prices increases to $9.795 dollars per bushel in 2007 and peaked at $12.825 dollars per bushel in 2008 because of various wheat production issues across the globe. In 2007 and 2008 U.S. wheat planted acres increased 3.13 million and 3.16 million, respectively. This represented a major reversal considering that from 1990 to 2006 wheat planted acres decreased from 77.24 million to 57.34 million or a decrease of 19.91 million. U.S. wheat planted acres started declining well before the Renewable Fuel Standard was enacted in 2005.

In 2007, U.S. cotton acres plunged from 15.27 million in 2006 to 10.83 million. While the higher corn price attracted cotton planted acres, the reason cotton planted acres declined was the world did not need U.S. cotton. U.S. eliminated the cotton export program Step 2 in August 2006. U.S. cotton exports declined 4,714 thousand bales in 2006/07, resulting in already high ending stocks to balloon to 9,479 thousand bales. Even after declining by 4.45 million planted acres in 2007, U.S. ending stocks increased from 9,479 thousand bales to 10,054 thousand bales. In 2008, cotton planted acreage declined an additional 1.36 million acres to fall to 9.47 million.

Figure 22: U.S. Cotton Ending Stocks and Stocks-to-Use Ratio



Source: USDA

From 2006 to 2008, corn planted acreage in the cotton growing regions of Southwest, Delta and Southwest increased 2.19 million or 38 percent of the cotton planted acres lost. Clearly cotton acres were being pushed into other crops. Specialized equipment and supply chain investments are the reasons cotton acreage did not decrease further. The increase in the RFS did provide relief to cotton farmers searching for alternative crops to raise.

The impact of the construction of ethanol plants largest impact is on the flow of corn and the creation of a new feed ingredient. For example, an Iowa farmer that could store the corn on farm, sell locally to a country elevator, sell to a local animal operation, or truck the corn 100 miles to a river elevator was provide an option to sell to an ethanol plant. Every market player in the supply chain had to adjust to the new competition for supply. Animal nutritionists now have more experience in feeding DDGs.

U.S. Acreage by Crop Trends

With commodities, it is always a question if acreage for a specific crop is being pulled into production or pushed out of production. Long-term acreage trends provide prospective on general market trends.

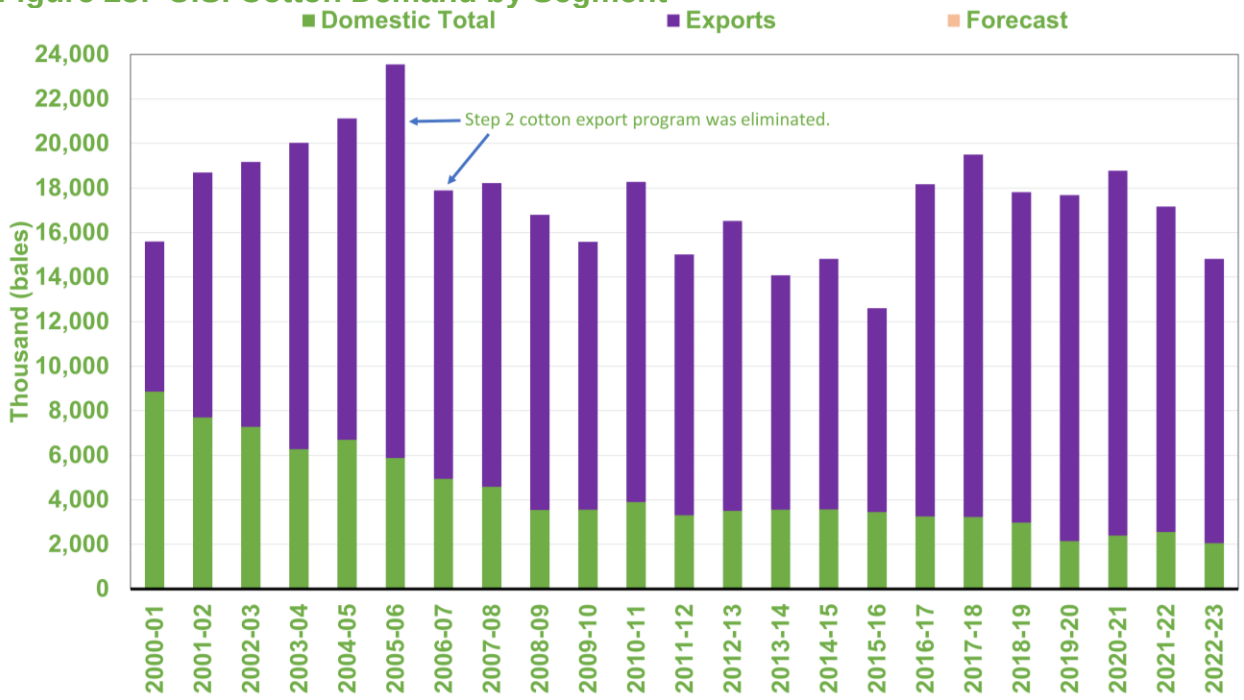
Barley, Cotton, Durum, Oats, Peanuts, and Sorghum

From 1990 to 2010, U.S. acres for barley, oats, sorghum, cotton, durum, and peanuts declined 20.7 million from 47 million to 26 million. During the ethanol buildout from 2000 to 2010, acreage decreased 14 million. From 2010 to 2022, acreage increased 2.5 million acres. Based on the last twelve years, switching additional acreage from these crops to corn and soybeans will be limited.

It is common for crops to have several uses depending on the price point. For example, low quality barley is a feed ingredient and can be substituted by other grains, such as corn and wheat. Malting quality barley is used to make beer and will not be substituted. The higher value the product the more difficult it is to replace.

The textile industry is labor intensive, which is why the industry is always migrating to politically stable countries that have the lowest wages. As a result, the domestic mill use for cotton is in decline. The decline in domestic use has turned the U.S. cotton industry into an export focused business. When the Deficit Reduction Omnibus Reconciliation Act of 2005, S. 1932 was signed that repealed the Step 2 program effective August 1, 2006, cotton exports declined.

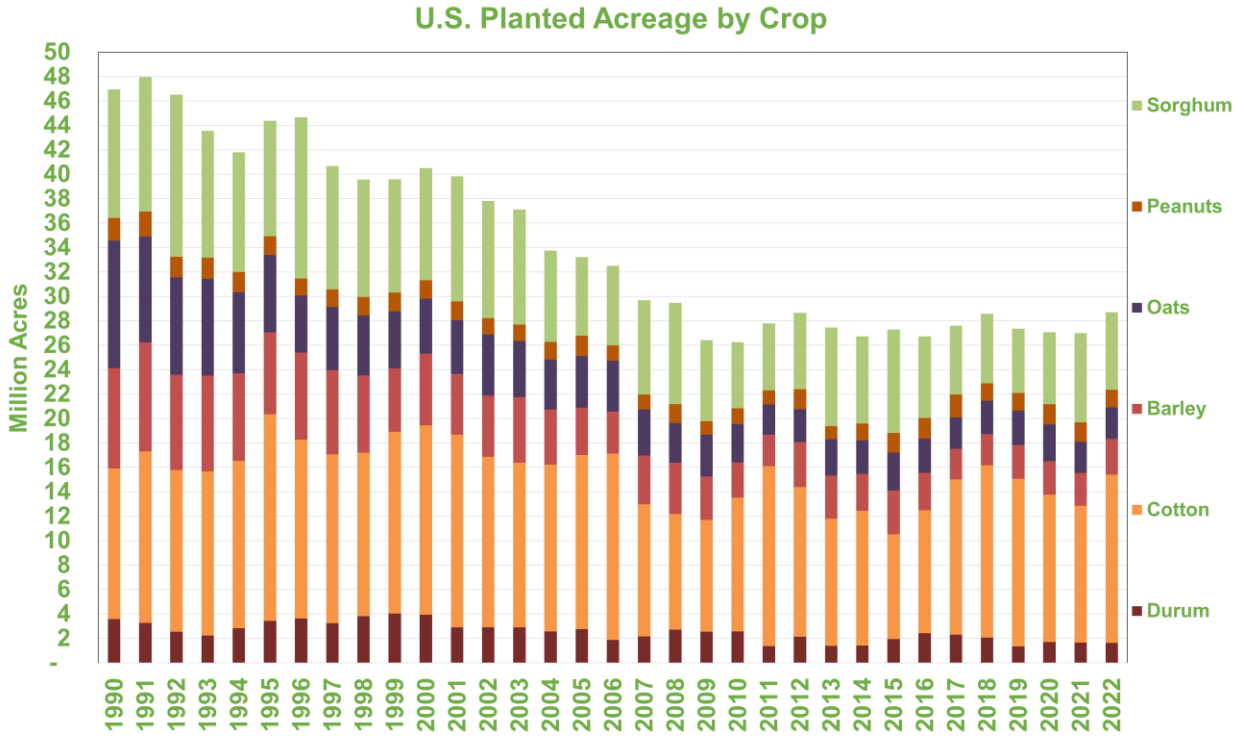
Figure 23: U.S. Cotton Demand by Segment



Source: USDA and Higby Barrett

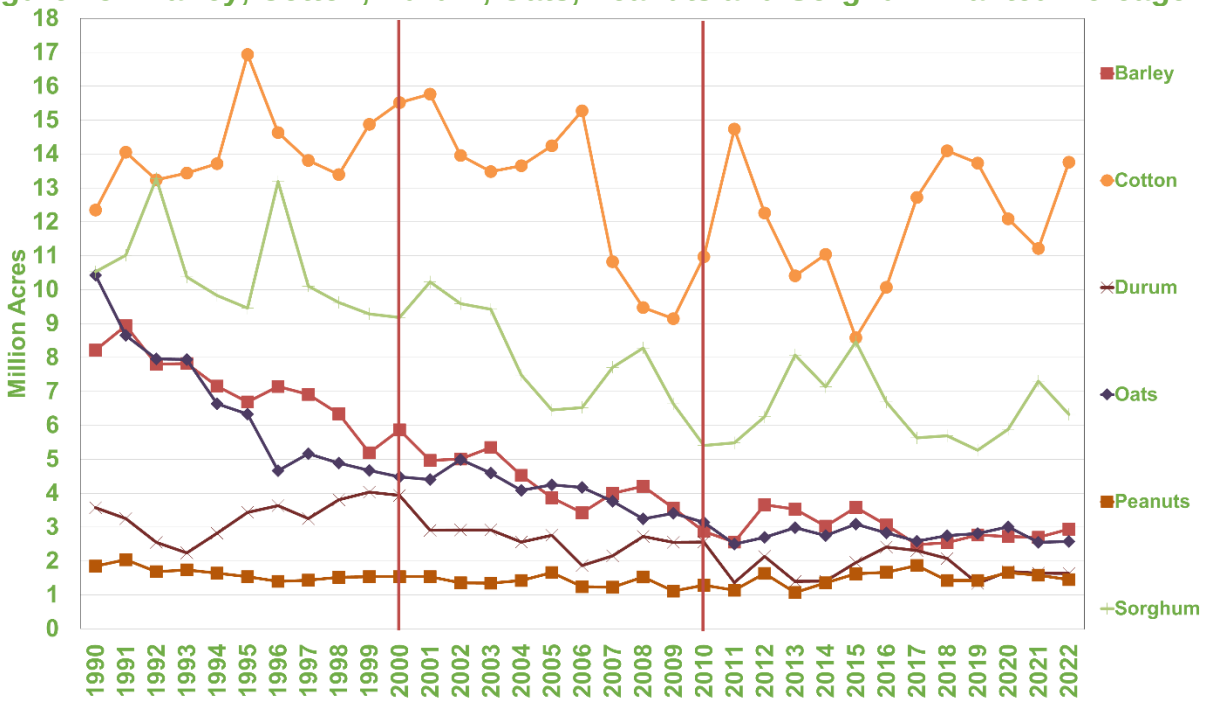
Sorghum and cotton can be grown in very hot, dry climates and still produce an acceptable yield. Corn and soybeans can also produce a yield with timely rains and/or irrigation. For example, the production risk of planting corn and soybeans in West Texas is much greater than in the Corn Belt.

Figure 24: Barley, Cotton, Durum, Oats, Peanuts and Sorghum Planted Acreage



Source: USDA and Higby Barrett

Figure 25: Barley, Cotton, Durum, Oats, Peanuts and Sorghum Planted Acreage

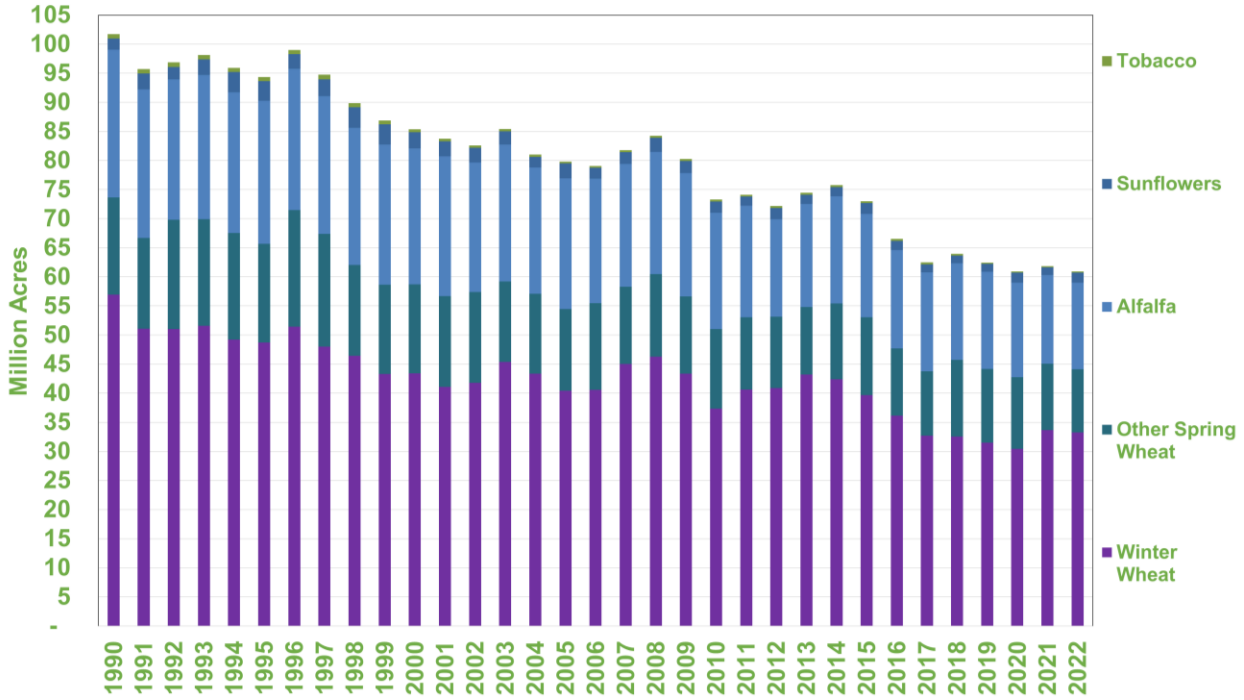


Source: USDA and Higby Barrett

Alfalfa, Other Spring Wheat, Sunflower, Tobacco, and Winter Wheat

For alfalfa, sunflower, tobacco, other spring wheat, and winter wheat, U.S. acreage from 1990 to 2010 has declined from 102 million to 73 million or a 28.4-million-acre decrease. During the ethanol buildout from 2000 to 2010, acreage decreased nine million. From 2010 to 2022, acreage has declined an additional 12.4 million acres for a total reduction of 40.8 million. The switching rate is slowing as acreage for lower value uses is rationed. For example, feed wheat versus high grade milling wheat.

Figure 26: Alfalfa, Other Spring Wheat, Sunflower, Tobacco, and Winter Wheat Planted Acres

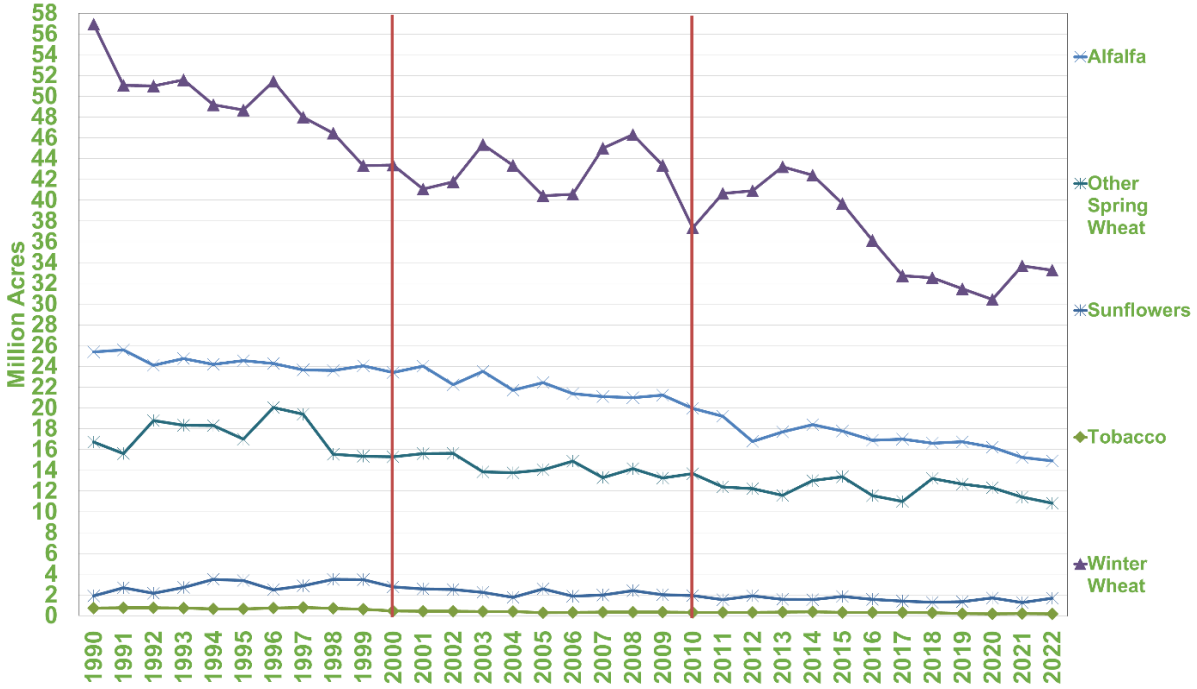


Source: USDA and Higby Barrett

In the 2000s, trans fats were a major issue. High oleic oil could fry food and maintain its structural integrity like partially hydrogenated soybean oil. Mid oleic sunflower varieties boosted sunflower acreage in the 2000's.

Sunflower's low meal value decreases its value compared to the other oilseeds. Sunflowers and wheat are extremely tough plants that can endure limited precipitation and cold weather. New seed varieties of corn and soybean acreage is enabling corn and soybeans to be planted further north and west, which is replacing wheat and sunflower acres.

Figure 27: Alfalfa, Other Spring Wheat, Sunflower, Tobacco, and Winter Wheat Planted Acres

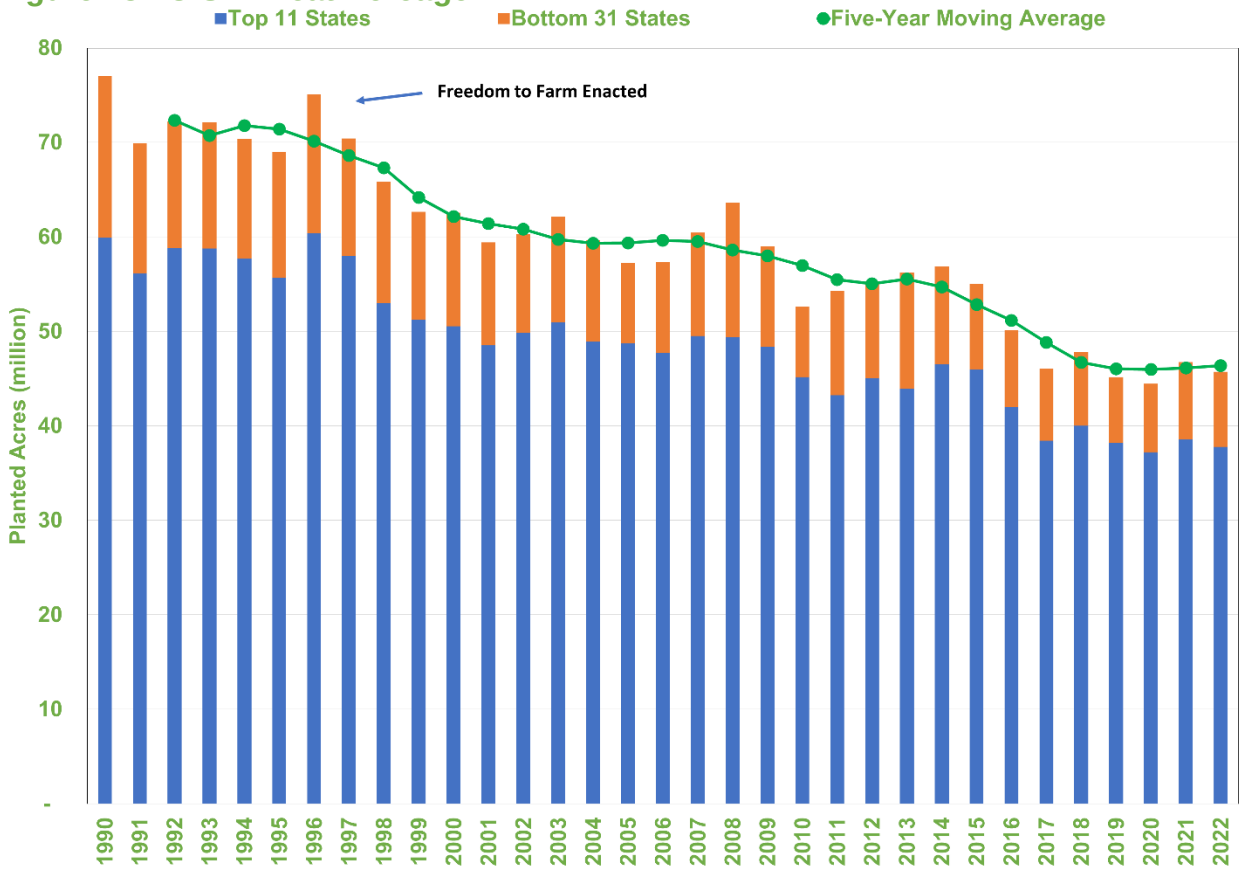


Source: USDA and Higby Barrett

Wheat is a crop that many countries produce very well, which limits U.S. export opportunities. By comparison, only a few countries have yields that produce corn and soybeans very well. Soybeans are crushed to produce two principal products. Soybean meal is the best vegetable meal in terms of nutritional value for a feed ration and represents 80 percent of soybean. Soybean oil is a useful vegetable oil that has a neutral taste and represents 19 percent of soybean. As the world population became wealthier, the demand for meat increased, which increased demand for soybean meal and corn. Wheat is a very good feed ingredient, but corn yields are much higher than wheat. So, a farmer can sell corn at a lower price than wheat and still make more money. Soybean meal has a higher protein level and a preferred amino acid profile than corn and wheat.

Ever since the Freedom to Farm policy in 1996 was enacted, wheat has been losing acreage to soybeans and corn. Total wheat acreage is down 41 percent. Wheat acreage is down 50 percent in the bottom 31 states that can easily grow corn and soybeans. The top 11 states for wheat acreage are basically the western and northern states. It should be noted that cotton and wheat can tolerate a hot dry climate better than soybeans and corn. Wheat, canola, and sunflowers also handle a cold dry climate better than corn, cotton, and soybeans. While it is logical that wheat will find a base level of acreage, the five-year moving average is a steady downward slope. Since 1996, the top 11 states for wheat acreage have lost 39 percent.

Figure 28: U.S. Wheat Acreage



Source: USDA NASS

Canola, Chickpeas, Dry Beans, Flaxseed, Potatoes, Rice, Sugar Beets, Sugarcane, and Sweet Potatoes

The acreage of the other crops (canola, chickpeas, dry beans, flaxseed, potatoes, rice, sugar beets, sugarcane, and sweet potatoes) was 9.6 million in 2004 (first year sugarcane was reported) and is forecast to be 9.4 million in 2024. During the ethanol buildout from 2000 to 2010, acreage increased 684 thousand. Except for canola, the other crops are food crops or processed into food. Food crops are very difficult to ration because of their higher return per acre.

Corn and Soybeans

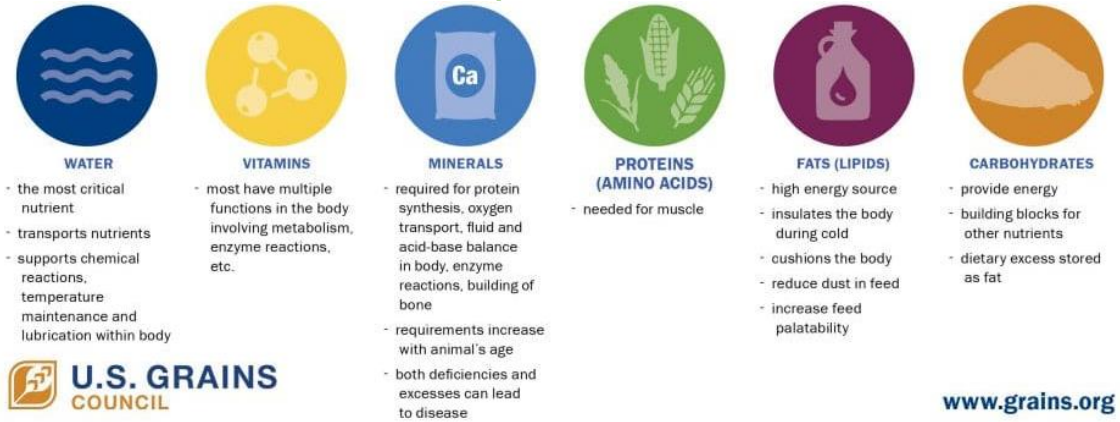
From 1990 to 2022, corn and soybean planted acreage has increased from 132 million acres to 176 million acres or an increase of 44 million acres. During the ethanol buildout from 2000 to 2010, acreage increased 12 million. The primary reasons for the increase in corn and soybean acreage are increased world demand for meat and biofuels, improved seed technology, crop rotations, and ease of growing and handling.

Meat is just feed ingredients in another form. As animal operations increase, grain and vegetable meal consumption increases. Meat production requires feed rations of grains and protein meals that are converted into weight gain. For example, if 1.6 pounds to 2 pounds of feed is required to add 1 pound of

chicken, switching, or just adding chicken to the dish results in an increase in per capita consumption of grains and protein meals.

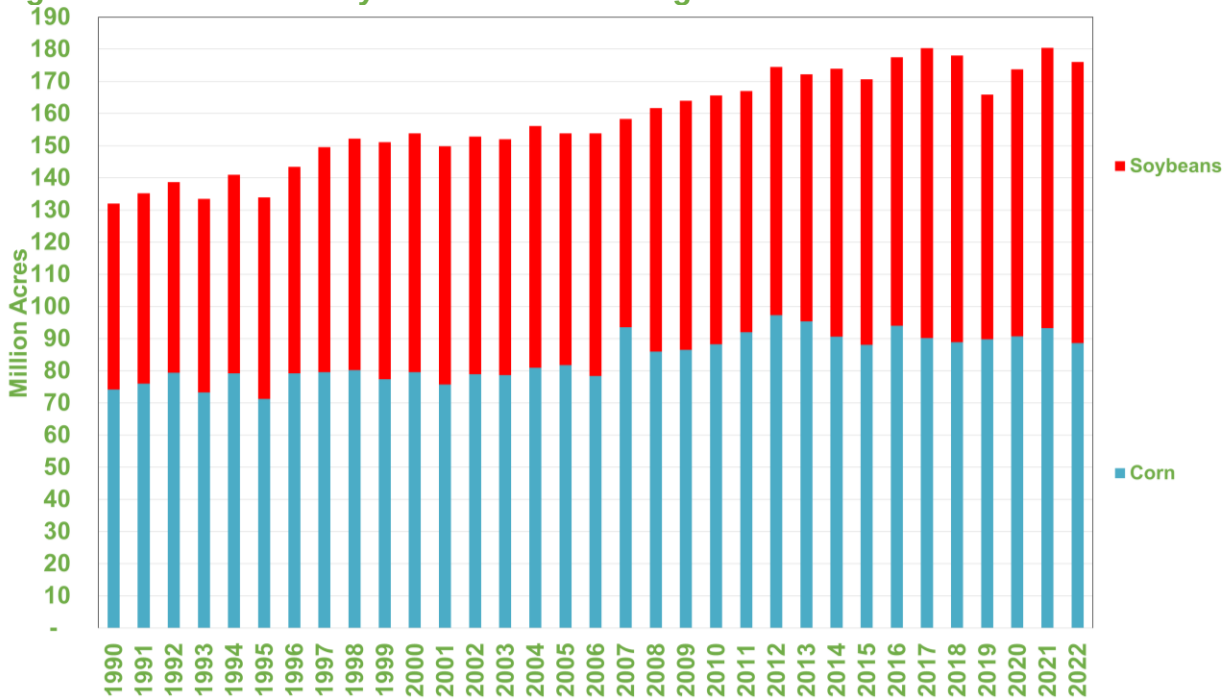
Soybean meal has higher protein level and a better amino acid profile (threonine, tryptophan, methionine, and valine) for feeding than the other vegetable meals and is often included with corn in a feed ration.

Figure 29: Animal Diet Six Basic Requirements



According to the Federal Drug Administration, in the 1990's. the first wave of GM seed varieties created through genetic engineering becomes available to consumers: summer squash, soybeans, cotton, corn, papayas, tomatoes, potatoes, and canola.

Figure 30: Corn and Soybean Planted Acreage



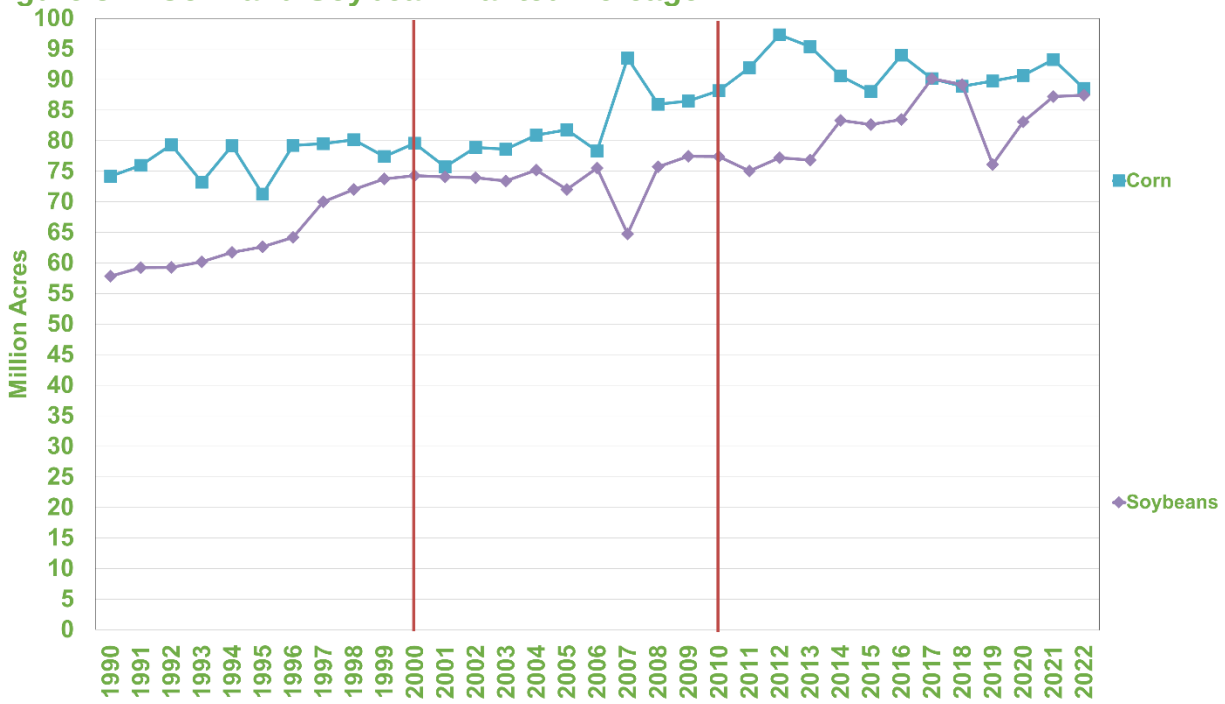
Source: USDA and Higby Barrett

It should be noted that wheat growers wanted wheat to be non-genetically modified, which resulted in seed companies investing more resources into developing higher yielding genetically modified corn and soybean varieties. The development of Roundup Ready soybeans that was introduced in 1996 greatly reduced the effort required to grow soybeans and reduced cost, which increased profitability. From 1996 until 2022, U.S. soybean acres increased 23 million.

ERS researchers compared the adoption of genetically engineered herbicide-tolerant (HT) and insect-resistant (Bt) corn. HT corn is immune to specific weedkillers, while Bt corn protects the corn crop from specific insect pests. Because of these valuable pest management traits, farmers began planting HT and Bt corn after their introduction in 1996, even though genetically engineered seeds were a novel and unfamiliar technology. Between 1996 and 2000, HT corn acreage increased from 3 percent to 7 percent of total U.S. corn acreage. Over this same period, Bt corn acreage increased from 1.4 percent to 19 percent. In the following years, corn farmers gained much more experience choosing, planting, and managing GM varieties, and adoption levels continued to rise. By 2012, nearly 75 percent of U.S. corn acres were planted to varieties with at least one GM trait.

Farmers have preferred crop rotations that they believe provide the greatest benefit. The corn soybean crop rotation is a very popular crop rotation. The reason for popularity is the two crops are compatible with machinery, are biologically different plants, and have competitive yields versus other crops. Machinery compatibility lowers costs. From a biological standpoint, having two totally different crops maximizes the benefit of decreasing diseases, lower pest and weed pressures.

Figure 31: Corn and Soybean Planted Acreage



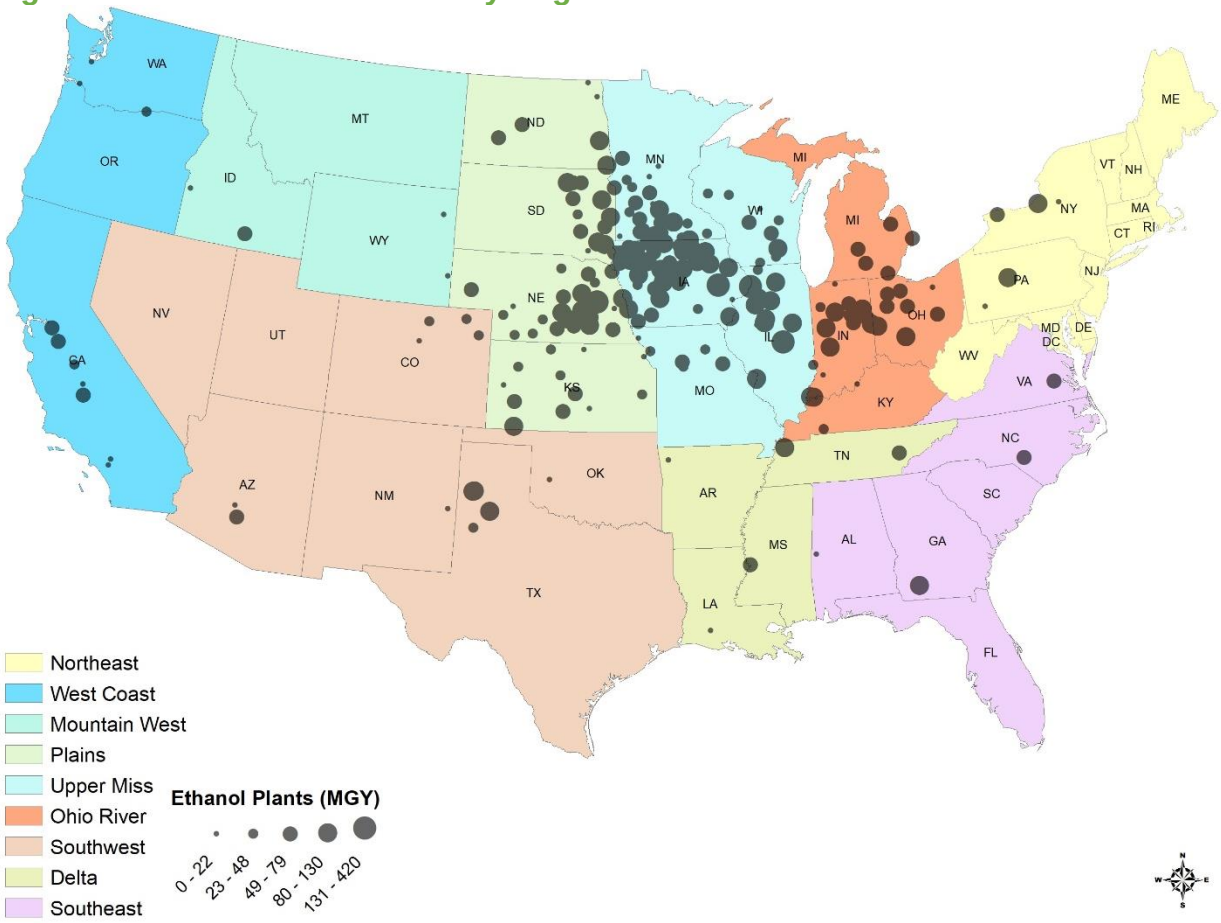
Source: USDA and Higby Barrett

U.S. Acreage Trends by Region

Between 1990 and 2022 planted acres decreased in all regions except the Plains, and during the ethanol buildout from 2000 to 2010 acres decreased in all regions except the Northeast and Mountain West. Northeast expanded 140 thousand acres while the Mountain West increased 370 thousand acres.

Exploring the acreage trends by region highlights the influence weather, soil types, and alternative uses for the land has on planting decisions. When cotton price reached 155 cents per pound, farmers in North Dakota did not start planting cotton. In fact, most farmers in regions that have warm weather did not plant cotton. The reason is growing cotton requires expensive equipment. The farmer has a comfort level in growing a crop that they have expertise in. Farming is a low margin business, and one major mistake can wipe out the profit.

Figure 32: U.S. Ethanol Plants by Region



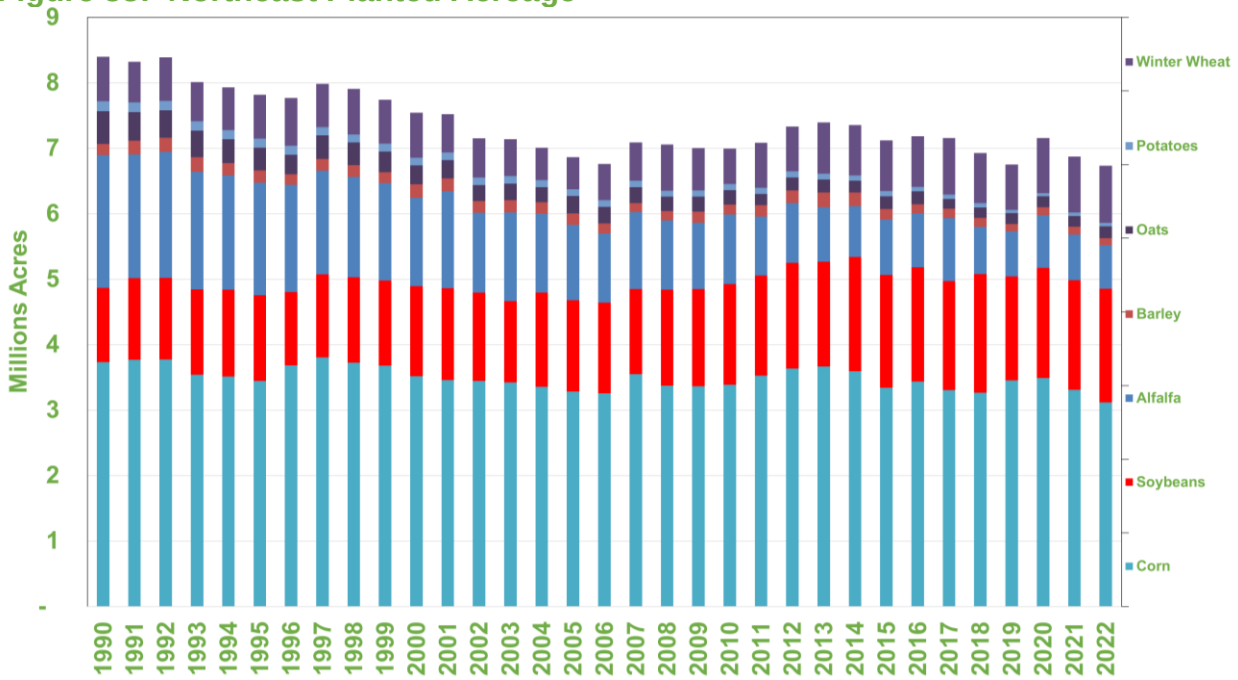
Source: Ethanol Magazine, Higby Barrett

Northeast Planted Acres

From 1990 to 2022, Northeast planted acreage decreased from 8.4 million acres to 6.7 or a decrease 1.7 million acres. Winter wheat is increasing in the Northeast. Alfalfa acres have declined over one million

from 1990 to 2023. During the ethanol buildout from 2000 to 2010, Northeast planted acreage increased 140 thousand.

Figure 33: Northeast Planted Acreage



Source: USDA and Higby Barrett

Urban creep continues to decrease land available for crop production. In 2020, the Census Bureau tightened up the definition of metropolitan, which is why total area declined. Also, metropolitan area definition changes as metropolitan areas merge. Still, the land trend is urban area increasing. From 1990 to 2010, at least 7.5 million acres have become urban areas. In addition to agricultural land being converted to residential, increased population results in push back against animal operations that in turn reduces the need for land to grow feed. Also, infrastructure is required to support the new urban areas, such as new roads and expanded roads.

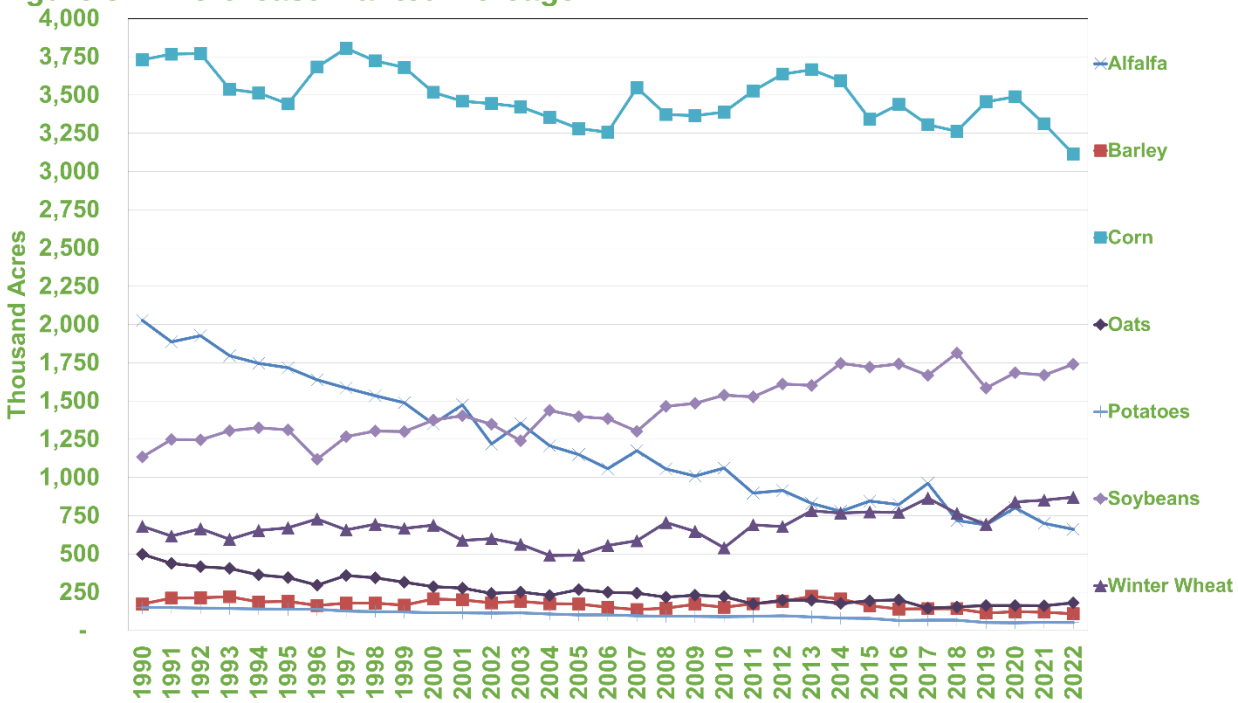
Table 1: Land Area for Metropolitan Areas Over One Million People in 2010

Crop Region	1950	1960	1970	1980	1990	2000	2010	2020
Delta	247,040	353,280	463,360	600,960	700,160	658,560	839,040	861,754
Northeast	1,841,920	2,997,120	3,825,280	4,915,200	5,365,760	7,177,600	7,688,320	7,277,670
Ohio River	698,880	1,271,680	1,714,560	1,978,880	2,152,960	2,510,080	2,937,600	2,810,195
Plains States	95,360	180,480	304,000	376,960	487,680	373,760	433,920	457,024
Southeast	471,680	910,080	1,616,640	2,625,920	3,298,560	4,387,200	5,609,600	5,567,571
Southwest	614,400	1,637,760	2,076,160	3,072,000	3,624,320	3,561,600	4,787,200	4,892,870
Upper Mississippi River	812,160	1,492,480	1,866,240	2,285,440	2,488,320	2,773,120	3,158,400	3,025,107
West Coast	1,082,880	2,031,360	2,659,200	3,180,800	3,608,320	3,502,720	3,729,920	3,640,826
Total	5,864,320	10,874,240	14,525,440	19,036,160	21,726,080	24,944,640	29,184,000	28,533,018

Source: Census Bureau

Soybean acres increased 605 thousand with corn acres decreased 616 thousand. Between in Northeast dairies and Delmarva broiler operations, if the RFS was squeezing corn supply, the Northeast corn price ratios should have pulled corn acres into production. Corn acres are basically in a 30-year downward trend.

Figure 34: Northeast Planted Acreage



Source: USDA and Higby Barrett

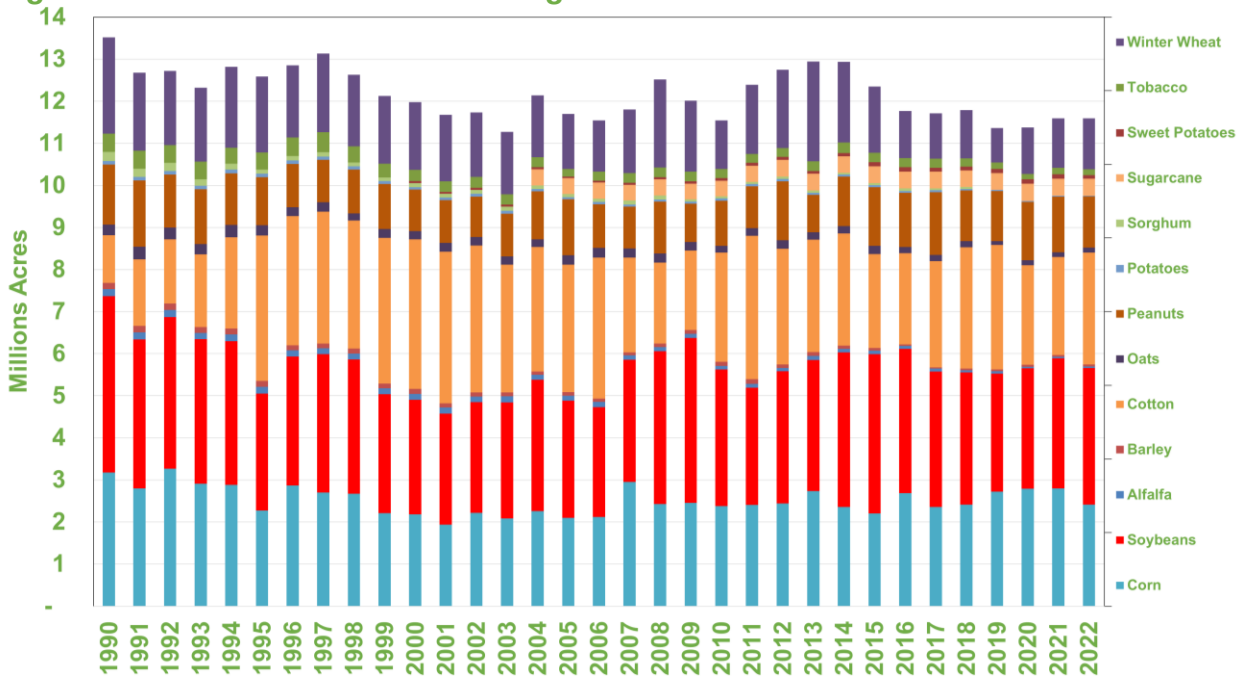
Southeast Planted Acres

From 1990 to 2022, Southeast planted acreage decreased from 13.5 million acres to 11.6 or a decrease 1.9 million acres. Over the same period, urban area increased 2.3 million acres. Winter wheat acres have declined over one million from 1990 to 2022. The only crops to expand acreage are cotton (1.5 million) and sweet potatoes 84 (thousand). Corn and soybeans experienced the second and third largest acreage declines with 765 thousand and 940 thousand, respectively.

During the ethanol buildout from 2000 to 2010, Southeast planted acreage decreased 434 thousand. The elimination of Step 2 drove cotton acres down 963 thousand. Soybean acres increased 530 thousand, but still below 1990.

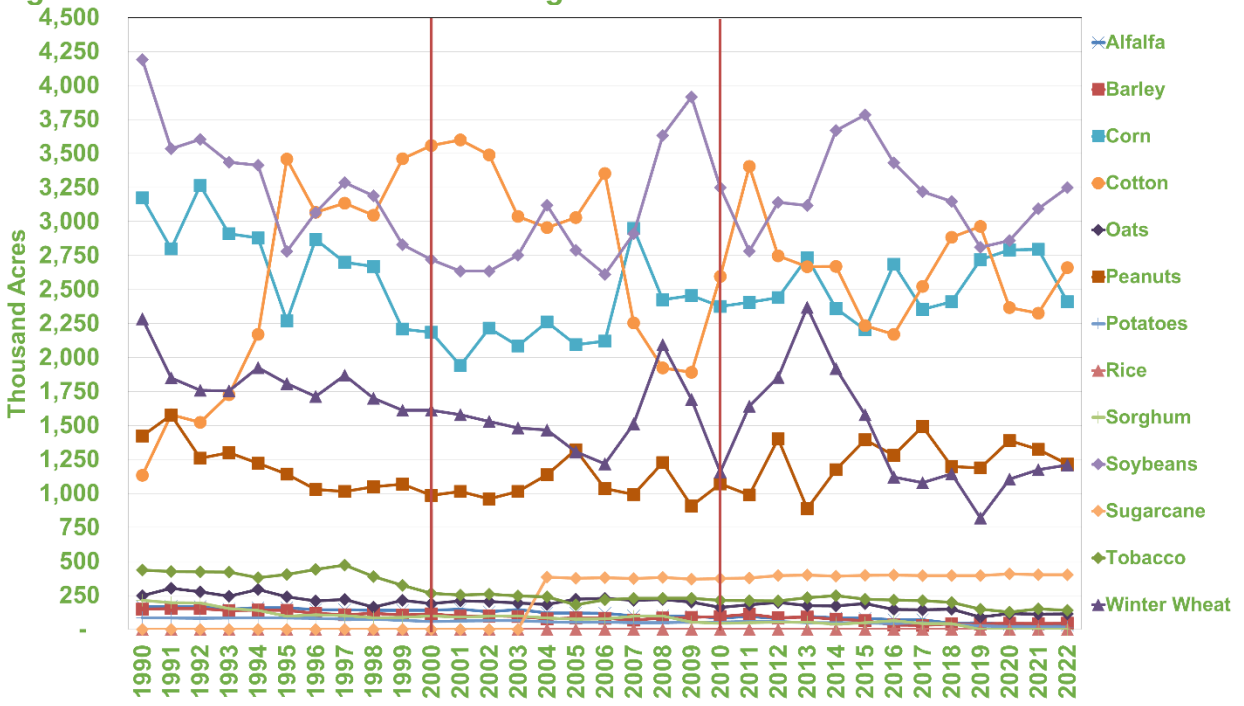
In 1972, EPA issued a cancellation order for DDT based on its adverse environmental effects. The Southeast was not able to control the boll weevil and cotton acreage plummeted. Research on new farming techniques and pesticides better controlled boll weevil pressures. In the 1990s, world demand for cotton increased price to a level where the farmer could “wildcat” (plant acres outside the farm program). After several years of wildcatting the farmer could build base cotton acres in the farm program. Once the base acres were reestablished, the infrastructure was rebuilt. Examples of infrastructure are cotton pickers, cotton gins and warehouses. The infrastructure investment has created an incentive to plant cotton even when other crops are more profitable.

Figure 35: Southeast Planted Acreage



Source: USDA and Higby Barrett

Figure 36: Southeast Planted Acreage



Source: USDA and Higby Barrett

In the Southeast, a strong argument can be made that cotton is king and all the other crop planting decisions revolve around cotton. When the Deficit Reduction Omnibus Reconciliation Act of 2005, S. 1932 was signed that repealed the Step 2 program effective August 1, 2006, cotton exports declined. The decline in exports increased domestic stocks and ultimately resulted in lower cotton acres.

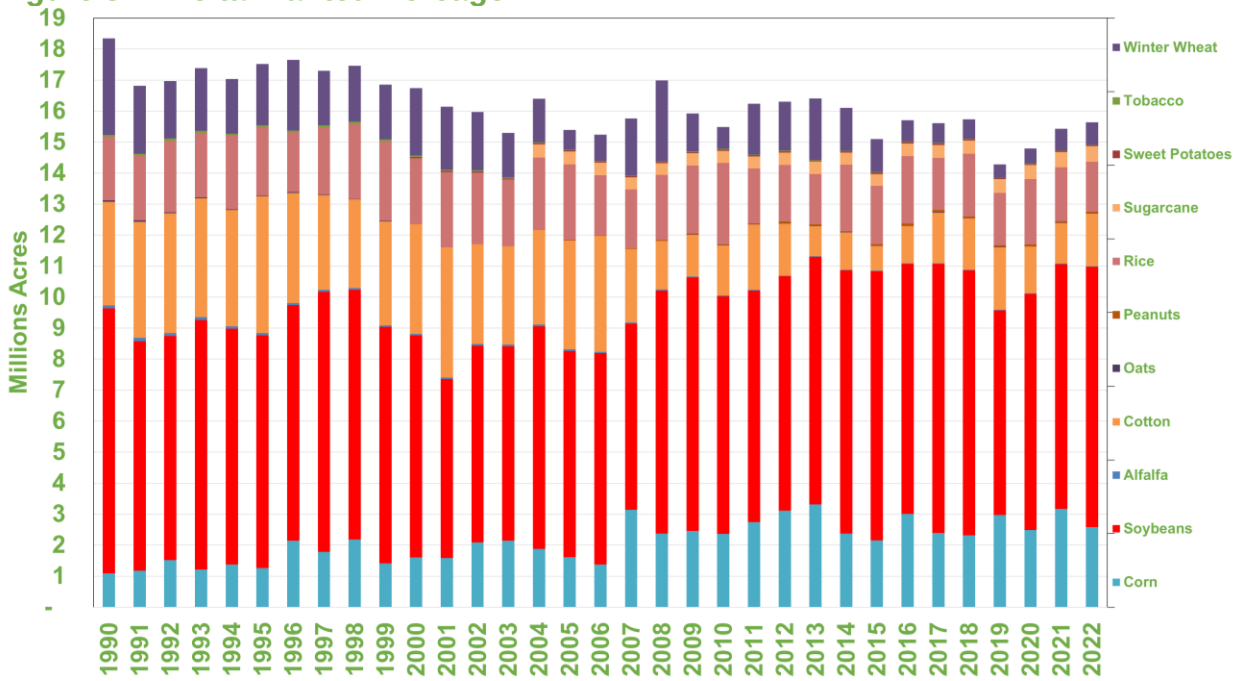
Delta Planted Acres

From 1990 to 2022, Delta planted acreage decreased from 18.9 million acres to 15.6 or a decrease 3.3 million acres. Cotton and winter wheat acreage declined by 4 million while corn acres increased 1.6 million. Sorghum acres fell so low the USDA no longer surveys for sorghum in the Delta. Soybean acres decline by 150 thousand.

During the ethanol buildout from 2000 to 2010, Delta planted acreage decreased 1.6 million. The increase in cotton acres in the Southeast, end of Step 2 export program, and the cotton infrastructure was older than the Southeast led to a sharp decline in Delta cotton acres. As the number of gins declined, the time and expense for ginning increased. Ginning is separating the seed from the lint.

Corn and soybean acres increased 1.3 million from 2000 to 2010 but did not replace the total cotton acres lost. Typically, in the Delta, “cotton is king” and would be planted to the highest yielding land. The fact that soybean and corn acres did not completely replace cotton acres is interesting.

Figure 37: Delta Planted Acreage

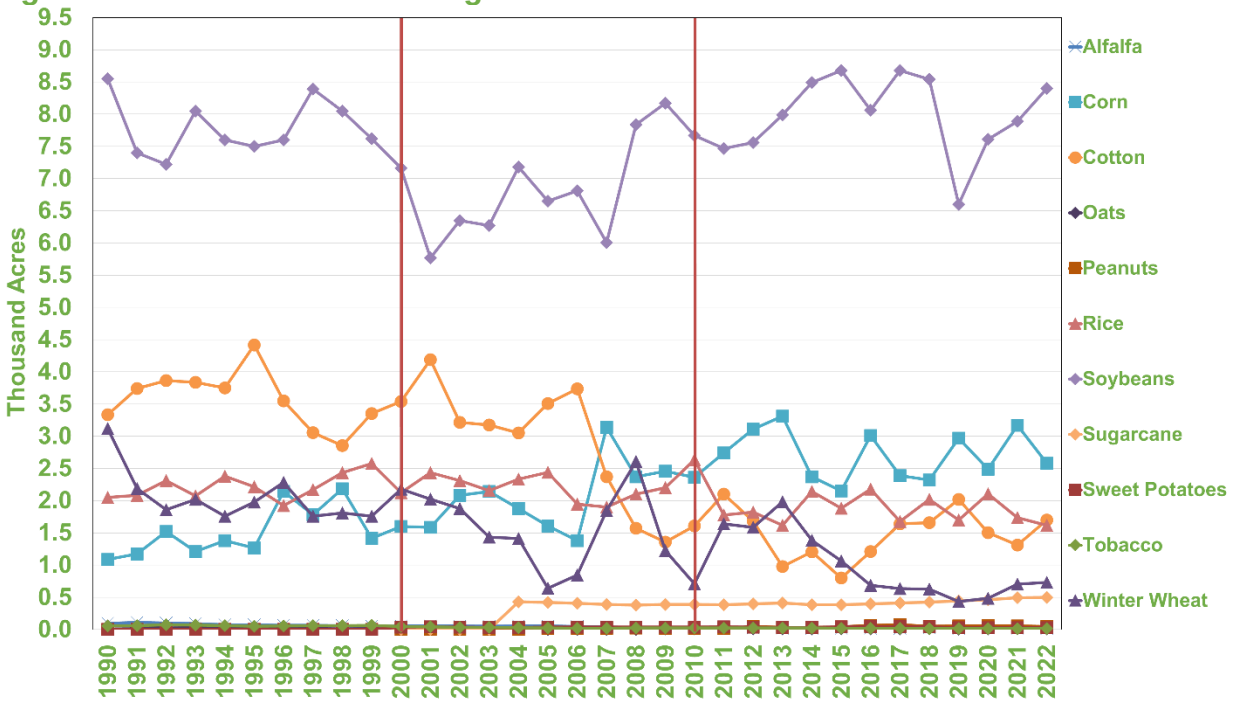


Source: USDA and Higby Barrett

Another factor that should have pulled more soybean and corn acres into production is an early harvest price premium, especially in years South America experiences crop issues or lower than expected yields. When South America crop yields are disappointing the world price increase to entice stockholders to release supply. Because the Delta states harvest first, the best marketing more is to sell directly to the export market before the world supply pipeline is resupplied and prices decline. One downside for the

farmers is the Delta has lost much of its soybean crushing infrastructure due to the competition from exports for local supply.

Figure 38: Delta Planted Acreage



Source: USDA and Higby Barrett

Southwest Planted Acres

From 1990 to 2022, Southwest planted acreage decreased from 35.6 million acres to 30.8 or a decrease 4.8 million acres. The reality is the Ogallala Aquifer is not replacing the water it loses. To irrigate requires deeper wells that are more expensive to build and need more diesel to pull the water from deeper depths. No answer to this long-term problem has been identified.

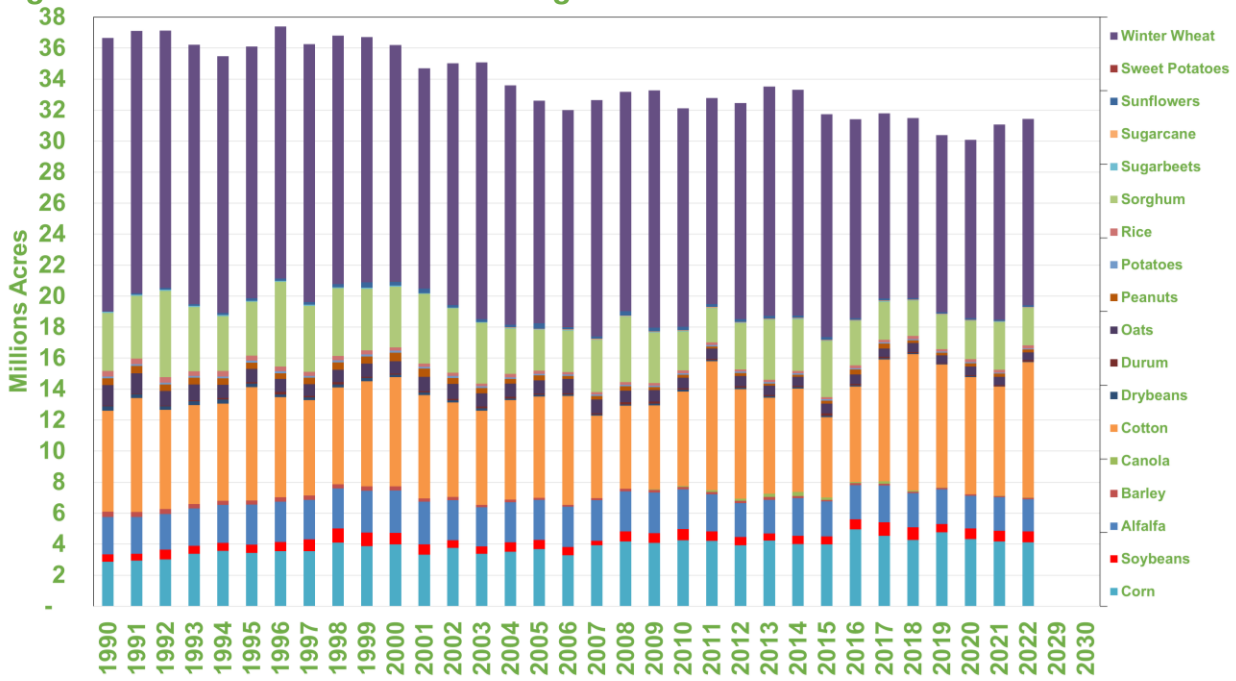
During the ethanol buildout from 2000 to 2010, Southwest planted acreage decreased 4.1 million. The increase in cotton acres in the Southeast, end of Step 2 export program, and the cotton infrastructure was older than the Southeast led to a 957 thousand decline in Southwest cotton acres. As the number of gins declined, the time and expense for ginning increased. Corn acres increased 265 thousand which is significant because every other crop experienced a decline in acres.

Winter wheat acreage has declined 5.5 million from 1990 to 2022 and sorghum acres declined 1.2 million. Corn and cotton acres increased by 1.2 million and 2.2 million, respectively.

Farmers have increased corn acreage primarily in the eastern most area of the Southwest region. Farmers would love to plant more corn acres, but the western reach of the Southwest just lacks available water.

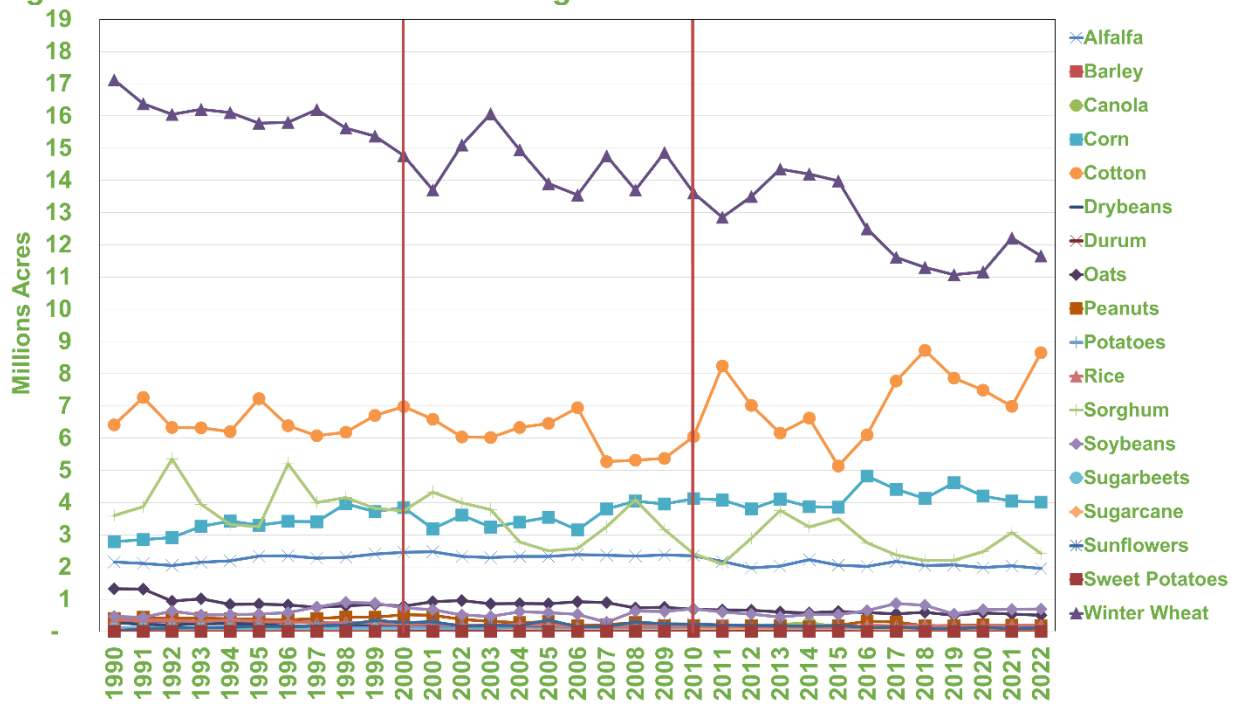
Corn is railed from the Corn Belt into the Southwest. The local price is basically Iowa corn price plus freight. The point is the corn price is great and a local market exists, but the current corn varieties require more water to produce a yield.

Figure 39: Southwest Planted Acreage



Source: USDA and Higby Barrett

Figure 40: Southwest Planted Acreage



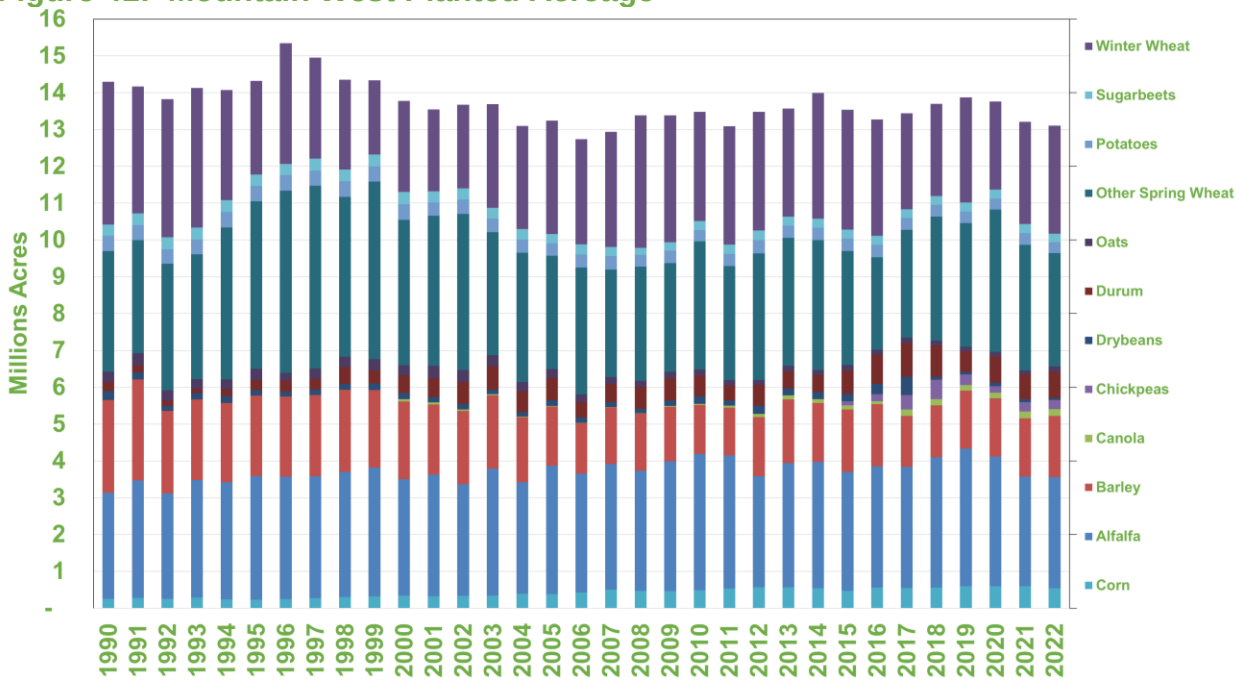
Source: USDA and Higby Barrett

Mountain West Planted Acres

From 1990 to 2022, Mountain West planted acreage decreased from 14.3 million acres to 13.2 or a decrease of 1.1 million acres. Alfalfa, canola, corn, durum, and flax acres have been increasing. While canola acres have increased, considering a crushing plant was built, the acreage increase is disappointing.

During the ethanol buildout from 2000 to 2010, Mountain West planted acreage increased 370 thousand. Corn and barley acreage increased 110 thousand and 254 thousand, respectively.

Figure 41: Mountain West Planted Acreage

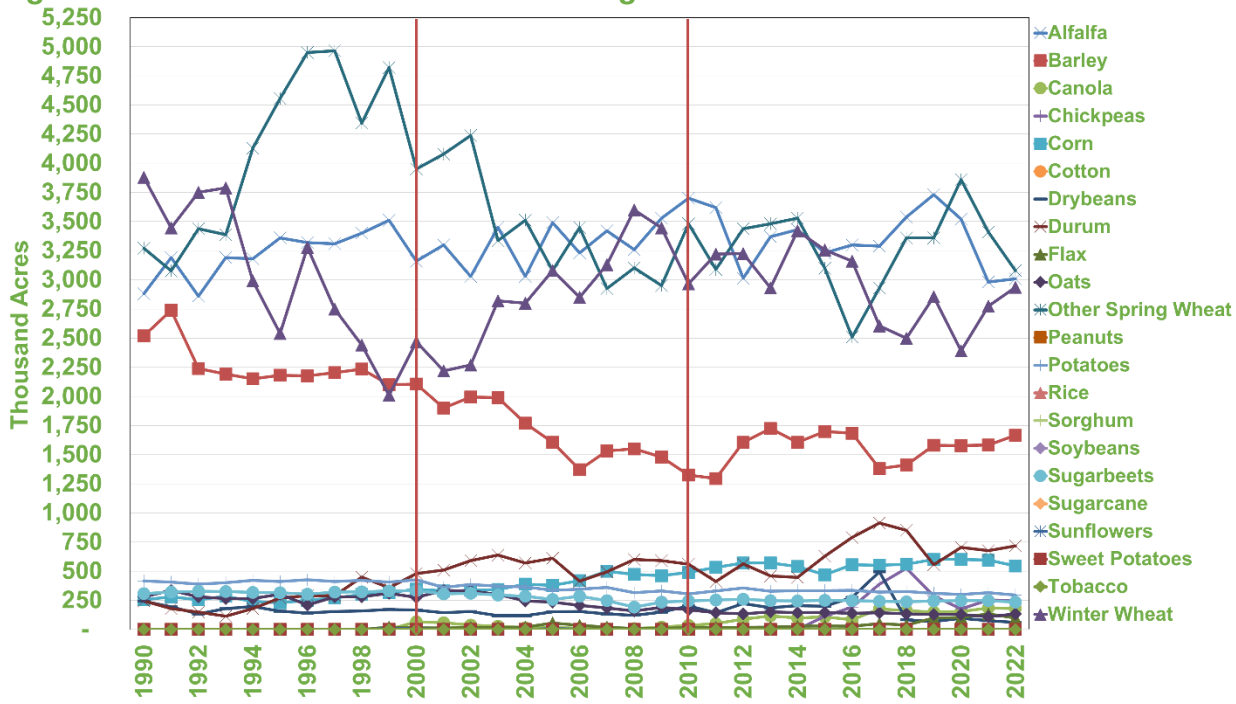


Source: USDA and Higby Barrett

Mountain West durum acres have increased 472 thousand acres to reach 717 thousand from 1990 to 2022. Nationally, durum acres have declined 2 million to 1.6 million. Durum plantings illustrate why acreage trends should be viewed at a more granular level than the whole U.S.

Corn increased 290 thousand acres to 545 thousand. No data is collected for soybean planted acreage in the Mountain West states.

Figure 42: Mountain West Planted Acreage



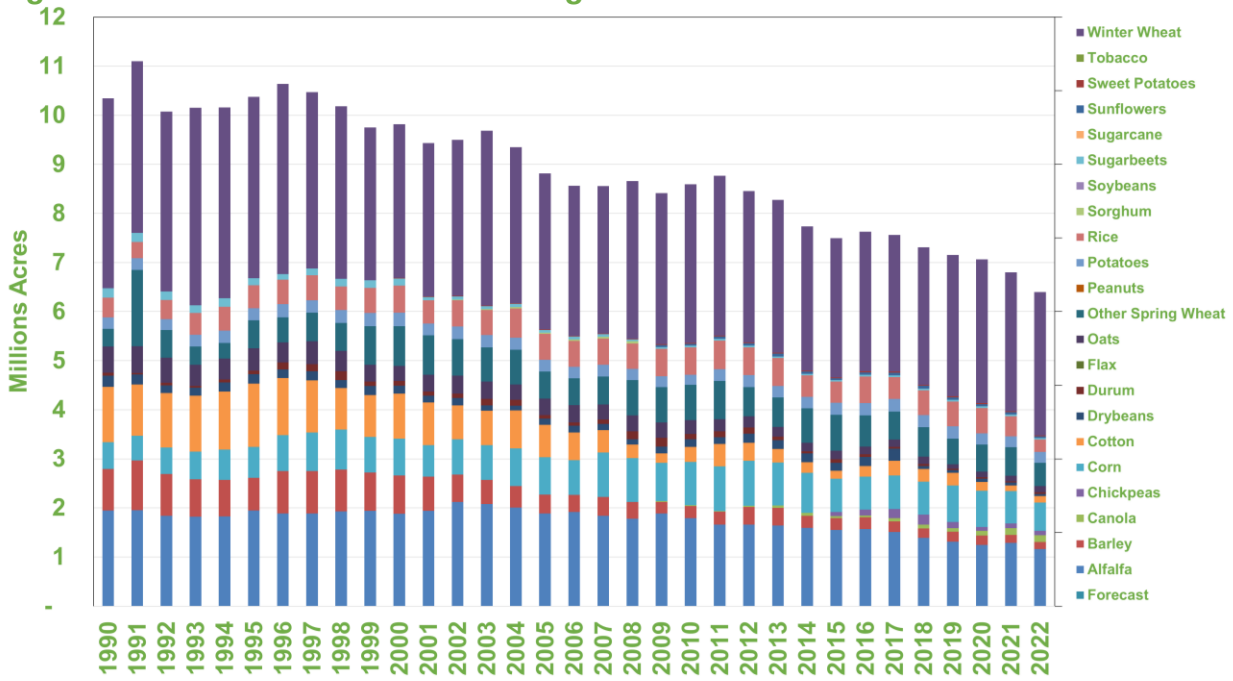
Source: USDA and Higby Barrett

West Coast Planted Acres

From 1990 to 2022, West Coast planted acreage decreased from 10.3 million acres to 6.4 or a decrease of 3.9 million acres. California has serious water availability issues that extend beyond agriculture. Washington has added a canola crushing plant, which is supporting canola acreage growth. Canola acres increased 135 thousand. While other spring wheat is down nationally, acres increased 115 thousand on the West Coast.

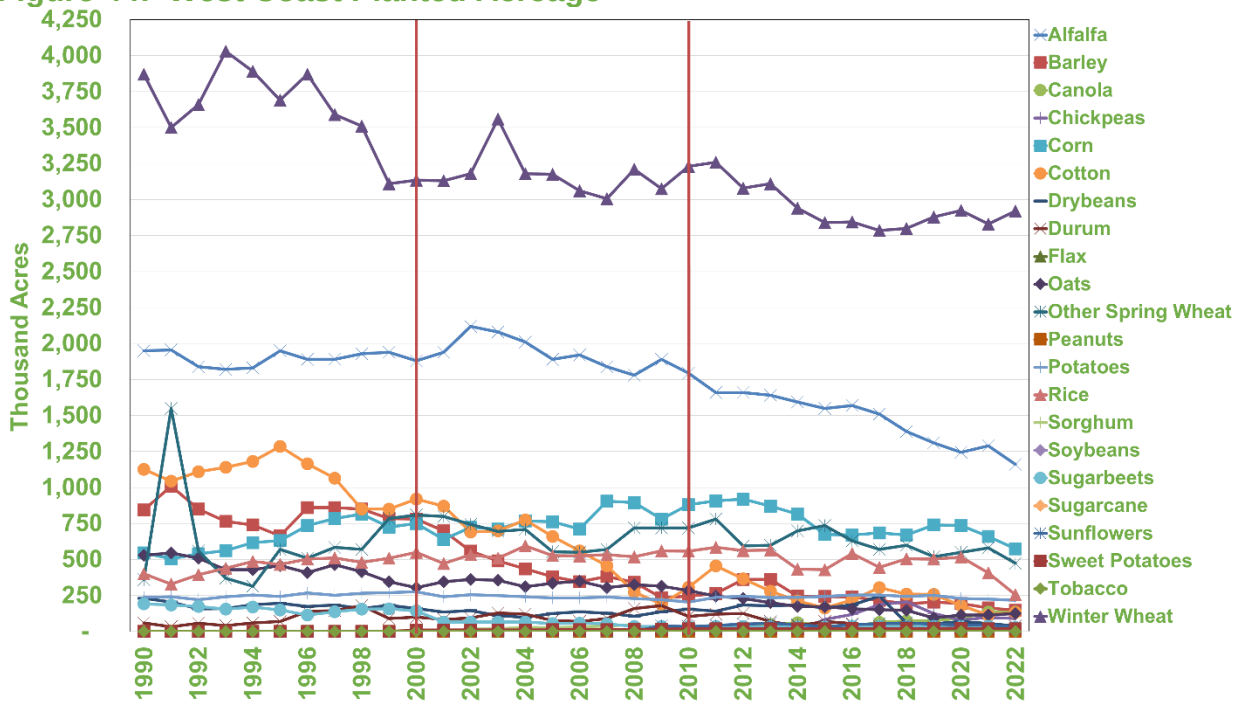
During the ethanol buildout from 2000 to 2010, West Coast planted acreage decreased 1.2 million. Barley and cotton accounted so almost all the acreage loss with the other crop slightly higher or lower.

Figure 43: West Coast Planted Acreage



Source: USDA and Higby Barrett

Figure 44: West Coast Planted Acreage



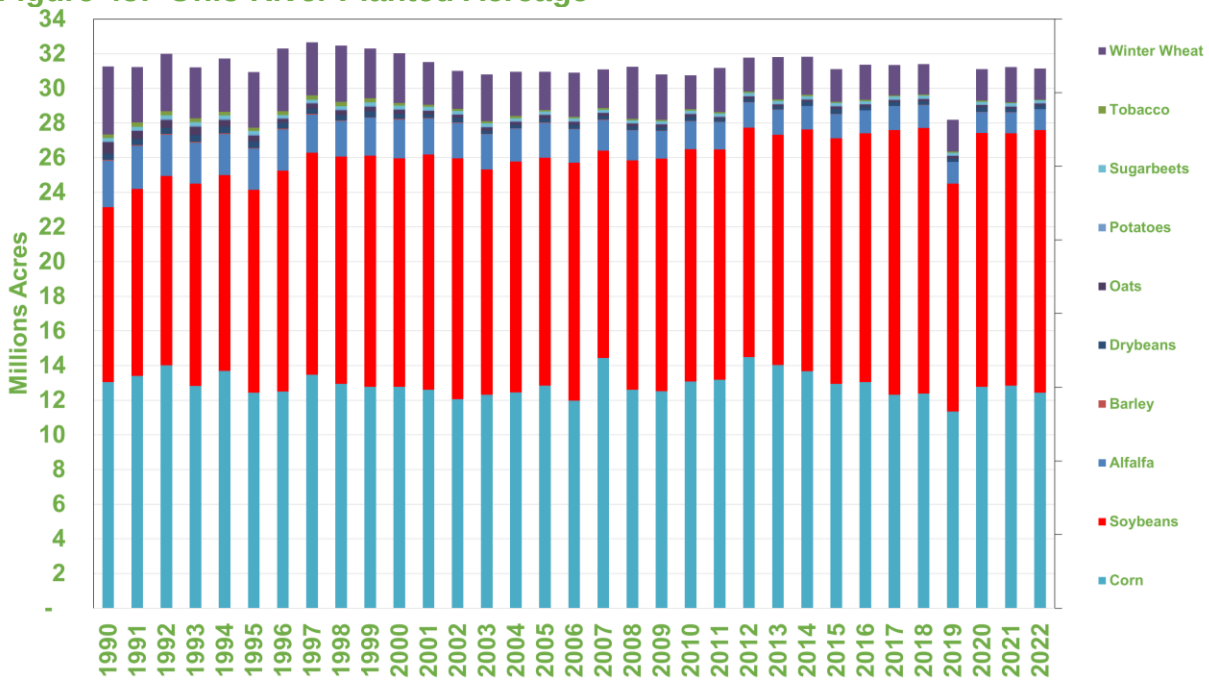
Source: USDA and Higby Barrett

Ohio River Planted Acres

From 1990 to 2022, Ohio River planted acreage decreased from 31.3 million acres to 31.1 or a decrease of 200 thousand acres. With urban area increasing approximately 550 thousand acres, assuming some of the land was agriculture explains the total acreage decline.

During the ethanol buildout from 2000 to 2010, Ohio River planted acreage decreased 1.3 million. Corn and soybean acres increased 310 thousand and 220 thousand, respectively. In 2007, corn planted acres increased 2.4 million in response to the expansion in the RFS but declined 1.8 million in 2008. All other crops planted acres declined.

Figure 45: Ohio River Planted Acreage



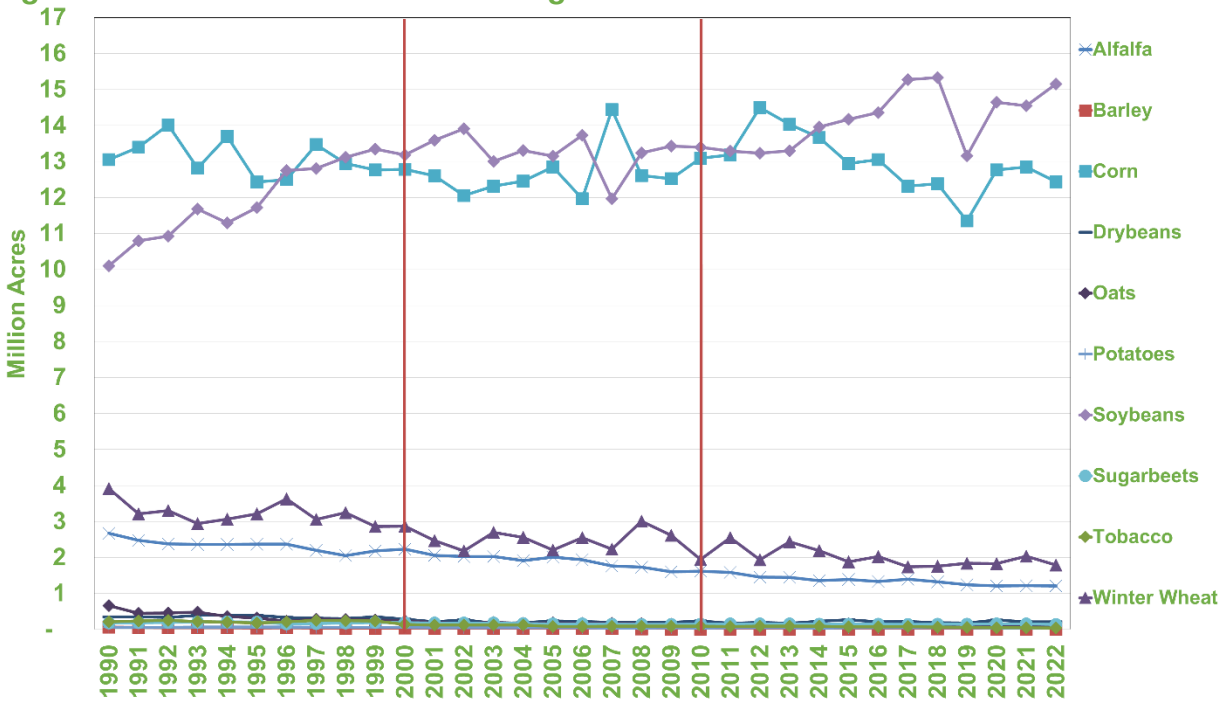
Source: USDA and Higby Barrett

In 1990 74 percent of the planted acres were corn and soybeans. By 2022, 89 percent of the total acreage was corn and soybeans. The region has very limited opportunities to increase corn and soybean area.

Corn planted acres declined 610 thousand while soybean planted acres increased 5.1 million. As the chicken industry has expanded in the Southeast, soybean crushing plants were constructed to increase the supply the soybean meal. In January 2000, Kentucky, Indiana, Ohio, and Michigan soybean crushing capacity was 32,285 short tons per day and by December 2022 it was 44,945 short tons per day.

In addition, improvements in short season soybean varieties allowed Michigan farmers to plant an additional 1.1 million soybean acres while every other crop planted acres declined.

Figure 46: Ohio River Planted Acreage



Source: USDA and Higby Barrett

Upper Mississippi River Planted Acres

From 1990 to 2022, Upper Mississippi River planted acreage decreased from 84.1 million planted acres to 83 million acres. Over the same period, corn and soybean acreage share increased from 74 percent to 91 percent. The region has very limited opportunities to increase corn and soybean area. Corn planted acres increased by 3.1 million and soybean acres increased by 10.1 million. Soybean crushing capacity increased from 76,019 short tons per day in 2000 to 96,178 in 2022.

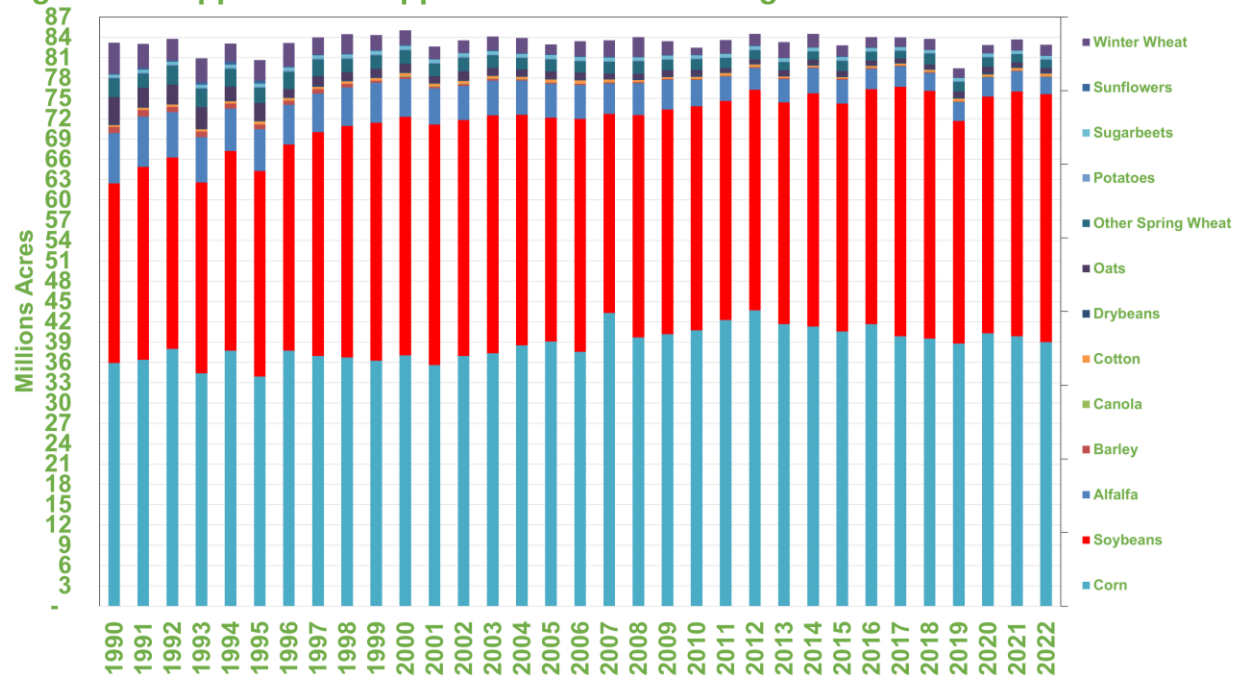
Oat planted acres declined by 3.4 million, winter wheat by 3 million, alfalfa by 4.9 million other spring wheat by 1.6 million, barley by 841 thousand and sorghum by 760 thousand.

During the ethanol buildout from 2000 to 2010, Upper Mississippi River planted acreage decreased 2.8 million. Corn acres increased 3.7 million and soybean acres declined 2.1 million. In 2007, corn planted acres increased 5.8 million in response to the expansion in the RFS but declined 3.6 million in 2008.

Missouri was included with Iowa, Illinois, Minnesota, Wisconsin to form the Upper Mississippi River region. From a marketing standpoint, Missouri is above and below the locking areas on the Mississippi River and both a southern and northern state. The increase in cotton and rice planted acres was in the Bootheel of Missouri. The increase in sugar beets and dry beans occurred in the northern states.

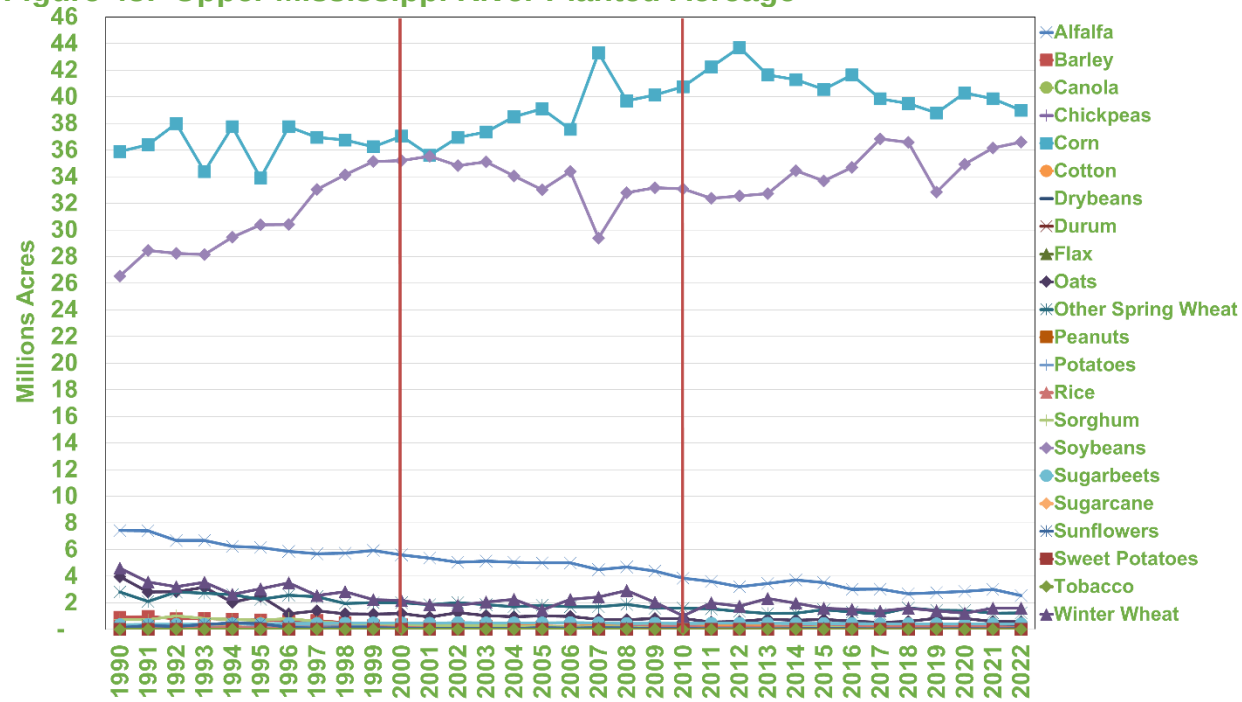
The Flint Hills or pasture is clearly part of the Plains States. Missouri has net gained 880 thousand acres with corn and soybean acres increasing 1.3 million and 1.9 million, respectively.

Figure 47: Upper Mississippi River Planted Acreage



Source: USDA and Higby Barrett

Figure 48: Upper Mississippi River Planted Acreage



Source: USDA and Higby Barrett

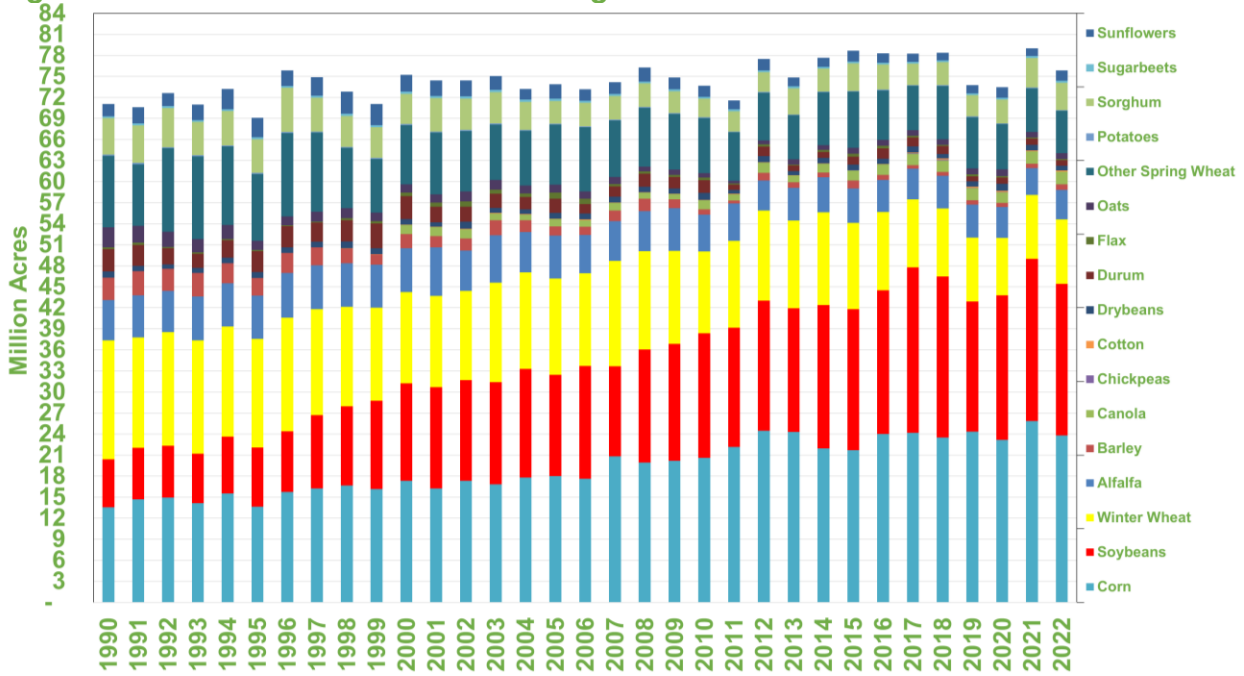
Plains States Planted Acres

From 1990 to 2022, Plains States planted acreage increased from 71 million acres to 75.9 or an increase of 4.8 million acres. In 2021, planted acreage did reach 79 million or 8 million higher than 1990. The challenges in the Plains States are water availability and a short growing season.

Canola is first reported in 2010 with 1.3 million acres. So, the 4.8 million could really be 3.5 million acres. In 1990, the canola acres number was likely closer to zero than 1.3 million due to Freedom to Farm.

During the ethanol buildout from 2000 to 2010, Plains States planted acreage decreased 1.5 million. Corn and soybean acres increased 3.3 million and 3.9 million, respectively. In 2007, corn acres increased 3.2 million while soybean acres declined 3.2 million in response to the expansion in the RFS. In 2008, corn acres decreased 860 thousand and soybean acres increased 3.9 million.

Figure 49: Plains States Planted Acreage



Source: USDA and Higby Barrett

The increase in corn demand infrastructure or ethanol plants provided farmers with more local consumption. Since 1990, corn planted acres increased 10.3 million and soybean acres increased 14.8 million. It should be noted that canola acres have increased half a million since 2000. Before Freedom to Farm in 1996, farmers were locked into growing their base acres and forced to set aside acreage. After Freedom to Farm, Plains State farmers could experiment with growing new varieties of soybeans and corn.

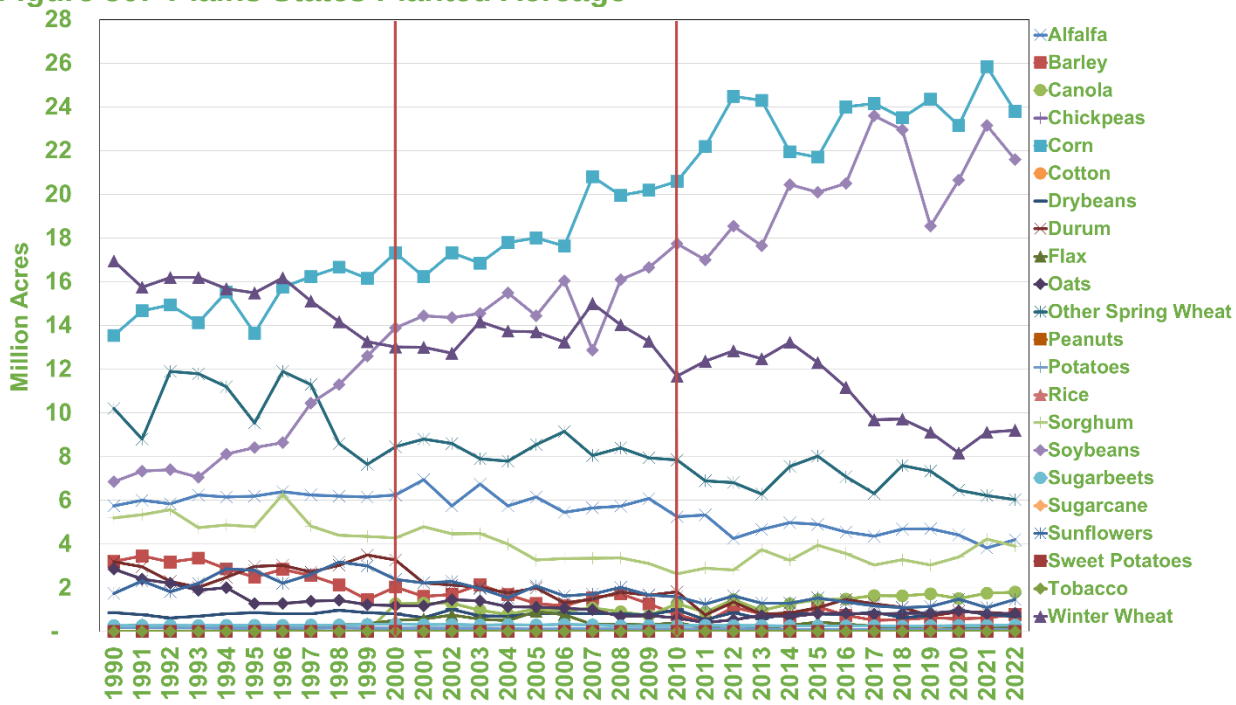
In 1990, wheat acreage accounts for 43 percent of total Plains States acres and in 2022, wheat acreage only accounted for 21 percent. Wheat acres in the Plains States have been in a steady decline since Freedom to Farm was passed. From 1990 to 2022, corn and soybean acreage share increased from 29 percent to 60 percent.

Common issues with growing corn and soybeans in the Plains States are water availability and being able to knife ammonia in the field before snowfall. Knifing in ammonia carries a risk that spring weather will not cooperate with planting corn.

The increase in soybean acres is clearly farmers taking advantage of new varieties increasing the viability of growing soybeans. Ever since Freedom to Farm, soybean acreage increases have consistently increased for 25 years.

Plains States is the only region with crop acreage increasing. If the seed technology enables corn and soybeans to be planted further north and west, corn and soybean acreage will continue to replace pasture.

Figure 50: Plains States Planted Acreage



Source: USDA and Higby Barrett

U.S. Land Intensification Versus Land Extensification

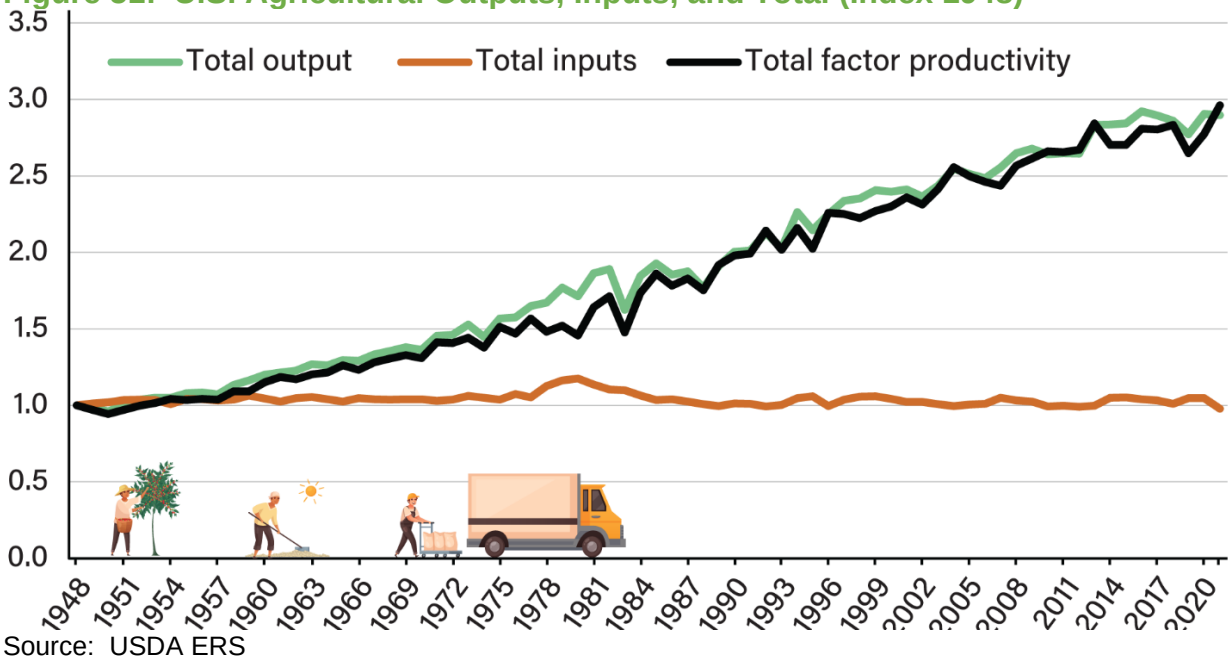
The U.S. has experienced an acreage decline in crop acreage over the last 30 years. On a national level, the statistics indicate no land extensification or cropland expansion has taken place. On a regional crop level, it was demonstrated in the U.S. Acreage Trends by Region that the Plains States increased cropland and ethanol played a major role, but not the only role.

On a national level, the production increase has occurred because of land intensification or increased productivity. USDA ERS calculations indicate more productive inputs enabled the food supply to increase while not increasing the amount of inputs. It should be noted the improved inputs do cost more money. From an accounting standpoint, the farmer is spending more money on inputs.

One key to the U.S. economic success was the ability to increase food production with fewer inputs, especially labor. The productivity increases allowed people to leave the farm and fill other jobs while still providing an abundance of food. USDA ERS reported:

> *Technological developments in agriculture have enabled continued output growth without requiring much additional inputs. Innovations in animal and crop genetics, chemicals, equipment, and farm organization have made it possible for total agricultural output to nearly triple between 1948 and 2021. During that period, the amount of inputs used in farming declined slightly over time, meaning that the growth in agricultural output over the long term has depended on increases in total factor productivity (TFP). TFP measures the amount of agricultural output produced from the combined inputs (land, labor, capital, and intermediate inputs) employed in farm production. Therefore, growth in TFP indicates positive changes in the efficiency with which inputs are transformed into outputs. It can also be seen as an indicator of technical change. In the short term, total output growth and estimated TFP growth can be affected by random events, such as adverse weather. In the most recent TFP calculation period spanning 2020–21, agricultural output grew, which was due entirely to TFP growth, even as the amount of inputs used in farming fell.*

Figure 51: U.S. Agricultural Outputs, Inputs, and Total (Index 1948)



Source: USDA ERS

Single-factor measures of productivity—such as corn production per acre (yield or land productivity) or per hour of labor (labor productivity)—have often been used because the underlying data are readily available. While useful, such measures can also mislead. For example, yields could increase simply because farmers add more inputs (such as agricultural chemicals, labor, or machinery) to their land base. USDA produces measures of total factor productivity (TFP), which takes into account the use of all inputs to the production process.

Specifically, annual TFP growth is the difference between growth of aggregate output and growth of all inputs used. TFP, therefore, measures changes in the efficiency with which inputs are transformed into outputs. Furthermore, in USDA-ERS's U.S. productivity accounts, input measures are adjusted for changes in their quality, such as improvements in the efficacy of chemicals, or changes in the demographics of the farm workforce. As a result, long run agricultural productivity growth is driven by innovations in on farm tasks, changes in the organization and structure of the farm sector, and research aimed at improvements in farm production. In the short-term, measured agricultural productivity change can also be affected by random events like weather.

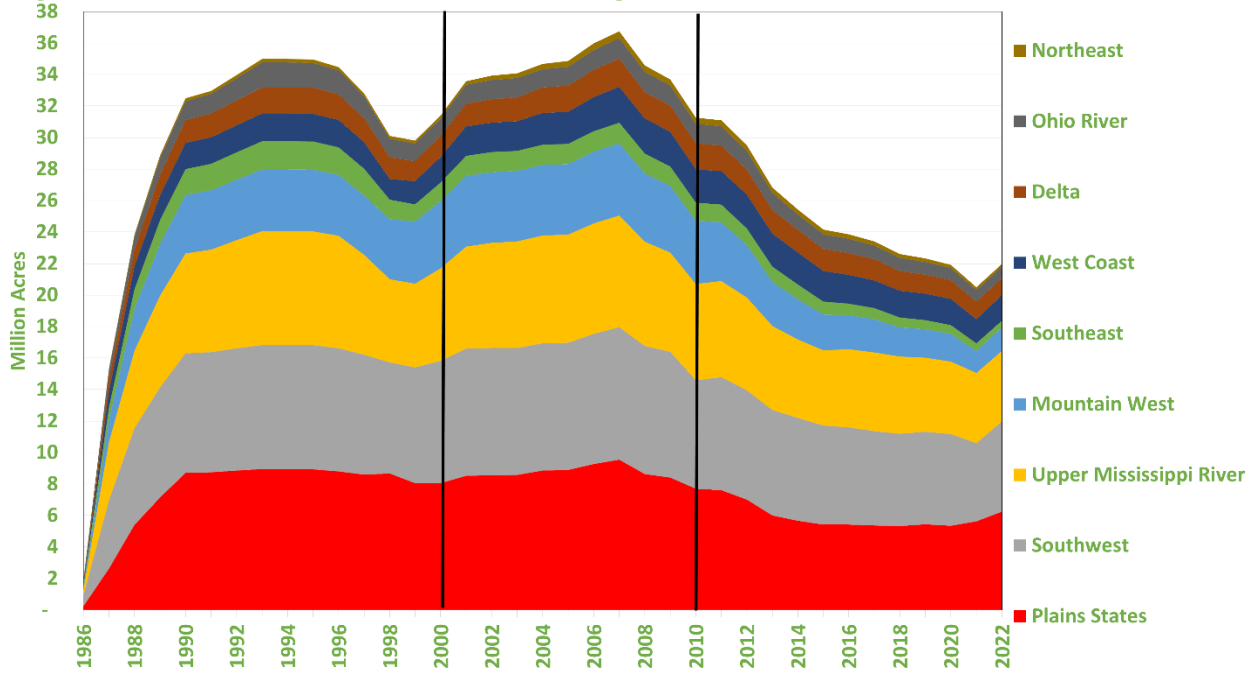
Summary findings include:

1. *According to the latest update, the level of U.S. farm output in 2021 was 190 percent more than in 1948, growing at an average annual rate of 1.46 percent. Over 1948–2021, aggregate input use decreased by -2 percent overall, at a rate of -0.03 percent annually, so the growth in farm sector output was entirely attributed to total factor productivity growth, which increased at an annual average rate of 1.49 percent over the full period.*
2. *ERS also examines trends by subperiods (measured from cyclical peak-to-peak in U.S. aggregate economic activity). A notable reduction in inputs was seen in the 2019–2021 subperiod, at -3.35 percent per year on average, driven by declines in hired labor input. During this most recent subperiod, average annual growth in agricultural output was 2.23 percent, led by a rebound in crop production in 2020 after a decline in 2019. Output for crops increased by 4.21 on average annually in the 2019–2021 subperiod. Output for "livestock and products" growth increased from an annual average of 1.14 percent in 2007–2019 to 1.29 percent in 2019–2021.*
3. *Looking at the latest subperiods, measured average annual TFP growth increased from 0.7 percent in 2007–2019 to 5.57 percent per year during 2019–2021, which has offset the negative impacts of input reduction and allowed 2021 farm output growth to return to its 2017 level after slowing in previous years.*

While inputs used for agriculture did not increase, the crop mix and where the crops are planted did change. Urbanization or cities growing replaced agriculture land. For example, the Long Island New York sub state crop region is no longer reported by USDA NASS. Another change in crop location is driven by government policies. Some government policies are directly aimed at farming practices. For example, The Food Security Act of 1985 has provisions that discourage the conversion of wetlands and highly erodible land into cropland and discourages native land and forest from being turned into cropland. In the same year the Conservation Reserve Program (CRP) was created to reduce soil erosion and crop production.

One theory why CRP acreage declined after 2007 is the RFS made cropland more valuable while the land enrollment value decreased. It should be noted that Congress lowered the cap on total CRP acres. In 1990, the CRP paid an average of $49 per acre versus $45 in 2000. It is likely some CRP land returned to crop production from 2007 through 2014 before cropland returned to a downward trajectory. After 2014, both CRP enrolled land and crop acreage declined.

Figure 52: Conservation Reserve Acreage



Source: Conservation Reserve Acreage

From 2007 through 2014 crop acreage in the Plains States increased from 74.2 million to 77.7 million or an additional 3.5 million. From 2014 through 2022 crop acreage in the Plains States ranged from 73.4 million to 79 million.

The ethanol buildout definitely increased the profitability of planting corn in the Plains States, but it should be remembered that corn acres were increasing before the ethanol buildout and after the ethanol buildout, which means ethanol was not the only reason for increasing corn acres. The increase in corn demand infrastructure or ethanol plants provided farmers with more local consumption. Since 1990, corn planted acres increased 10.3 million and soybean acres increased 14.8 million. Before Freedom to Farm in 1996, farmers were locked into growing their base acres and forced to set aside acreage. After Freedom to Farm, Plains State farmers could experiment with growing new seed varieties of soybeans and corn.

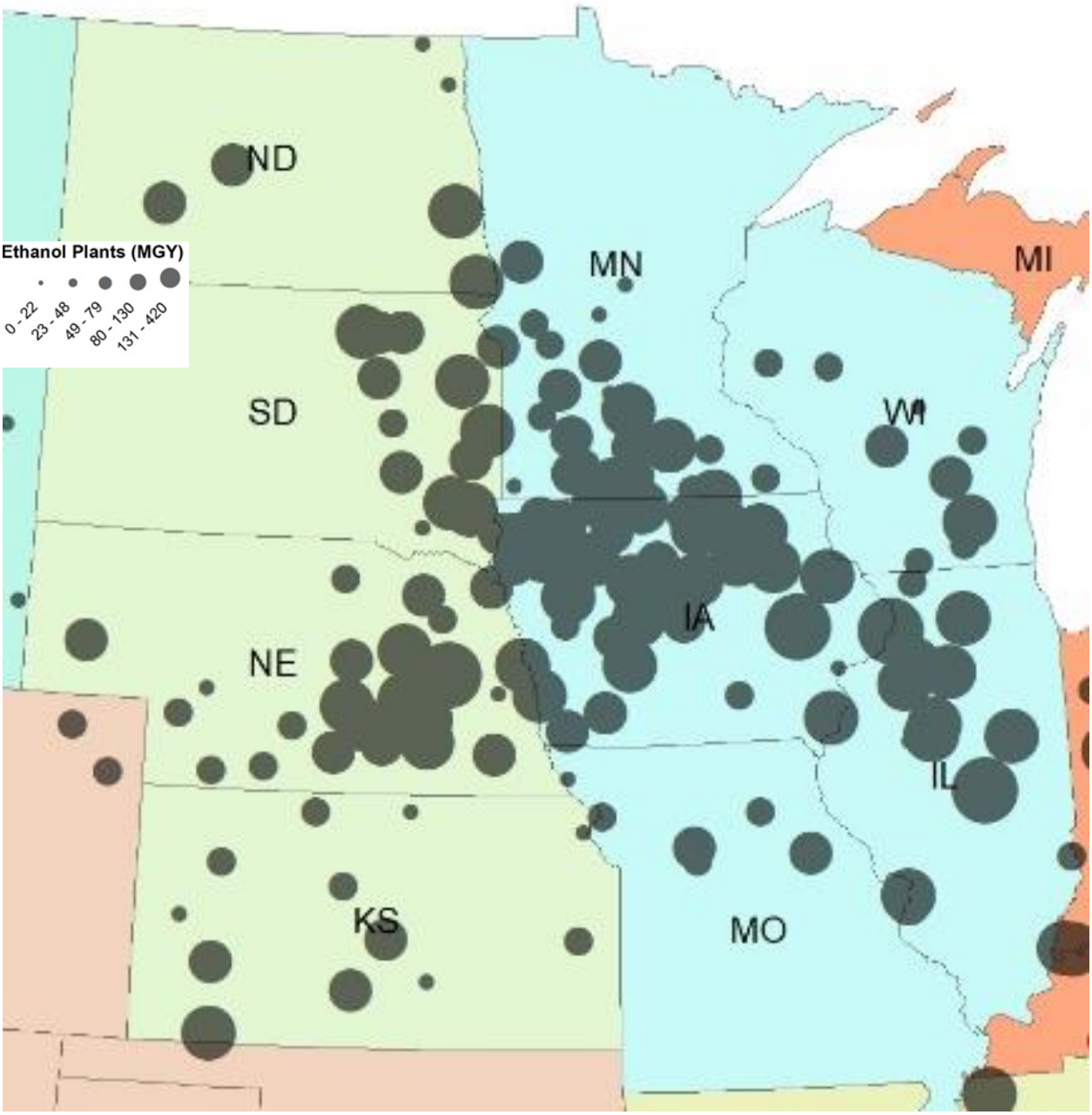
From 1990 to 2022, Plains States planted acreage increased from 71 million acres to 75.9 or an increase of 4.8 million acres. In 2021, planted acreage did reach 79 million or 8 million higher than 1990. Canola is first reported in 2010 with 1.3 million acres. So, the 4.8 million could really be 3.5 million acres. In 1990, the canola acres number was likely closer to zero than 1.3 million due to Freedom to Farm.

During the ethanol buildout from 2000 to 2010, Plains States planted acreage decreased 1.5 million. Corn and soybean acres increased 3.3 million and 3.9 million, respectively. In 2007, corn acres increased 3.2 million while soybean acres declined 3.2 million in response to the expansion in the RFS. In 2008, corn acres decreased 860 thousand and soybean acres increased 3.9 million.

The ethanol buildout was a driver in the Plains States adding 4.8 million acres and Missouri adding 880.6 thousand acres for a total of 5.7 million acres. Other government programs and urbanization also drove the need for more acres.

Even if none of the other drivers had occurred, crop input technology advances would have resulted in pastureland to cropland conversion to capture the higher land value. We know this because in the Plains States from 1990 to 2000 or before the ethanol buildout, crop acres increased 4.1 million.

Figure 53: Plains States Ethanol Plants

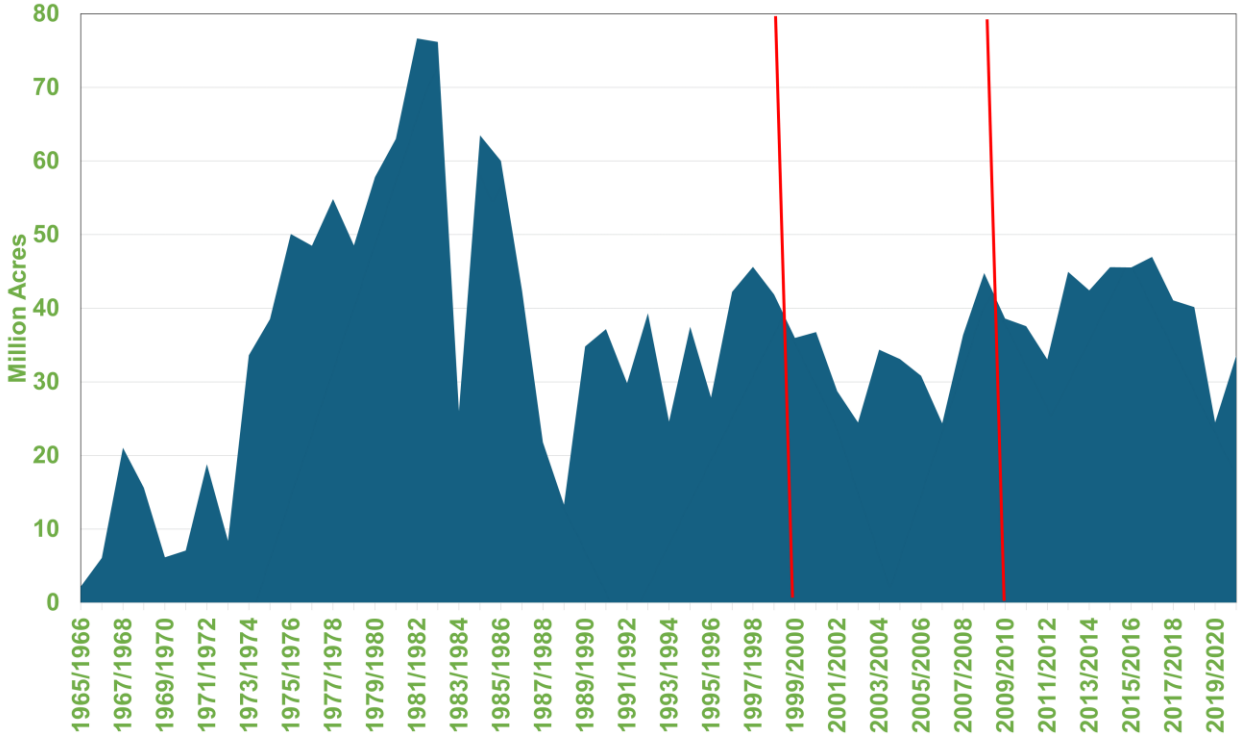


Source: Ethanol Magazine, Higby Barrett

Focusing on the primary food and feed crops, excluding cotton, exemplifies how cropland acreage has been declining since 1981/82. A portion of corn and soybean acreage increase came from switching cotton

and alfalfa acres to corn and soybeans, which means the acres are not new cropland. It should be noted we used 1965 as a starting point because that is when the USDA PSD data started.

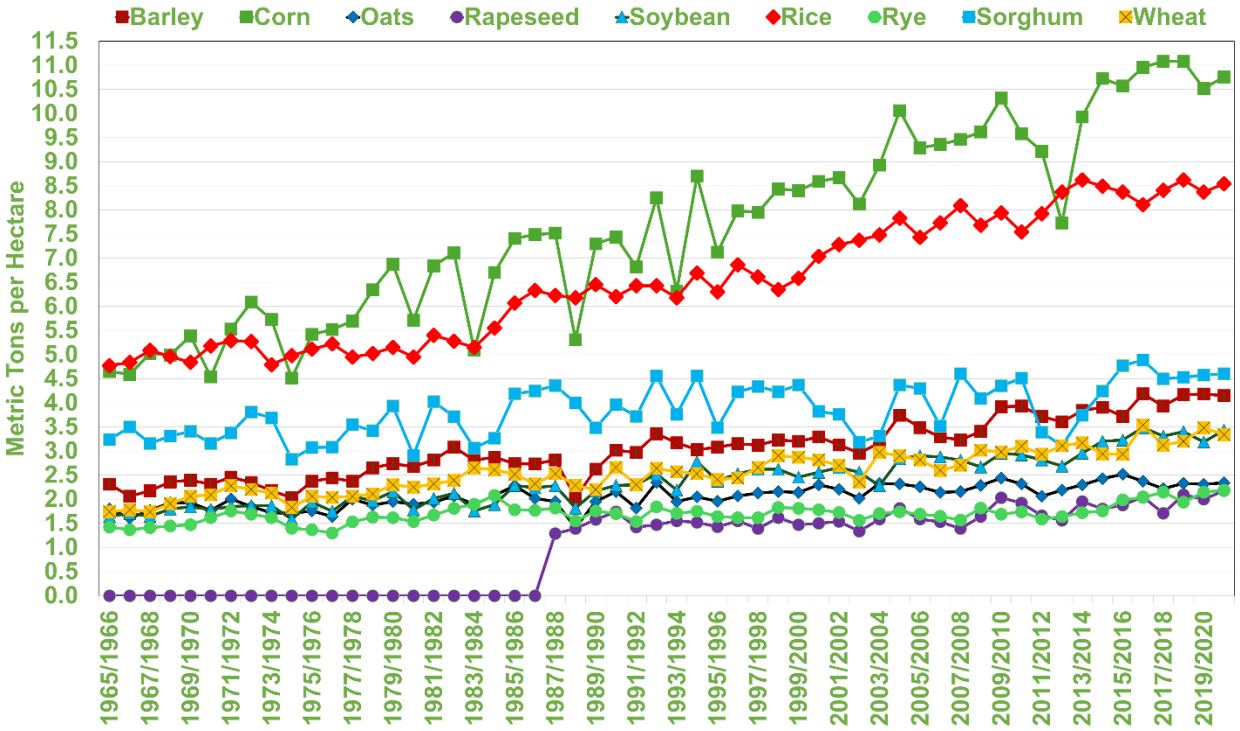
Figure 54: U.S. Incremental Harvested Acres Since 1964/65



Note: Crops included are barley, corn, oats, rapeseed, soybeans, rice, sorghum, wheat
Source: USDA PSD

Focusing on the primary food and feed crops, excluding cotton, exemplifies how long crop yields have been increasing. Corn is the highest yielding crop and more importantly, the gap in yields between corn and other crops continues to increase, which means farmers will continue to have incentive to plant more corn. It should be noted that corn is increasingly being planted in areas with lower yields, which pulls average yields lower. The same is true for soybeans.

Figure 55: U.S. Crop Yields



Source: USDA PSD

Since 1964/65, approximately 77 percent of production growth or 281.2 MMT has come from yield increases or intensification versus at most 23 percent or 85.2 MMT from extensification or increase in grain and oilseed land area. It should be remembered that 17 percent of the increase in grain and oilseed acreage came from cotton, which while not a food crop is still an agricultural row crop. Also, a switch from alfalfa to food crops accounted for 37 percent. Approximately 54 percent of the of the 85.2 MMT or 46.2 MMT came from land that was in agricultural production. Because extensification is new agricultural land in production, since 1964/65, approximately 89 percent of production growth or 327.4 MMT has come from yield increases and cropland switching from nonfood crops to food crops or intensification versus 11 percent or 39 MMT from extensification.

Since 1990, if all the cropland increase in the Plains States and Missouri acres are attributed to ethanol, ethanol would be responsible for 5.7 additional acres entering production. Using a 180-bushel corn yield and a 50-bushel soybean yield, and assuming a corn soybean crop rotation, ethanol demand can attribute to increasing crop production 655.5 million bushels or 17.2 MMT. In terms of total production increase, 17.2 MMT is about five percent of the total production increase.

It should be remembered that during the ethanol buildout from 2000 to 2010, Plains States planted acreage decreased 1.5 million. This undercuts the logical economical argument that ethanol consumption increased total cropland.

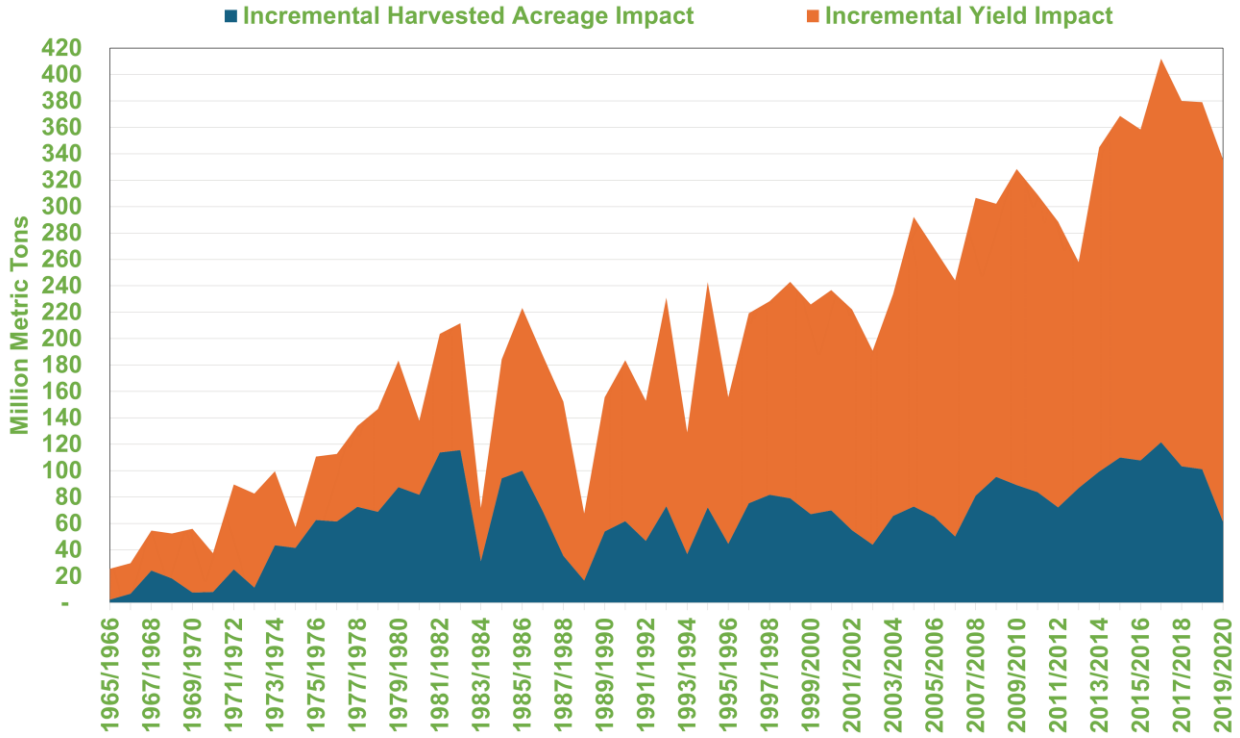
What occurred is a common occurrence in agriculture. The Plains States had surplus corn that attracted plants that require corn as a feedstock. Once the plants are built, extra local consumption encourages farmers to plant more corn. An ethanol plant nearby increases local corn price and reduces transportation

costs. Some of the extra corn harvested acres came from switching acres from other row crops and some pastureland was converted to cropland.

The reason the supply comes first is because it is difficult to obtain financing on the Field of Dreams model of build the plant and supply will come. The financiers either want the plant location that is in excess supply of feedstock or a destination location that is ethanol deficit.

For market players that were taking advantage of the exportable supply to make money, the construction of an ethanol plant reduced exportable supply and lowered profits. Increasing yields have rebuilt the exportable supplies.

Figure 56: U.S. Production Change from 1964/65



Note: Crops included are barley, corn, oats, rapeseed, soybeans, rice, sorghum, wheat
Source: USDA PSD

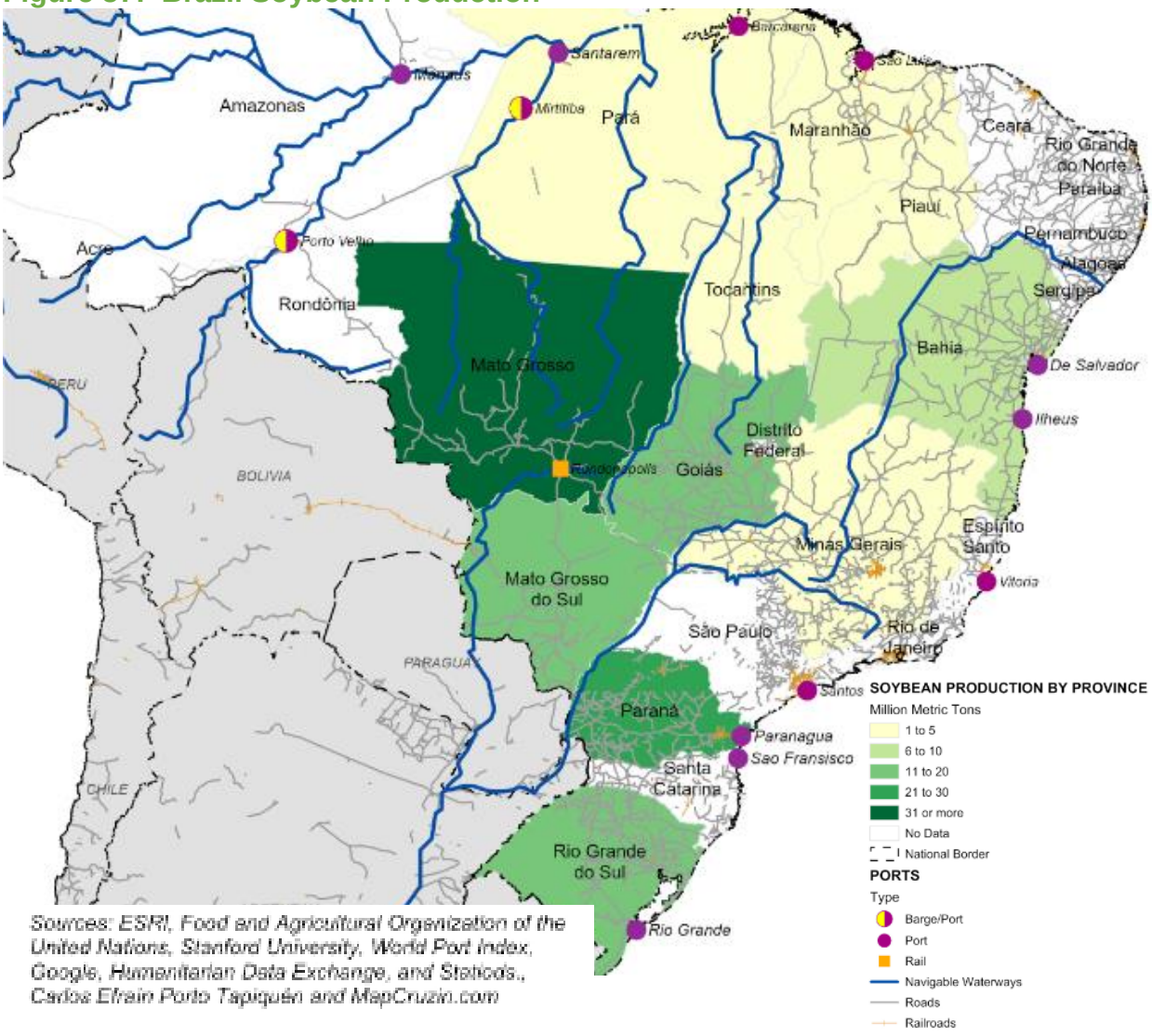
Brazil Acreage Drivers

Although Brazil's corn production has topped 100 million metric tons MMT, soybeans production is what is driving pastureland being converted into cropland.

The greatest portion of Brazil's soybeans are grown in the center-west region, which includes nearly a third of overall output in Mato Grosso. Rio Grande do Sul and Parana also account for nearly a third of the remaining production scattered across the country.

Mato Grosso is Brazil's largest soybean production state and the furthest from the ports. Some export routes, such as Mato Grosso to a southern port, involve a truck move of more than a thousand miles. Additional soybean acreage is occurring in regions that are not near the export ports.

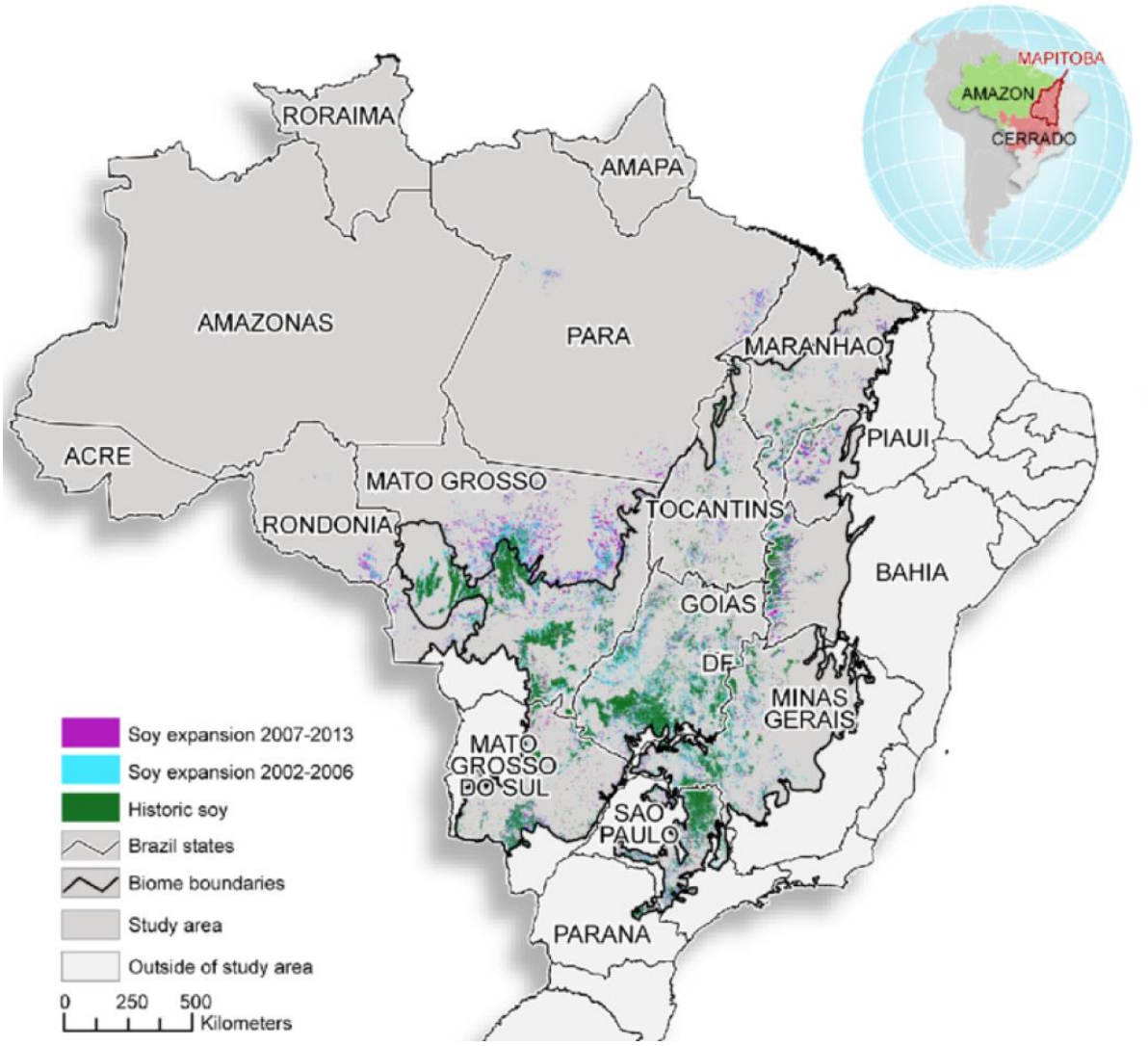
Figure 57: Brazil Soybean Production



Brazilian Sustainability Concerns

Growing world populations and developing consumer preferences towards greater protein consumption are two global features that have boosted demand for soybean products. Brazil is a major supplier of the land required to meet world demand. Recent trends in the development of the Amazon region of north-central Brazil have brought greater soybean plantings over the past decade along with negative attention regarding the sustainability of Brazilian soybeans. The following map highlights the two areas of Brazil that are of special interest to environmental groups – the Amazon and its neighboring Cerrado region. Soybean Moratorium primarily applies only to the Amazon Biome. The idea is companies will not soybeans grown in the Amazone Biome from farmers who clear the rainforest, use slave labor or threaten Indigenous Lands.

Figure 58: Brazil's Amazon Biome Region Soybean Acreage



Source: ABIOVE

Brazil soybean acreage continues to increase aggressively in areas not covered by the Soybean Moratorium agreement. With the Cerrado region being approximately 789,600 square miles or the size of

England, France, Germany, Italy, and Spain combined, it is unlikely the Soybean Moratorium will have an appreciative impact on preventing soybean acreage expansion. To support the demands of extra volume on the transportation system, Brazil is investing in long discussed projects that are easing congestion, reducing cost, lowering the environmental footprint, and increasing Brazil's export competitiveness in the world market.

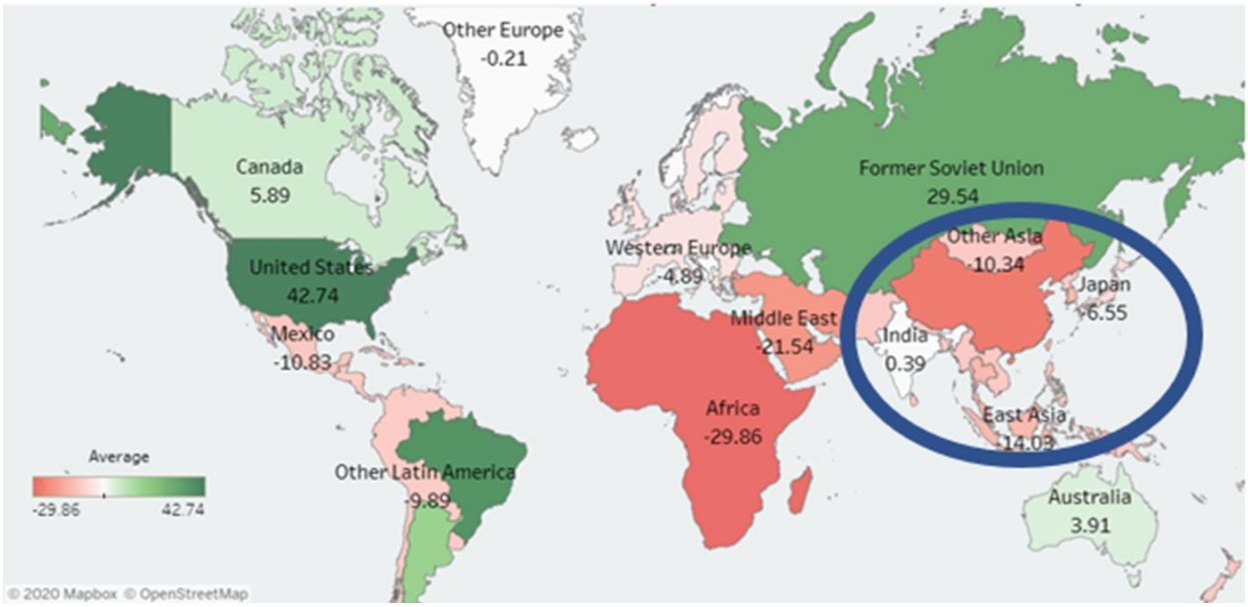
Figure 59: Brazil's Biome Regions

Source: ESRI and Brazil's Institute for Space Research "Biomass of Brazil"

Asian Growth Zone

Asian countries have little additional land available for agriculture. With China, India, and other Asian countries within the circle in Figure 60 accounts for half the world's population, marginal improvements in economic wellbeing translates into increased food consumption, creating demand for imported products.

Figure 60: Asian Growth Center Driving Agriculture and Energy Trade



Source: USDA, Higby Barrett

Aside from the Chinese importing more agricultural products, many other Asian countries have experienced strong gains in disposable income since 2000. Because of the low starting point, the absolute income gain is quite small. The area consists of extreme poverty, which is important for commodity consumption, but especially food products. As income increases, a wealthier person responds by switching to high-end food products and eating at restaurants. Although a wealthy person is spending more money on eating, the volume of coarse grains, wheat and protein meals consumed might not increase. By comparison, as income increases for poor people, they respond by adding ingredients to a basic diet. Eating higher quality dishes often requires vegetable oil, meat, fruits, and vegetables. Meat production requires feed rations of grains and protein meals that are converted into animal weight gain. For example, if 1.8 pounds of feed is required to produce 1 pound of chicken, switching, or just adding chicken to the dish results in an increase in per capita consumption of grains and protein meals.

China's economy has experience great growth for decades. Eventually, to sustain economic growth more inputs are required from the rest of the world. Even with improved yields, China's limited supply of agricultural land prevented domestic supply from meeting domestic demand. China either had to increase agricultural imports or risk an inflation problem.

China's government policy of self-sufficiency does not allow economics to slowly ease the country into importing more product over time. The two most dramatic examples are coal and iron ore. Within a decade China went from a major exporter to the largest importer of coal and iron ore. Inflation is the one issue that will influence government policy because inflation is viewed as a national security issue.

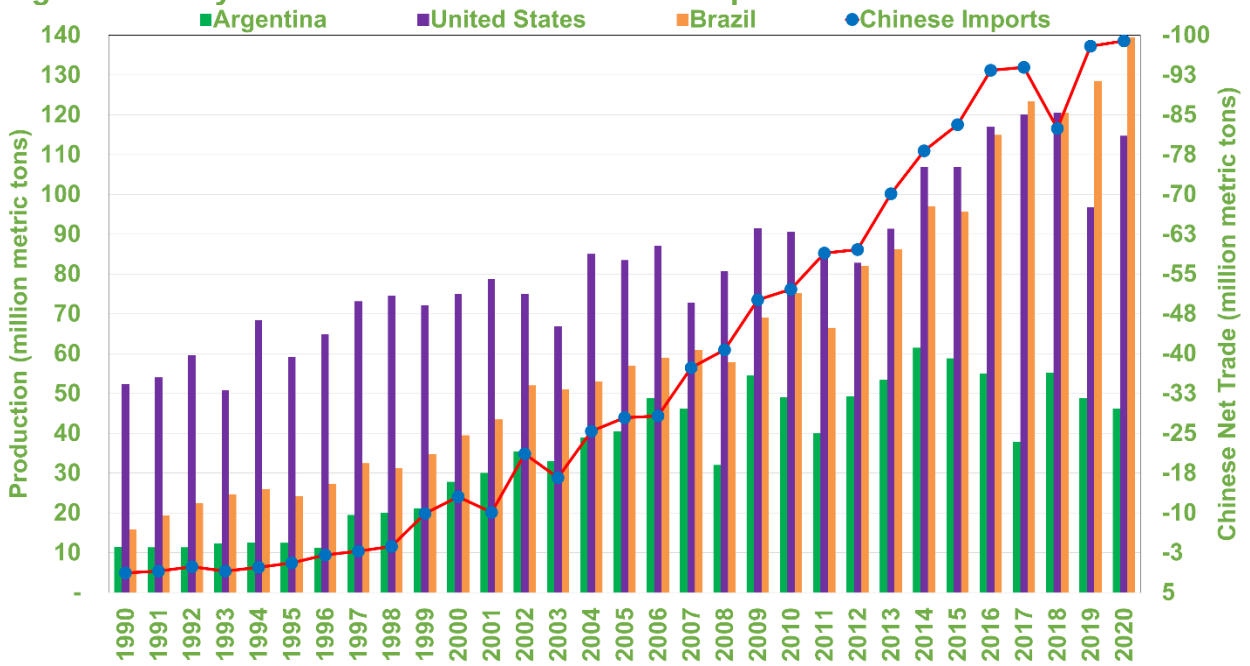
As its citizens wanted more meat, prices started to increase. Pork is a staple in China. So, just letting prices ration demand will result in an upset populous. To prevent inflation, the government has taken intensive steps to increase crop yields, and lower meat feed conversions, but the policies were not enough. This left China with the options of importing more meat, and more feed ingredients to produce meat.

China chose to allow soybean imports to increase and try to stay self-sufficient in production of meat and food crops. This also allowed China to build its own soybean crushing plant capacity. It is widely believed that corn imports were not allowed to increase because the U.S. in the 1990s dominated world trade. By comparison, South America was already a major player in the world soybean market. The assumption was the self-sufficient policy was altered from producing everything domestically to not being too dependent on one country. Regardless of the reason, China started to import greater volumes of soybeans.

Once soybean imports were allowed to increase, China's meat industries expanded. The expanding Chinese economy also kept increasing demand for a more diverse diet.

China increasing soybean imports by approximately 100 MMT in 25 years pulled land into production. Brazil farmers in Mato Grasso increased investment in expanding crop land in soybean production to meet the challenge of suppling China. It should be noted that other countries increased soybean meal consumption.

Figure 61: Soybean Production and Chinese Imports



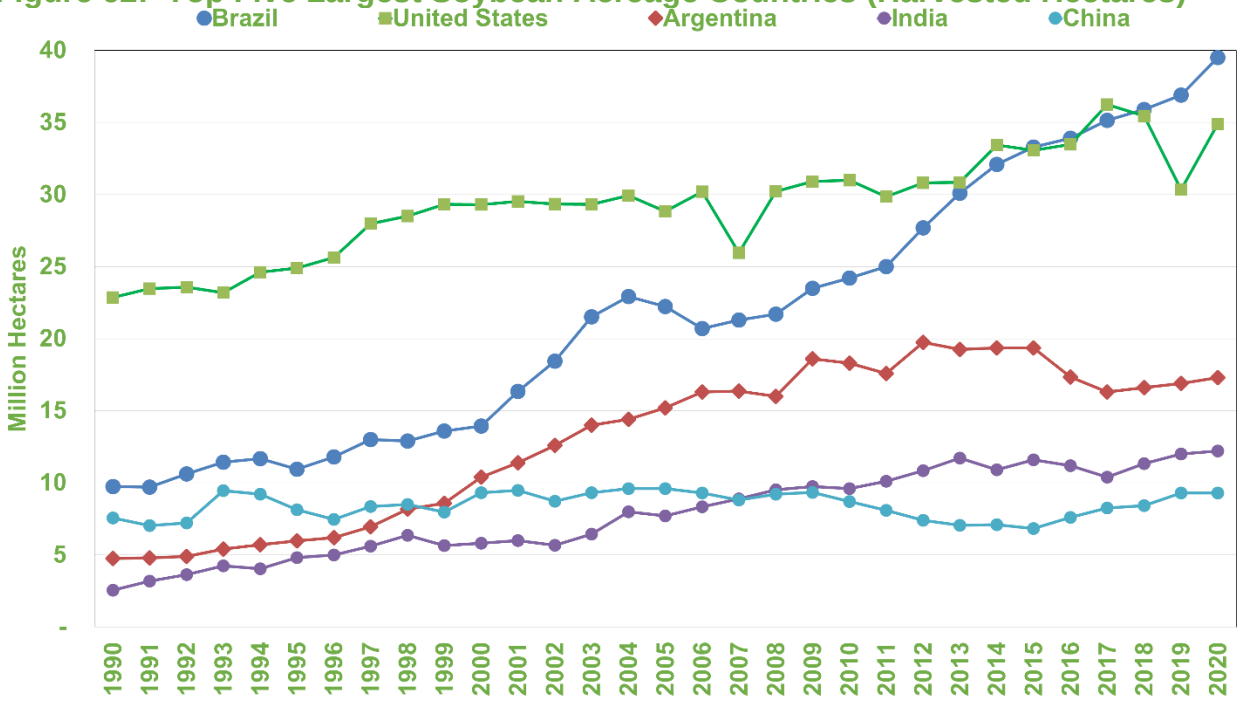
Source: USDA, Higby Barrett

While Brazil, U.S., Argentina, and India all increased soybean acreage, Brazil was the country that expanding total acreage versus primarily switching acres from other crops.

India government policy is for total self-sufficient or domestic supply equals domestic consumption. In poor crop production years, India will import. In great crop production years, India will export. For this reason, farmers in other countries will not make long-term investments, such as converting pastureland into cropland, based on India importing.

The U.S. soybean acreage increase was explored in depth in earlier sections.

Figure 62: Top Five Largest Soybean Acreage Countries (Harvested Hectares)



Source: USDA, Higby Barrett

Brazil Mato Grasso Soybean versus Corn Comparison

Crop enterprise budgets analyze revenue, expenses, profit (value of production minus total costs), and other metrics on common unit of land, such as a per hectare basis. By analyzing crops on a per hectare basis, it is easier to compare the financial returns of a crop type by region or with other crop types. The difference in how costs are allocated across countries is confusing, but the purpose is to explain why soybeans were the primary driver of crop acreage expansion in Brazil. A few key definitions for the enterprise budgets are listed below:

1. Gross Value of Production: Total revenue per hectare
2. Gross Value of Production, Primary product grain: Price per metric ton of the crop multiplied by the yield per hectare of that crop.
3. Operating Costs: Variable costs that are required for each hectare of crop being produced and that vary by crop type and region.
4. Allocated Overhead: Fixed costs on a per hectare basis. This cost category will often vary among different farms more than operating costs, which is why these costs are separated.
5. Total Costs Listed: Total operating costs plus total allocated overhead.
6. Value of Production less Total Cost Listed: Net profit per hectare.

7. Value of Production less Operating Costs: Operational margin, which ignores the "Allocated Overhead". This metric helps compare farmer performance among farmers who may have various levels of equity and capital in their business. For example, lease expense is relatively less for a farmer that owns their land versus a farmer that leases the farmland that they operate.

8. Yield: the quantity of a crop that is grown on each hectare, such as metric tons of soybeans per hectare.

9. Price: the estimated average prices farmers receive for the crop being grown and measured in US$/metric ton.

A quick look at the budgets shows Brazilian farming operations are making approximately $200 per hectare on soybeans and losing $200 on corn. Because the soybean crop is covering overhead costs, double cropping corn adds $135 per hectare of margin and keeps the workers employed.

Table 2: U.S. (Heartland) and Brazil (Mato Grasso) Enterprise Budgets

	U.S. Corn	U.S. Soybean	Brazil Corn	Brazil Soybean
Gross value of production				
Primary product, grain	2,457.90	1,689.42	790.72	1,417.26
Secondary product, silage	4.23	0.00	3.20	0.00
Total, gross value of production	**2,462.13**	**1,689.42**	**793.92**	**1,417.26**
Operating costs				
Seed	290.98	175.52	160.00	128.00
Fertilizer	591.43	154.46	272.00	285.00
Chemicals	157.43	143.49	135.00	296.00
Custom services	83.72	35.43	0.57	0.00
Fuel, lube, and electricity	81.15	49.07	32.00	28.00
Repairs	108.48	81.72	34.00	43.00
Purchased irrigation water	0.00	0.00	0.00	0.00
Interest on operating capital	16.01	7.81	24.89	21.00
Total, operating costs	**1,329.20**	**647.50**	**658.46**	**801.00**
Allocated overhead				
Hired labor	7.78	8.75	26.00	29.00
Opportunity cost of unpaid labor	71.07	46.48	14.00	20.00
Capital recovery of machinery and equipment	382.61	319.92	121.00	150.00
Lease	528.92	504.60	96.00	96.00
Taxes and insurance	44.11	34.79	30.00	44.00
General farm overhead	66.30	57.77	56.62	78.00
Total, allocated overhead	**1,100.78**	**972.31**	**343.62**	**417.00**
Costs listed				
Total, costs listed	**2,429.98**	**1,619.81**	**1,002.08**	**1,218.00**
Net value				
Value of production less total costs listed	**32.15**	**69.61**	**-208.16**	**199.26**
Value of production less operating costs	**1,132.93**	**1,041.92**	**135.46**	**616.26**

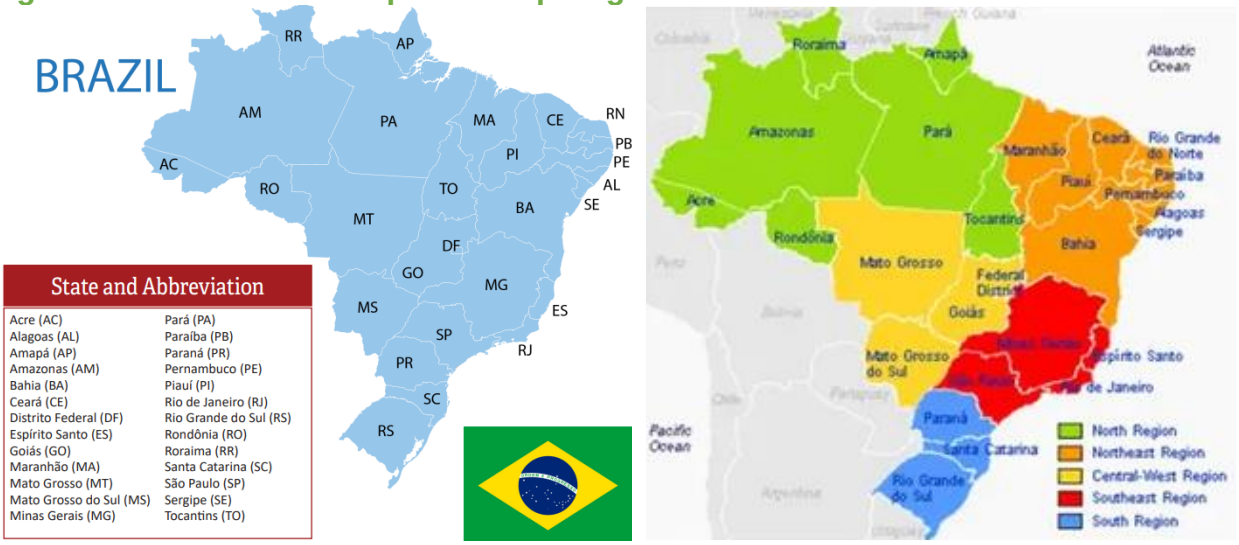
Source: USDA, IMEA, Higby Barrett

Brazil Land Intensification Versus Land Extensification

Brazil expanding soybean crop acres and double cropping with corn is solving a tough issue for China. China can increase soybean imports while maintaining national security. In 2023, after China removed trade barriers, China imported over 12.8 MMT of corn from Brazil.

From 1990 to 2022, Brazil has added almost 65 million acres of cropland. The North crop region is primarily the Amazon, which is off limits to crop expansion, but land entering crop production keeps expanding. Since 1990, land in production (not double cropped) in the North crop region has expanded by 7 million acres or an increase of 662 percent. This represents 11 percent of the total cropland expansion. Since 1990, the South crop region has expanded by 10 million acres or 38 percent while the Northeast crop region expanded under 6 million acres or 77 percent. The Southeast crop region had the smallest expansion of under 2 million acres or 17 percent. The story is about the Central West crop region. The Central West crop region land expansion was over 40 million acres or an increase of 365 percent and accounted for over 60 percent of the total cropland expansion.

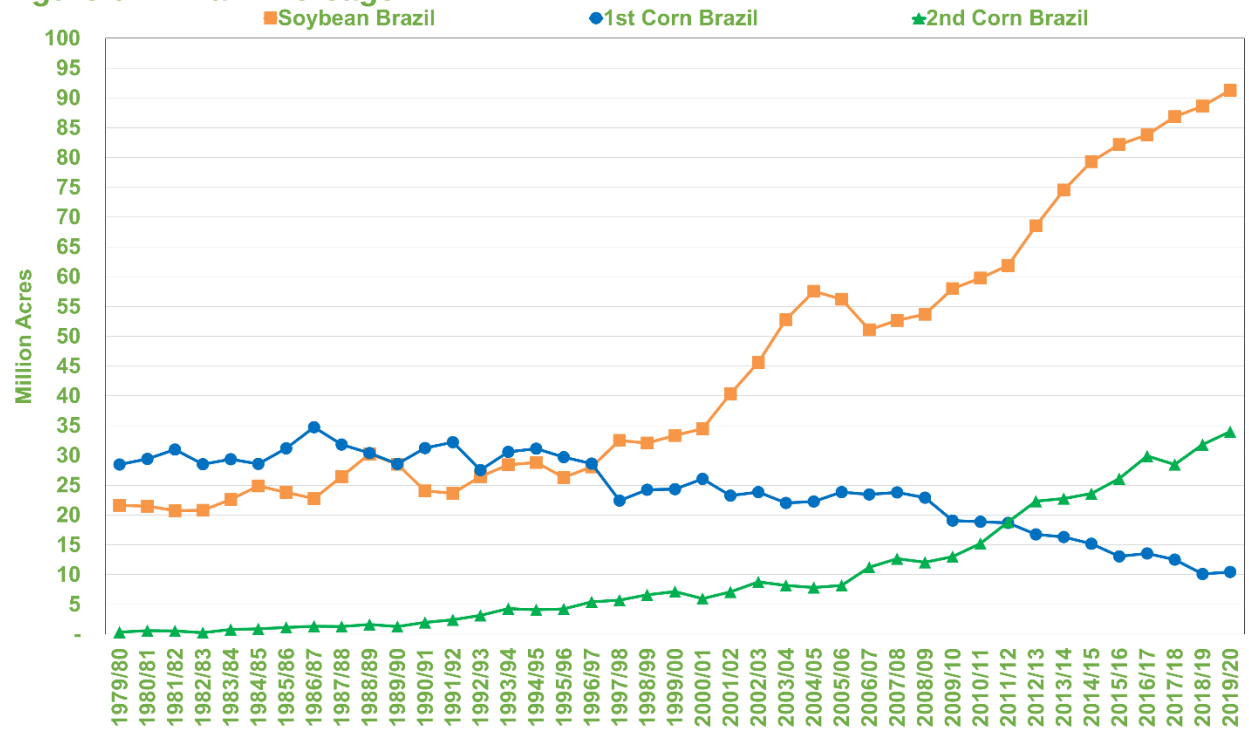
Figure 63: Brazil State Map and Crop Regions



Source: USDA ERS

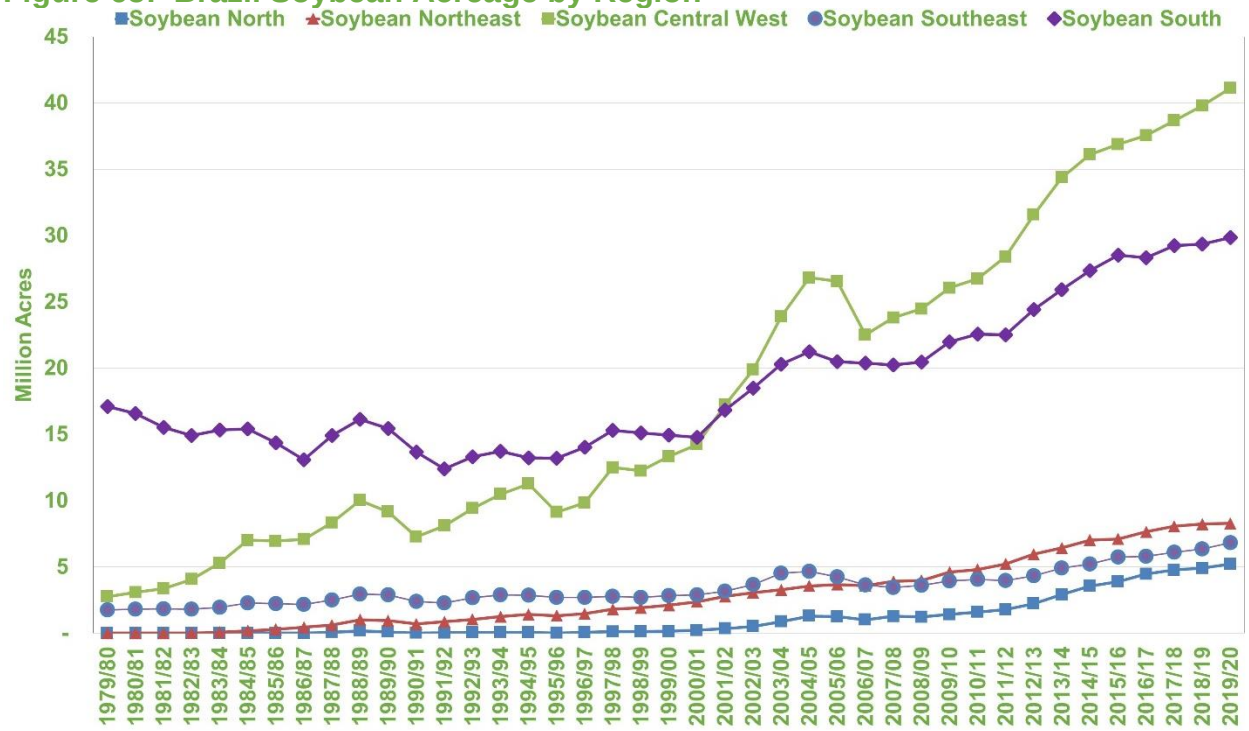
Soybean acres and second crop corn acres expanded while first crop corn acres declined. It should be noted that the soybean acreage expansion started before the RFS was expanded. After severe disease issues, continuous soybeans were outlawed, which put an emphasis on improving double crop corn results.

Figure 64: Brazil Acreage



Source: CONAB

Figure 65: Brazil Soybean Acreage by Region

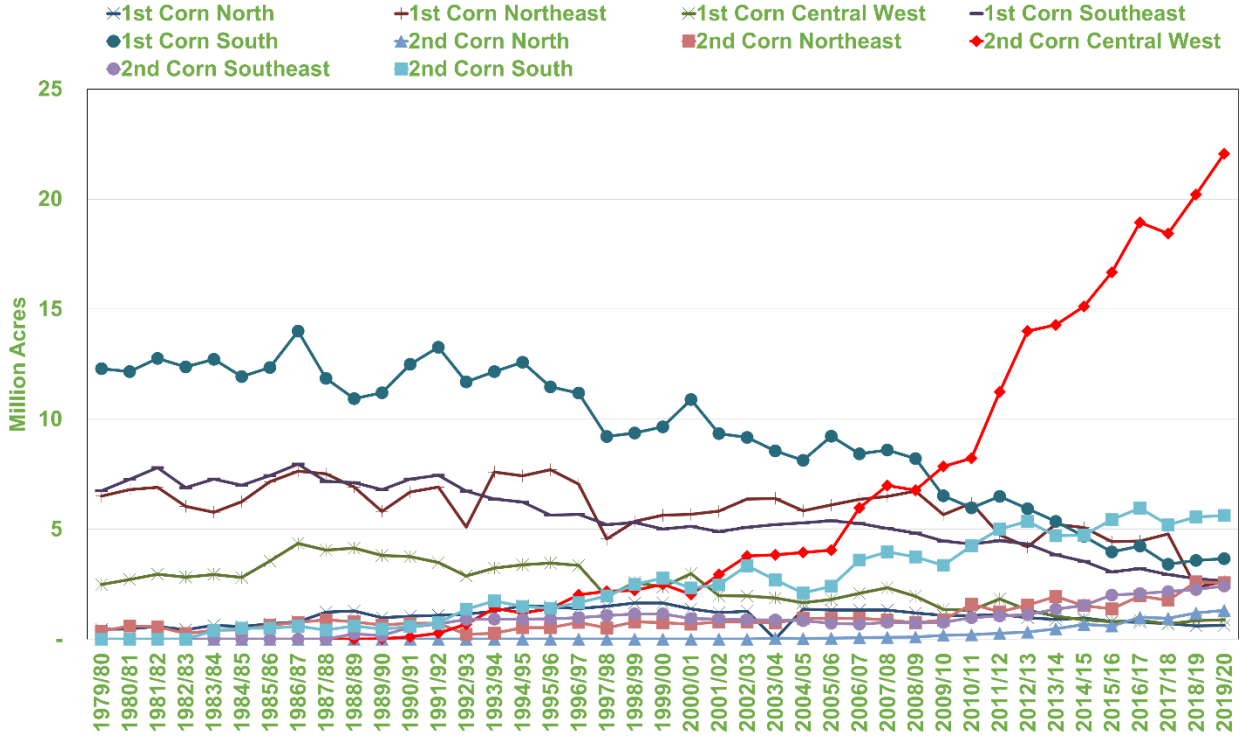


Source: CONAB

USDA reported in *Brazil's Corn Industry and the Effect on the Seasonal Pattern of U.S. Corn Exports*:

> *Mato Grosso, second-crop corn is planted beginning in January after the first-season soybean harvest. Mato Grosso is now the largest producer of second crop-corn and planted area has increased greatly because of technological improvements, including the use of lime to reduce acidity levels in the soil and the adoption of no-tillage systems. While the onset of the dry season in the later stages of growth limits second-crop yield potential somewhat, double cropping spreads fixed costs over two crops, enhancing profitability.*
>
> *However, the most significant driver of corn cultivation in the Center-West region of Brazil, since the 1960s, has been EMBRAPA's (Brazil's Ministry of Agriculture Research Company) development of cultivars better suited to a tropical climate—high yielding corn hybrids and soybean varieties that have complemented the correction of nutrient deficiencies in low-fertility Cerrados soils. These technological advances made it possible to cultivate marginally suitable soils, resulting in a large expansion of Brazil's agricultural frontier since the 1970s. Regulations constrain planting soybeans after soybeans to control diseases. Some other crops, including cotton, compete with corn to be double cropped after soybeans, but corn is predominant.*

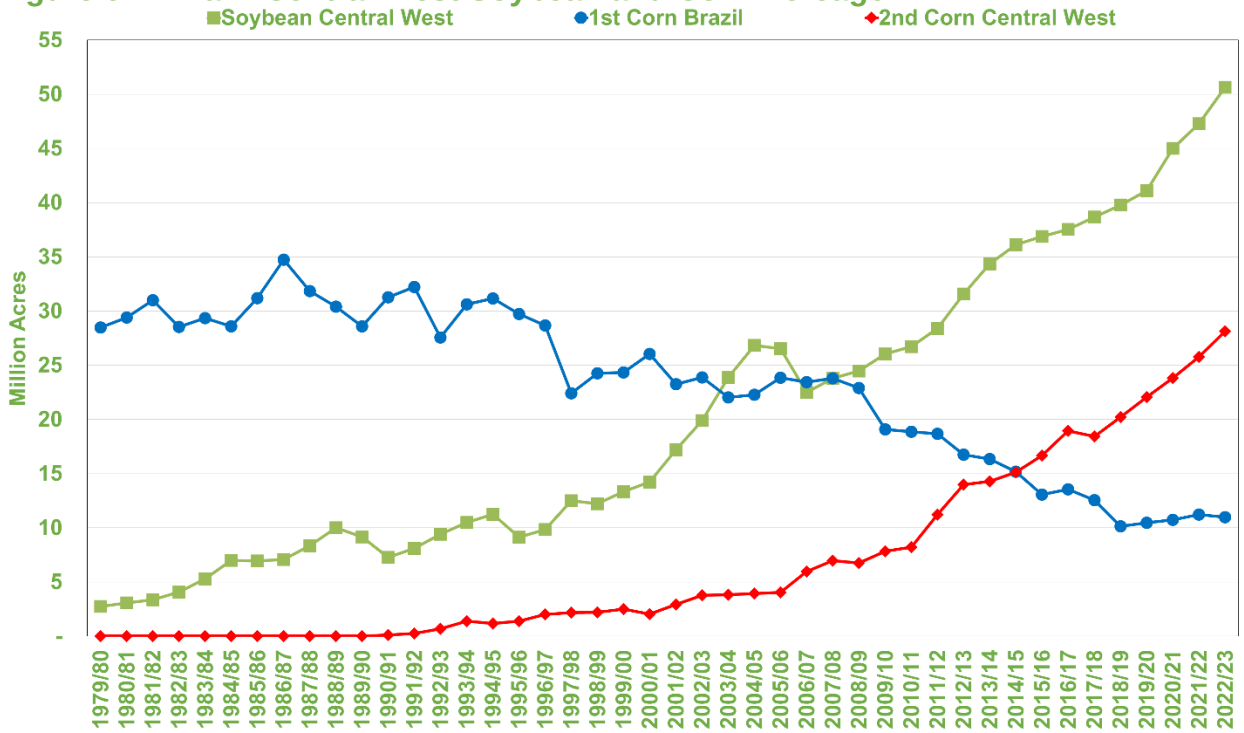
Figure 66: Brazil Corn Acreage by Region



Source: CONAB

To better show the relationship between Brazil Central West corn and soybean acreage expansion, the following chart was made. Without China's economy entering a deep recession, the acreage trends should continue in Brazil.

Figure 67: Brazil Central West Soybean and Corn Acreage



Source: CONAB

USDA reported in *Brazil's Corn Industry and the Effect on the Seasonal Pattern of U.S. Corn Exports*:

> *Brazil contains two distinct areas to produce corn: the traditional Southern and Southeastern agricultural producing regions, principally the States of Minas Gerais and Paraná; and the Center-West agricultural frontier, principally the State of Mato Grosso where land is abundant and less expensive. In the Southern and Southeastern regions, the bulk of the first crop is planted in September and harvested in March and corn yields are typically higher, reflecting better seed varieties and highly capitalized farmers. First-crop corn is mostly destined for the nearby domestic animal feed market, so planting flexibility is limited by local demand for feed from swine and poultry producers.*

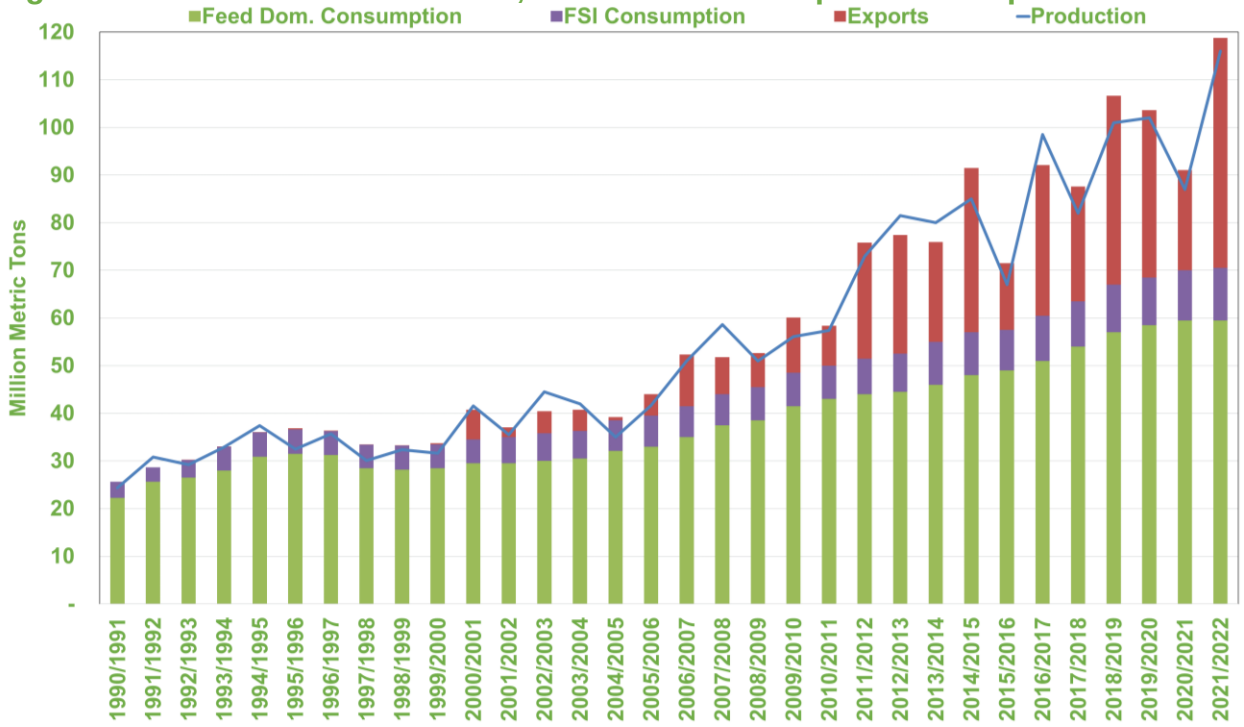
Brazil's first corn crop has a buyer in place. Plus, the crop is located near export ports, which means inexpensive transportation.

Brazil's second corn crop volume is being pushed into the world market not pulled. Due to the second crop being a far distance from the export ports, the low local price reflects the high transportation costs required to export. For local meat producers the second crop provides a competitive advantage for meat production. Higher personal income combined with affordable meat increased local consumption.

Despite increased local corn consumption, Brazil's corn production outpaced its domestic consumption, and the excess was pushed into the world market. As crop yields have increased and the soil improved, more soybean acres are being double cropped.

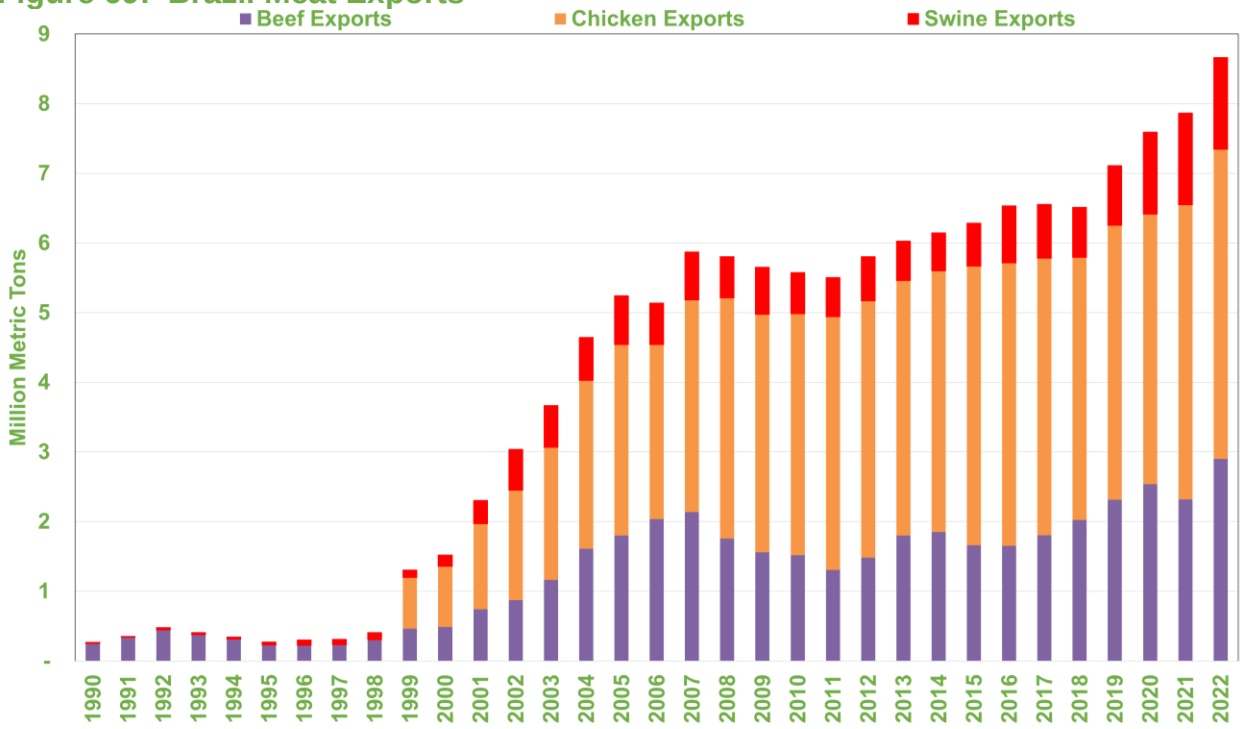
Brazil's meat industries are flourishing and show no signs of being squeezed for corn supply by the RFS. It can be argued that chicken is just soybean meal and corn in another form. Exporting chicken is another method of pushing corn into the world market.

Figure 68: Brazil Corn Production, Domestic Consumption and Exports



Source: USDA PSD

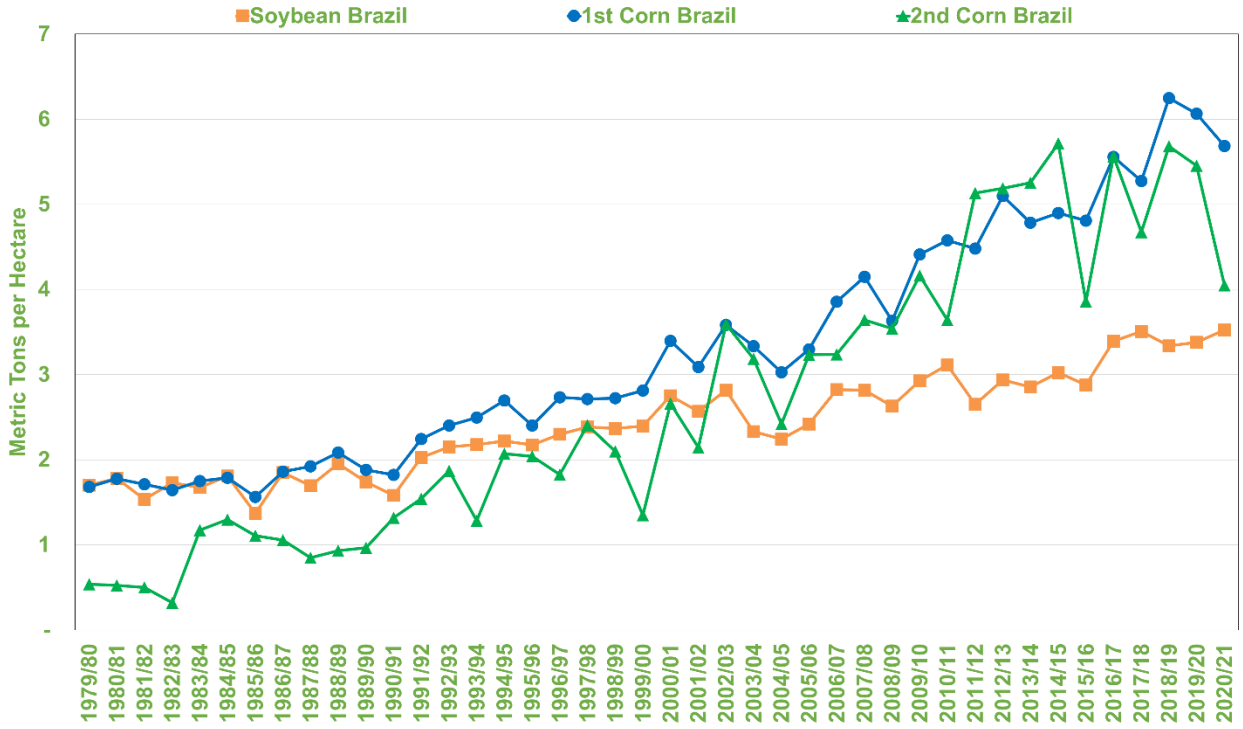
Figure 69: Brazil Meat Exports



Source: USDA PSD

The Mato Grasso corn crop is being double cropped behind soybeans. Second crop corn is not being grown at an ideal time to maximize yields. In the Center West region, first crop corn yields are between one MT to four MT higher per hectare than second crop. U.S. corn yields are much larger. For Brazil to replace one U.S. corn acre will almost require two Brazil corn acres.

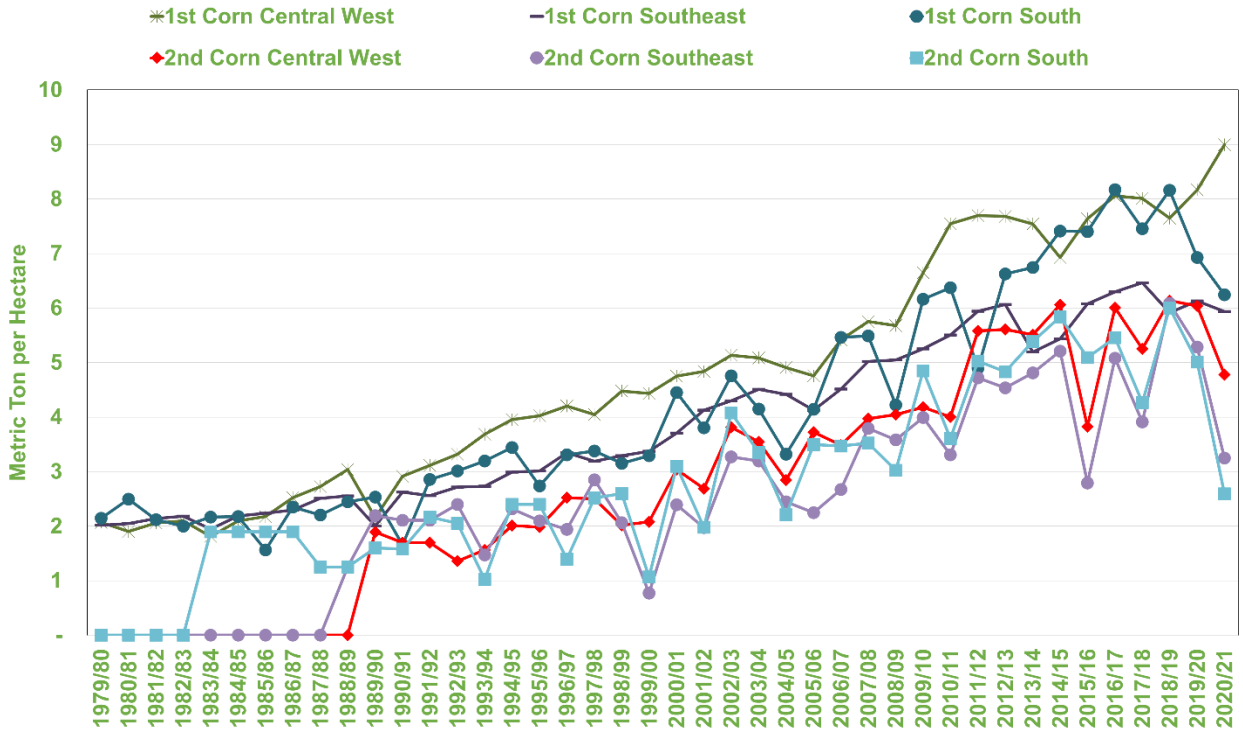
Figure 70: Brazil Yield



Source: CONAB

From 1995 until 2020, second crop corn yields have increased approximately 300 percent. Agronomists have developed seed varieties, soil improvement additives, and farming methods that lower disease pressures. The success enabled farmers to increase acreage and remain profitable. Still, not planting at the ideal time makes the crops more vulnerable to weather risks.

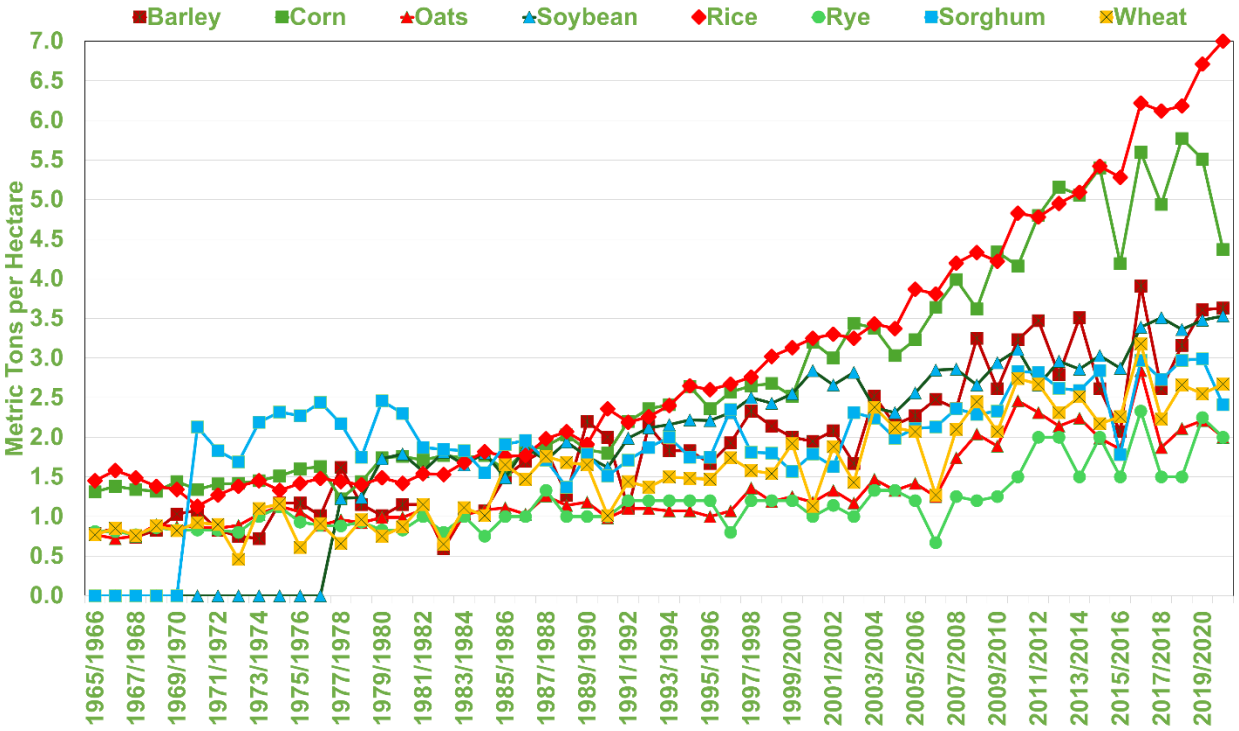
Figure 71: Brazil Corn Yields by Region



Source: CONAB

Focusing on the primary food and feed crops, excluding cotton, exemplifies how long crop yields have been increasing except for sorghum and rye. Corn yields have increased from being on par with the other crops to now being clearly the second highest yielding crop behind rice. The yield difference between corn and sorghum, rye, barley, and wheat suggest farmers should replace those crops with corn. It should be noted that corn is increasingly being planted in areas where many people thought corn could never be grown profitably. Soybean yields have increased 287 percent since 1977.

Figure 72: Brazil Crop Yields

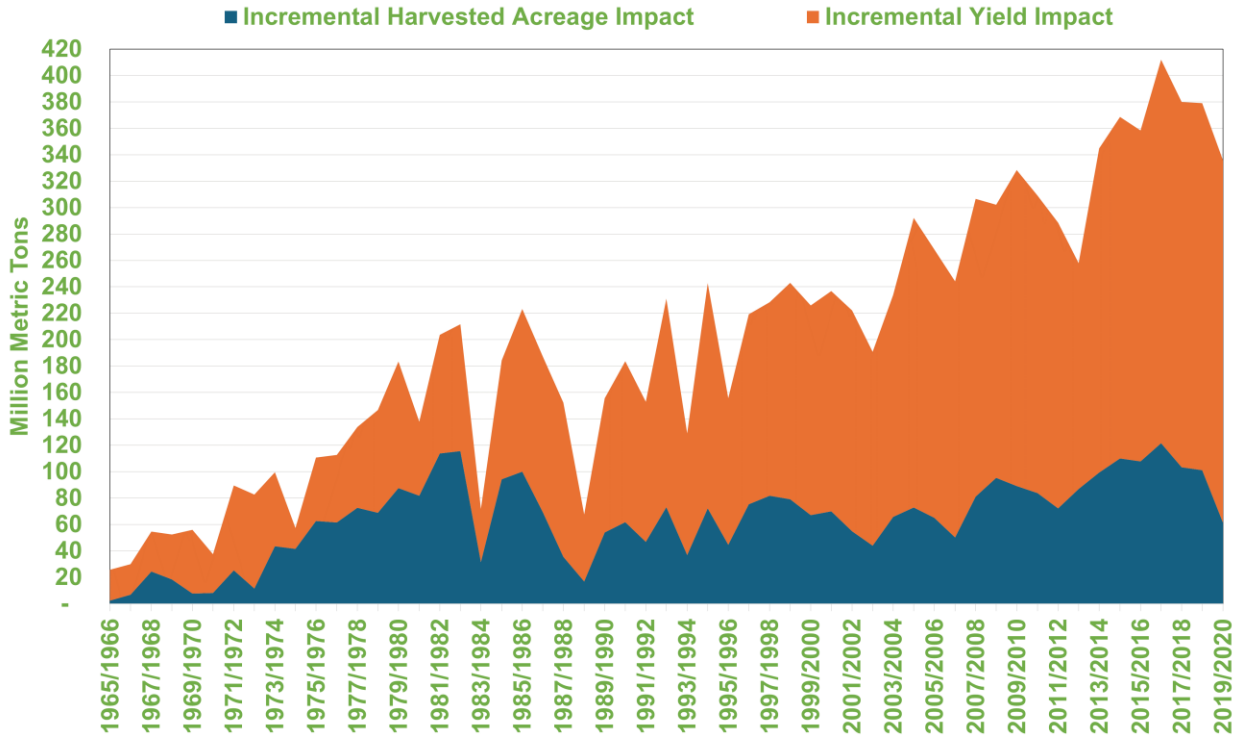


Source: USDA PSD

From 1964/65 to 2020, approximately 40 percent of production growth or 94.2 MMT has come from yield increases and double cropping or intensification versus 60 percent or 135.4 MMT from extensification or increase in land area.

Much of the acreage expansion has occurred in regions covered with forests and native grasses. For farmers inland, grazing cattle was an enterprise that monetized owning grassland. When grassland was converted to soybeans, a feed demand was created for corn to replace the lost pastureland. As shown earlier, the availability of soybean meal and corn enabled the hog and poultry industries to expand.

Figure 73: Brazil Production Change from 1964/65

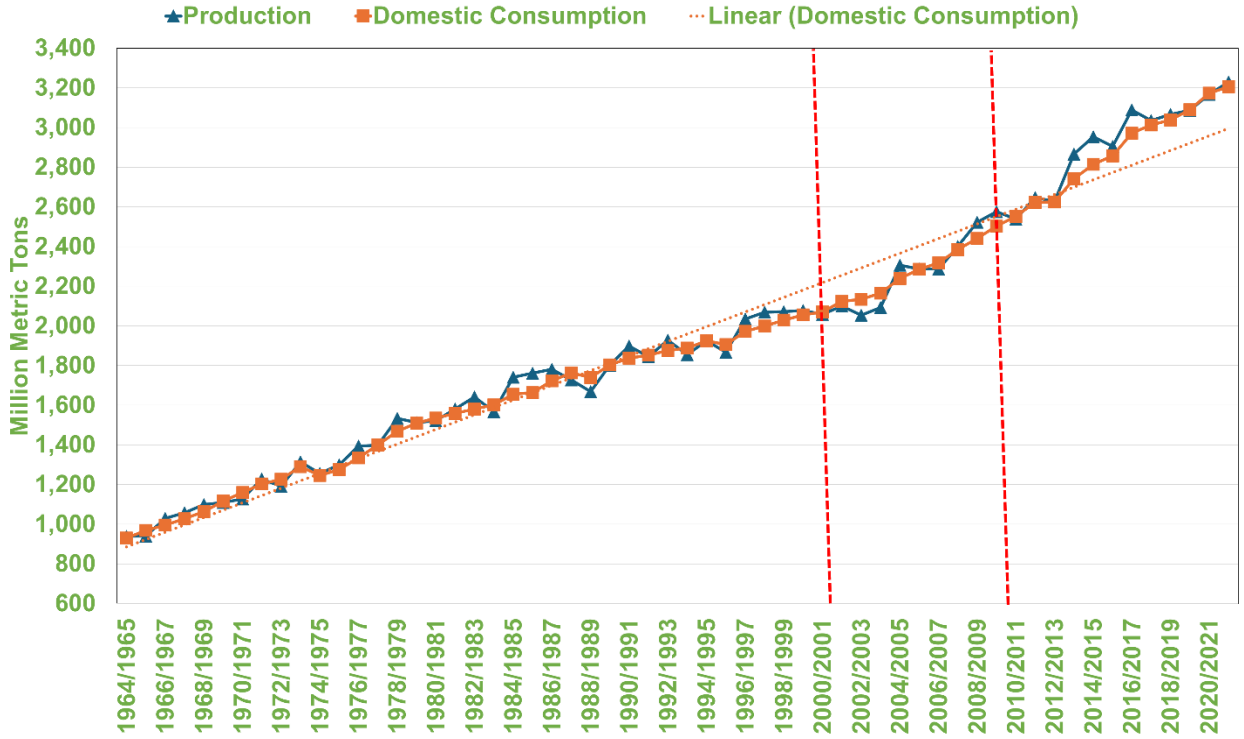


Note: Crops included are barley, corn, oats, rapeseed, soybeans, rice, sorghum, wheat
Source: USDA PSD

Land Intensification Versus Land Extensification

Interestingly, the peak years of ethanol buildout were below the trendline of world major grain and oilseed consumption for the 55-year period when USDA PSD data is available. USDA PSD data is the summation of barley, corn, millet, mixed grain, oats, rapeseed, soybeans, rice, rye, sorghum, and wheat. The same is true of world production. The need for more world crop production has been occurring for a long time.

Figure 74: World Production and World Consumption



Note: Summation of Barley, Corn, Millet, Mixed Grain, Oats, Rapeseed, Soybeans, Rice, Rye, Sorghum, Wheat
Source: USDA PDS

Academia is engaged in a debate as to how the improved crop production was achieved. Extensification involves increasing the total area of land under cultivation to meet increasing world consumption while intensification increases crop yields on existing cropland to meet increasing world consumption.

Extensification requires resources to clear new land and a commitment to invest in improving the quality of the soil. Extensification is typically a longer-term commitment. Pastureland or grassland is the easiest land to convert into cropland. Flint Hills Prairie is a location of contention. The conversion to cropland is occurring on land that is in the cow-calf cattle business.

Intensification is usually the lever governments pull to increase crop production. To quickly increase crop production, government policies will incentivize farmers to apply more inputs by either raising the price farmers receive and/or providing subsidized crop inputs. Policies will also encourage farmers to engage in improved farming practices to improve yields. For example, China encourages intercropping of corn and soybeans to increase yields.

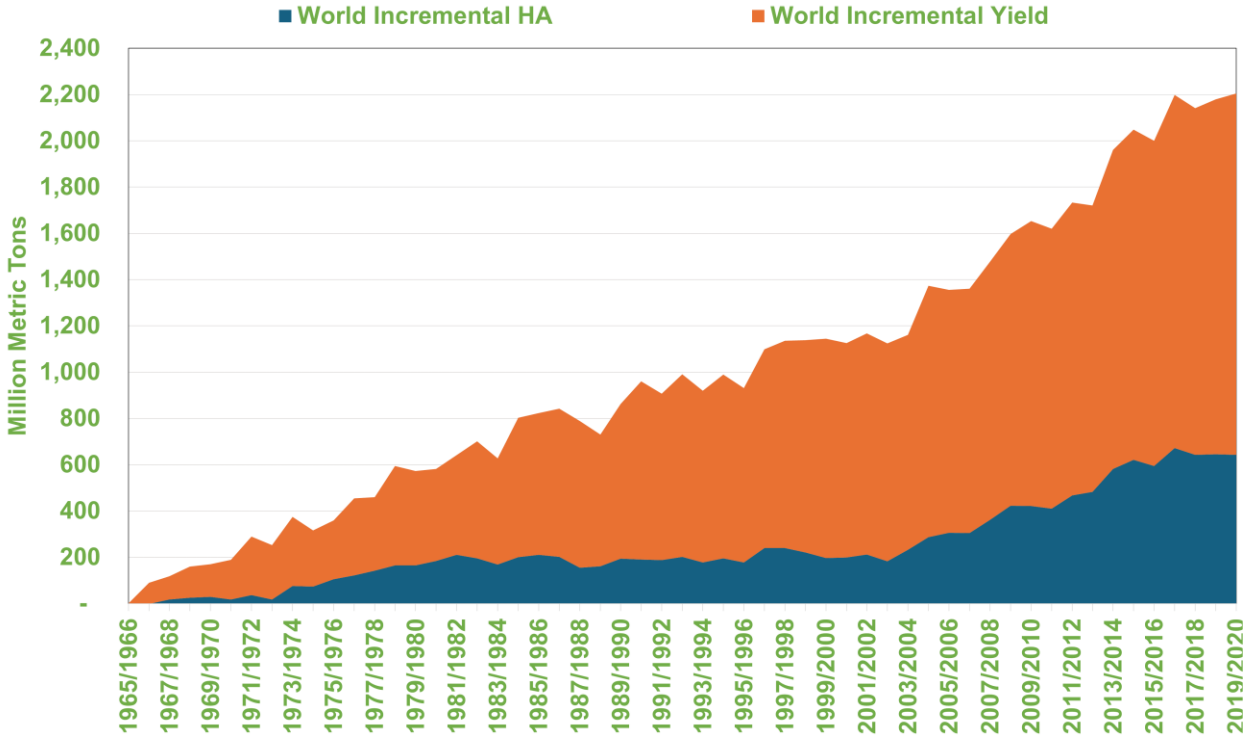
To ensure a long-term increase in food supply, government programs focus agricultural extension offices to educate the farmers about the newest developments that often originate in Agricultural Universities, such as on improving seed varieties, crop rotations, improved chemicals, and new farming methods. Private companies also fund research both independently and with government bodies.

Comparing the incremental harvest acreage impact on world production versus incremental yield impact since 1964/65 demonstrates how improving yields are the driving force behind world production increases. Approximately 70 percent of the extra food production results from yield increases versus 30 percent from additional cropland entering crop production.

Since about 2002, the impact from harvested acres has increased. Production from Brazil double crop corn production was included in incremental yield because double cropping is a more intensive use of the land. The data on double crop acreage in other countries is limited. Some of the increase in the incremental harvested acreage impact on world production was the result of double cropped acreage in other areas of the world.

Additional cropland entering crop production is generally not ideal for crop production or it would have already been in production. The food production impact from additional land is overstated because the calculation is based on average yield. For these reasons, the 30 percent extra food production to additional land overstated.

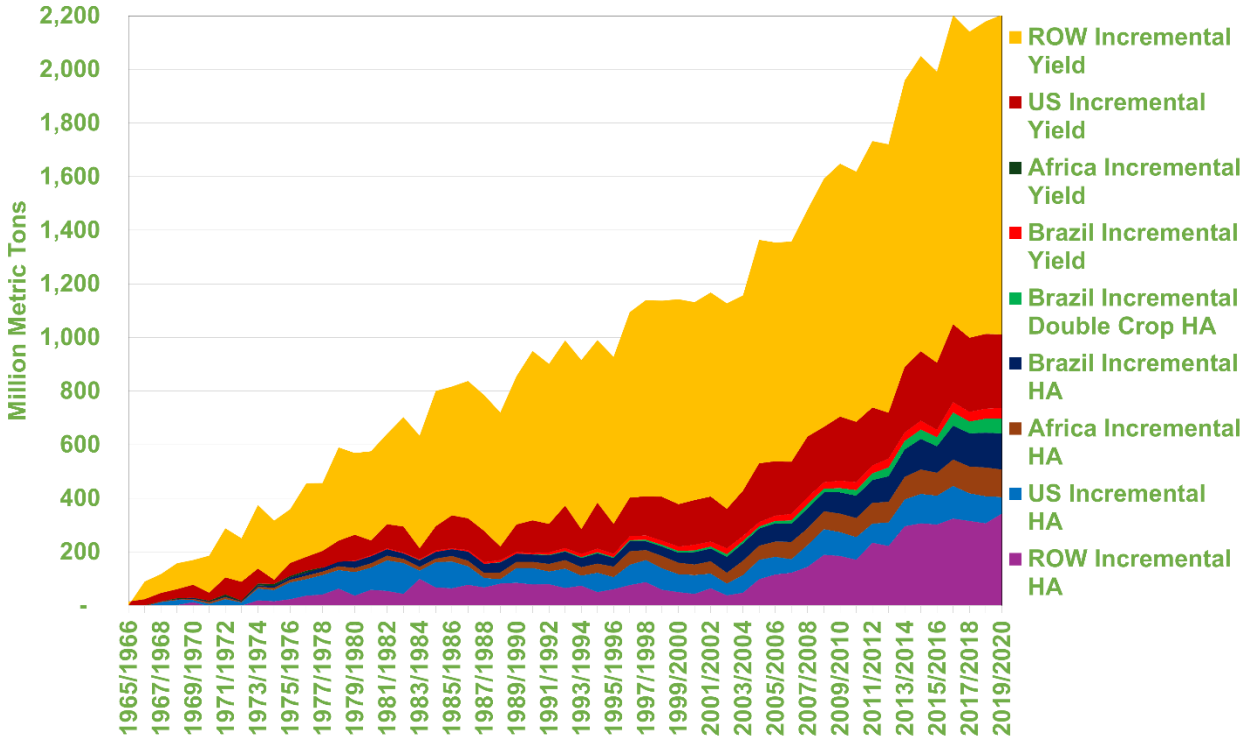
Figure 75: World Production Change from 1964/65



Note: Crops Included, Barley, Corn, Millet, Mixed Grain, Oats, Rapeseed, Soybeans, Rice, Rye, Sorghum, Wheat
Source: USDA PSD, Higby Barrett

Since 1965, Brazil incremental harvested acres accounts for six percent of total incremental food production, U.S. accounts for three percent, Africa accounts for five percent, and rest of world accounts for 16 percent. Brazil incremental double crop accounts for three percent of total incremental food production, Brazil incremental yield accounts for two percent, U.S. yield accounts for 12 percent, Africa yield accounts for two percent, and rest of world yield accounts for 52 percent.

Figure 76: World Production Change Broken Out from 1964/65



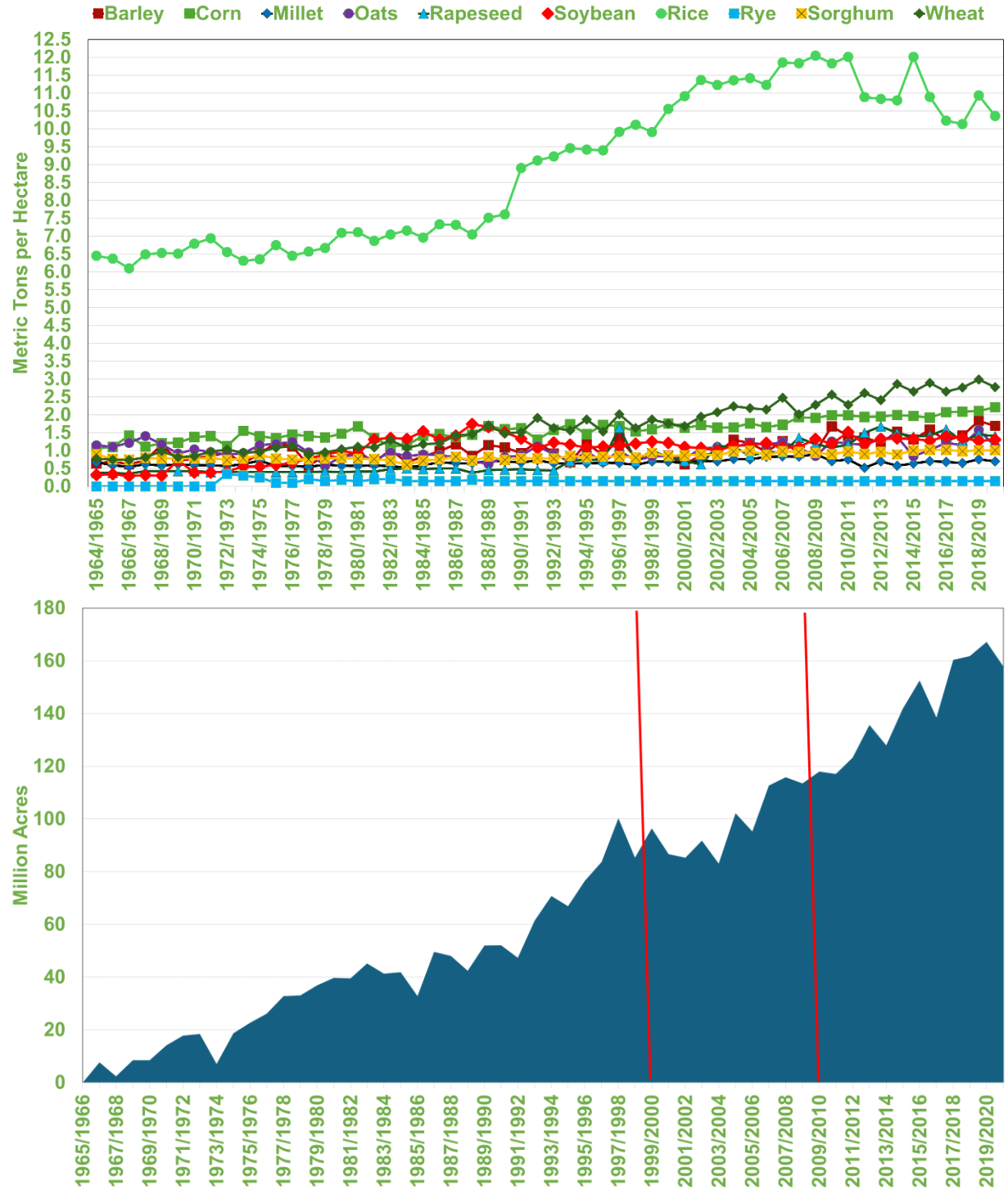
Note: Crops Included, Barley, Corn, Millet, Mixed Grain, Oats, Rapeseed, Soybeans, Rice, Rye, Sorghum, Wheat
Source: USDA PSD, Higby Barrett

It should be remembered the Former Soviet Union countries harvested acreage peaked in 1977/78 at 120 million hectares and decline to 67 million hectares in 1999/00 before rebounding to 88 million hectares in 2019/20. The collapse of the FSU sent food importing countries searching for greater domestic production and replacement countries. Therefore, the number of incremental harvest acreage must be underestimating how much virgin land entered cropland production by 53 million hectares in 1999/2000.

After 2000, Former Soviet Union countries readjusted their transportation system from sending products to Moscow to sending products to export ports. China and Africa bought most of the imports. Therefore, much of the additional harvested acreage after 2000 was agricultural land returning to cropland or overestimating how much virgin land is entering crop production by 21 million hectares. While the return of 21 million hectares correlates nicely with the RFS, it is a coincidence.

Africa is net deficit for every food category. Due to lack of resources and infrastructure the option to import food is not always available. If people are hungry, it is reasonable to assume African crop acreage will continue to increase. On the surface, yields closer to world levels would quickly solve the hunger issues. Better yields would also reduce or even reverse the trend of more acreage in production.

Figure 77: Africa Crop Yields and Harvested Acreage

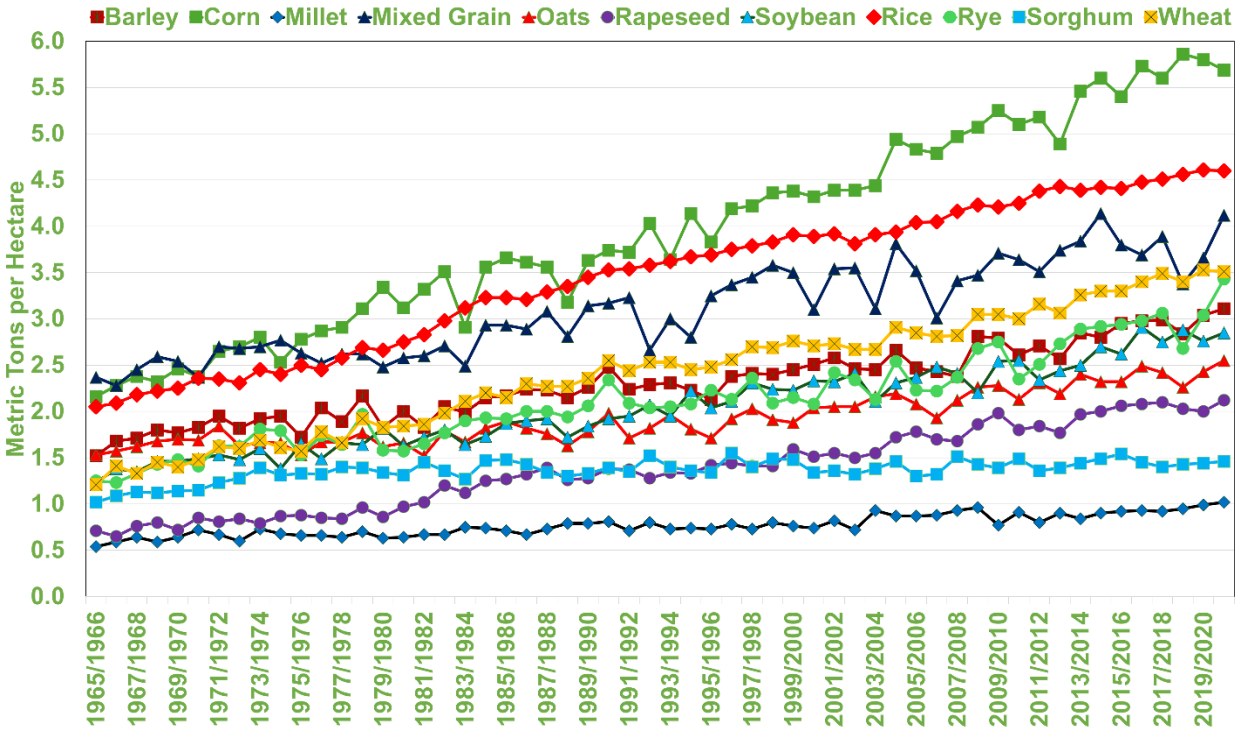


Source: USDA PSD, Higby Barrett
Note: Crops Included, Barley, Corn, Millet, Mixed Grain, Oats, Rapeseed, Soybeans, Rice, Rye, Sorghum, Wheat

For the crops covered, combined world barley, millet, mixed grains, oats, rye, sorghum, and wheat lost 59.5 million hectares while corn, rice, rapeseed, and soybeans gained 265.2 million hectares. Corn and rice have better yields and the oilseeds are more valuable.

The primary reason for raising barley, millet, mixed grains, oats, rye, sorghum, and wheat is the crops are tough or can tolerate extreme temperatures and lower rainfall better than corn and soybeans. The world corn yields appear to be a steady march higher over decades despite being increasingly grown on marginal land. Out of all the crops, only sorghum and millet have not experienced a steady uptick in yields. Sorghum yields have increased but the average yield has remained flat because the highest yielding sorghum land was converted to corn and soybeans. The highest yielding sorghum land in Texas through Nebraska is not as high yielding as corn land in Iowa or Illinois. When corn replaces wheat in North Dakota the corn yield gap between Iowa and North Dakota is approximately 40 bushels per acre or near 100 bushels per hectare, adding acreage in North Dakota is pulling U.S. average corn yields lower.

Figure 78: World Crop Yields



Source: USDA PSD, Higby Barrett
Note: Crops Included, Barley, Corn, Millet, Mixed Grain, Oats, Rapeseed, Soybeans, Rice, Rye, Sorghum, Wheat

Farmers plant what they have determined is best for their farm in the short run and long run. An individual farmer has no impact on the price of a crop and has zero control over where the price will be once the crop is harvested. This is especially true for a five-year forecast. The farmer does have control over a five-year farm improvement plan. The farmer is always taking steps to improve farm yields. Cropland values increase with greater production.

Most articles that mention intensification implicitly assume yields were increased by increasing chemical applications. While the statement is true, it is incomplete, misleading, and falsely depicts farmers as

uncaring about environmental damage. The implicit assumption is higher yields result in increased environmental damage. Improved farming practices, better seed varieties, land improvements and improved equipment also played major roles in improving yields. For example, no-till cultivation dramatically reduces soil erosion and has become a standard farming practice. The experiments farmers and university researchers are conducting concerning new cover crops rotations have potential to greatly improve soil health and yields. The primary driver is improving the health of the soil, but many farmers are reporting improved yields. As cover crop research develops cover crops that are tailored to a region, yields will increase while improving the quality of the soil. Many of the GM seed varieties have traits aimed at reducing chemical applications and reducing environmental impacts. Precision agriculture improves the percentage of chemicals absorbed by the plant and reduces chemical runoff. Many farmers are playing a significant role working to implement environmentally beneficial farming practices.

Hybrid corn varieties are described as “thoroughbreds” that will deliver great yields with enough fertilizer. Fertilizer implements that increase plant absorption will increase yields or the farmer could reduce the application rate.

Higher farm revenue does encourage landowners to invest in large capital expenditures. Many landowners invested in new equipment, buildings, land leveling, irrigation, and tiling to improve the value of the farm and reduce their tax obligation. One common mistake observed is forecasters will extrapolate the history out 40 years and estimate environmental damage without considering if that is possible. For example, only 100 percent of the cropland can be irrigated or tiled.

It needs to be noted that not all the improvements that occur in agriculture are privately funded. As mentioned earlier, government programs and government institutions fund research aimed at benefiting society and the world. A common goal is to increase yields while reducing environmental impacts. The point being that assuming higher crop prices are all that is driving yield increases completely discounts the quality research conducted every year in the public sector and ignores the fact yields increased even during periods of lower prices. State agriculture extension services play a vital role in disseminating information that advances technological innovations aimed at increasing yields while improving the environment.

U.S. corn yields this year are record large despite below average weather. With South America crop production rebounding to a more normal yield after three straight years of La Nina weather patterns has created a supply glut. The bottom line is years of research and investment will result in higher yields for the next ten years just as they have for the past 50 years.

Key Takeaways

The ultimate decision maker on how land is used is the farmer, but a variety of factors influence their decision making. The factors examined include:

- Prices
- Infrastructure
- Production Contracts
- Seed Varieties
- Farm Investments
- Crop Expertise
- Crop Rotations
- Government Policy
- Double Cropping
- Existing Trends

Farmers plant what they have determined is best for their farm in the short run and long run. An individual farmer has no impact on the price of a crop and has zero control over where the price will be once the crop is harvested. This is especially true for a five-year forecast. The farmer does have control over a five-year farm improvement plan. The farmer is always taking steps to improve farm yields. Cropland values increase with greater production.

Extensification involves increasing the total area of land under cultivation to meet increasing world consumption while intensification increases crop yields on existing cropland to meet increasing world consumption.

Extensification requires resources to clear new land and a commitment to invest in improving the quality of the soil. Extensification is typically a longer-term commitment. Pastureland is the easiest land to convert into cropland.

The U.S. has experienced an acreage decline in crop acreage decline over the last 30 years. On a national level, the statistics indicate no land extensification or cropland expansion has taken place. On a national level, the production increase has occurred because of land intensification or increased productivity. USDA ERS calculations indicate more productive inputs enabled the food supply to increase while not increasing the amount of inputs. One key to the U.S. economic success was the ability to increase food production with fewer inputs, especially labor. The productivity increases allowed people to leave the farm and fill other jobs while still providing an abundance of food.

While inputs used for U.S. agriculture did not increase, the crop mix and where the crops are planted did change. Urbanization or cities growing replaced agriculture land. Another change in crop location is driven by government policies. Some government policies are directly aimed at farming practices. For example, The Food Security Act of 1985 has provisions that discourage the conversion of wetlands and highly erodible land into cropland and discourages native land and forest from being turned into cropland. In the same year the Conservation Reserve Program (CRP) was created to reduce soil erosion and crop production.

One theory why CRP acreage declined after 2007 is the RFS made cropland more valuable while the land enrollment value decreased. In 1990, the CRP paid an average of $49 per acre versus $45 in 2000. It is likely some CRP land returned to crop production from 2007 through 2014 before cropland returned to a downward trajectory. After 2014, both CRP enrolled land and crop acreage simultaneously declined.

For the U.S., focusing on just food crops (barley, corn, oats, rapeseed, soybeans, rice, sorghum, wheat), Since 1964/65, approximately 75 percent of production growth or 281.2 MMT has come from yield increases or intensification versus 25 percent or 85.2 MMT from extensification or increase in land area. It should be remembered that a portion of the extensification came from switching cotton and alfalfa acres to corn and soybeans, which means a portion of the land was previously in agriculture.

What occurred is a common occurrence in agriculture. The Plains States had surplus corn that attracted ethanol plants that require corn as a feedstock. Once the plants are built, extra local consumption encourages farmers to plant more corn. An ethanol plant nearby increases local corn price and reduces transportation costs. Some of the extra corn harvested acres came from switching acres from other row crops and some pastureland was converted to cropland. Pastureland being converted to cropland created feed demand for corn.

The issues with blaming ethanol for the total crop acreage increase are during the ethanol buildout from 2000 to 2010, Plains States planted acreage decreased 1.5 million and in the Plains States from 1990 to 2000 or before the ethanol buildout, crop acres increased 4.1 million.

Since 1990, if all the increase in Plains States and Missouri acres are attributed to ethanol, ethanol would be responsible for 5.7 additional acres entering production. Using a 180-bushel corn yield and a 50-bushel soybean yield, and assuming a corn soybean crop rotation, ethanol demand can attribute to increasing crop production 655.5 million bushels or 17.2 MMT. In terms of total food production increase, 17.2 MMT is about five percent of the total food production increase.

Focusing on the primary food and feed crops, excluding cotton, exemplifies how long crop yields have been increasing. Corn is the highest yielding crop and more importantly, the gap in yields between corn and other crops continues to increase, which means farmers will continue to have incentive to plant more corn. It should be noted that corn is increasingly being planted in areas with lower yields, which pulls average yields lower. The same is true for soybeans.

Brazil soybean acreage expansion is driven by a change in China policy that allowed more soybeans to be imported. Investors believed the policy change was long term and invested in expanding acreage to satisfy world demand for more soybeans.

Brazil corn acreage expansion is driven by double cropping after soybeans. Brazil non double cropped corn acreage has steadily declined.

Brazil crop and meat exports continue to increase. If competition from renewable fuel policy was squeezing supply, exports and meat production would not be exploding higher.

Brazil corn yields have increased from being on par with the other crops to now being clearly the second highest yielding crop behind rice. The yield difference between corn and sorghum, rye, barley, and wheat are providing the farmer with more incentive to replace those crops with corn. It should be noted that corn is increasingly being planted in areas where many people thought corn could never be grown profitably. Soybean yields have increased 287 percent since 1977.

In Brazil, from 1964/65 to 2020, approximately 40 percent of production growth or 94.2 MMT has come from yield increases and double cropping or intensification versus 60 percent or 135.4 MMT from extensification or increase in land area.

Much of the acreage expansion in Brazil has occurred in regions covered with forests and native grasses. For farmers inland, grazing cattle was an enterprise that monetized owning grassland. When grassland was converted to soybeans, a feed demand was created for corn to replace the lost pastureland.

Africa is a food deficit continent. Due to lack of resources and infrastructure the option to import food is not always available. African crop acreage will continue to increase but yields closer to world levels would quickly solve the hunger issues. Better yields would also reduce or even reverse the trend of more acreage in production. Intensification or increased inputs to increase yields also has negative environmental impacts. It should be noted that not all input changes have negative environmental impacts.

In Africa, from 1964/65 to 2020, approximately 30 percent of production growth or 39.7 MMT has come from yield increases or intensification versus 70 percent or 102.9 MMT from extensification or increase in land area.

In rest of world or world total minus U.S., Brazil, and Africa, from 1964/65 to 2020, approximately 77 percent of production growth or 1,153 MMT has come from yield increases or intensification versus 23 percent or 343.3 MMT from extensification or increase in land area.

Comparing the incremental harvest acreage impact on world food production versus incremental yield impact since 1964/65 demonstrates how improving yields are the driving force behind world production increases. Approximately 70 percent of the extra food production results from yield increases or 1,561.4 MMT versus 30 percent from additional cropland entering crop production or 642.9 MMT.

The primary reason for raising barley, millet, mixed grains, oats, rye, sorghum, and wheat is the crops are tough or can tolerate extreme temperatures and lower rainfall better than corn and soybeans. The world corn yields appear to be a steady march higher over decades despite being increasingly grown on marginal land. Out of all the crops, only sorghum and millet have not experienced a steady uptick in yields. Sorghum yields have increased but the average yield has remained flat because the highest yielding sorghum land was converted to corn and soybeans. The highest yielding sorghum land in Texas through Nebraska is not as high yielding as corn land in Iowa or Illinois. When corn replaces wheat in North Dakota, the corn yield gap between Iowa and North Dakota is approximately 40 bushels per acre or near 100 bushels per hectare, adding acreage in North Dakota is pulling U.S. average corn yields lower. Likewise, the same is largely true for the rest of the world. For this reason, the incremental harvested acreage impact is overstated, and the incremental yield impact is understated.

Combined world barley, millet, mixed grains, oats, rye, sorghum, and wheat lost 59.5 million hectares while corn, rice, rapeseed, and soybeans gained 265.2 million hectares. Corn and rice have better yields and the oilseeds are more valuable.

Brazil incremental harvested acres accounts for six percent of world total incremental food production, U.S. accounts for three percent, Africa accounts for five percent, and rest of world accounts for 16 percent. Brazil incremental double crop accounts for three percent of total incremental food production, Brazil incremental yield accounts for two percent, U.S. accounts for 12 percent, Africa accounts for two percent, and rest of world accounts for 52 percent.

It should be remembered the Former Soviet Union countries harvested acreage peaked in 1977/78 at 120 million hectares and decline to 67 million hectares in 1999/00 before rebounding to 88 million hectares in 2019/20. The collapse of the FSU sent food importing countries searching for greater domestic production and replacement countries. Therefore, the number of world incremental harvest acreage must be underestimating how much virgin land entered cropland production by 53 million hectares before 1999/2000.

After 2000, Former Soviet Union countries readjusted their transportation system from sending products to Moscow to sending products to export ports. China and Africa bought most of the imports. Therefore, much of the additional world harvested acreage after 2000 was agricultural land returning to cropland or overestimating how much virgin land is entering crop production by 21 million hectares. While the return of 21 million hectares correlates nicely with the RFS, it is a coincidence.

Comparing the incremental harvest acreage impact on world production versus incremental yield impact since 1964/65 demonstrates that improving yields are the driving force behind world production increases. The world corn yields have steadily march higher over decades. Intensification is actively encouraged by governments and a few reasons yields have increased are:

- Improved Chemicals
- Improved Farming Practices
- Better Seed Varieties
- Irrigation and Tiling
- Precision Equipment
- Cover Crop Research and Other Soil Improvements
- More Plants per Acre

Conclusions

The Renewable Fuel Standard (RFS) continues to play a significant role in U.S. agriculture. Higby Barrett's goal was to examine the subject at a level of granularity that produced tangible findings.

1. Farmer are the decision makers for land use allocation. Planting decisions are made in response to a variety of variables that are not always price related.
2. The RFS supported existing U.S. acreage trend towards more corn and soybeans. Ethanol is not the only reason why corn acres have increased. New technologies and farm policies resulted in increased corn and soybean acres.
3. Ethanol plants provide the nearby farmer with an extra marketing option that encourages more corn acres. Ethanol plants were primarily built in corn surplus areas.
4. In the report we detail our analysis of what really shifted acreage in the U.S. While ethanol is part of this narrative it is not the sole cause of the changing crop mix. For example:
    a. Before, during, and after the 2000-2010 ethanol buildout, wheat acreage was declining, and corn and soybean acres were increasing.
    b. Only a third of the area formerly in cotton was replaced by corn and soybeans. This means that other factors were causing the decline in cotton acreage.
    c. A large portion of the conversion of pasture occurred before 2000 and after 2010.
    d. U.S. total cropland continued to decrease from 2000 to 2010.
5. The financial incentive from higher land prices when land is converted to a higher and better use of farming versus grazing was a driving force for pasture conversion. Ethanol played a role in driving crop margins that encouraged these decisions by landowners in the U.S.
6. Ethanol was one driver behind additional planted acreage in the Plains States, but much of the acreage expansion occurred in the years before the ethanol buildout. A farm bill that gave growers freedom to allocate their acreage, along with other government programs, urbanization, and loss of acres elsewhere also drove additional acres in certain areas.
7. Soybeans were the driving force for new acres in Brazil. Crop rotations and soybean economics in Brazil had the effect of driving corn acreage higher. The corn acreage increase was not driven by ethanol, but rather corn's place in the crop rotation with soybeans.
8. While pastureland has been converted into corn and soybean acres, overall cropland totals are down, which does not indicate there has been extensification in the U.S.
9. Ethanol is one of many factors that has driven corn intensification, but since corn is already one of the biggest crops in the U.S. new technologies and practices to increase yields were already being targeted.
10. In the U.S., from 1964/65 until 2020, approximately 89 percent of production growth, or 327.4 MMT, has come from yield increases and crop switching (intensification) versus 11 percent, or 39 MMT, from extensification.