The Role of Carbon Dioxide in Increasing Food Production and the Productivity of Agriculture for the US and Worldwide

University of Kentucky
Department of Agricultural Economics
Special Reserch Report 3
March, 2017

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Abstract

Climate scientists have long warned that global warming, even if by only a few degrees, would play global havoc, with devastating negative impacts on the entire planet. In the climate science world, there are no positive impacts of a temperature increase, only negatives. Climate scientists frequently blame global warming almost entirely on the steady increase in the use of fossil fuels by human beings as the world becomes ever more and more industrialized. Climate scientists generally believe that drastic and costly steps must immediately be taken to curb the burning of fossil fuels in an effort to reduce the pace of global warming, even if these drastic measures have only a minimal impact on atmospheric carbon dioxide levels, if at all.This paper takes an entirely different view grounded in both plant science and agricultural production economics. This has been largely if not entirely ignored by the climate scientists. The scientific basis is grounded both in agricultural production economics and the basics of plant physiology. *The conclusion I reach states that to the extent the planet is warming, while there may be some measurable and reasonable costs, the same warming undeniably generates large benefits to agriculture. These benefits accrue to farmers and consumers.* Farmers operating in the Northern Plains states have been and continue to be major beneficiaries. *These benefits include not only the direct impacts of the carbon dioxide on plant growth, but also benefits such as increased rainfall associated with greater cloud cover, longer growing seasons allowing a larger diversity of high-value species to be grown, more lush pasture growth for livestock and warmer winters that allow more fall-planted and high-yielding plant such as winter wheats to thrive.*

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Key Words:

Carbon dioxide
Farm Productivity
Crop yields
Agricultural productivity
Climate change
Global Warming

JEL Codes:

Q54
Q56
Q57
Q58
Q51
Q18
Q02

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Carbon Dioxide is not a pollutant. The minute amounts of carbon dioxide present in the atmosphere are absolutely essential for plant and animal life to exist at all. Carbon dioxide molecules are at the very core of life as we know it from the distant past to today.

A living plant can be thought of as a naturally-occurring solar energy collector. Basic plant physiology tells us that plant life is powered by the energy derived from photons of light coming from the sun known as photosynthesis. The leaves of a plant can best be thought of as naturally occurring "solar panels" that transform the sun's light energy into the chemicals needed for the plant to sustain itself and grow. A plant uses this energy to manufacture the variety of organic molecules that each contain carbon atoms via a process any school child knows from basic science. In any organic compound, the key atom is carbon, and for a growing green plant this carbon is largely obtained from the atmospheric carbon dioxide. This is the same carbon dioxide characterized by environmental activists as a "harmful pollutant". The very gas essential to plant life (and, ultimately, *all* life) is in the same sentence as the words, "harmful pollutant".

Plants have special structures that allow them to breath in atmospheric carbon dioxide while expelling another gas as a byproduct of photosynthesis. That gas is oxygen, which is important to animals including human beings. This symbiotic relationship between plants and animals requires plants to take in carbon dioxide and exhale oxygen, while animals (including human beings) exhale carbon dioxide and breath in the oxygen produced by a plant.

An interesting way to think of plants is that they are not only wonderful solar collectors that take in and use the sun's energy but are also marvelous at naturally *sequestering* the *greenhouse gas* carbon dioxide. The carbon dioxide the plants take in along with other plant nutrients in the soil is used to make all manner of organic compounds that the plant needs to have in order to grow and be a productive plant while giving back large amounts of clean oxygen in return.

Where does the carbon that the plant obtained from the atmospheric carbon dioxide end up? Well, some of it remains in the plant, living or dead, ultimately becoming part of the organic material in the soil. But a lot of the carbon dioxide ends up on our dining room tables, as food. A bowl of cereal, pasta, a dish containing rice, indeed any plant-based food contains sequestered atmospheric carbon dioxide. How about the turkey or the prime rib, both animal based? These animals likely ate grasses and grains, grasses and grains that grew and flourished because of the minute amounts of carbon dioxide in the atmosphere. It is safe to say that *everything* on your dining room table is there *because* of atmospheric carbon dioxide. If there were no carbon dioxide in the atmosphere, then we, as human beings, would soon be in very deep trouble as the world's food supplies would be completely exhausted, with no more plants to make any more as the plants would be dead.

As an NDSU undergraduate, I was deeply embedded in the biological sciences, but especially the plant sciences. Then I received both masters' and doctoral degrees in agricultural economics. However, this career change did not mean that I lost interest in what was happening in the plant and animal scientist. In fact, I regularly used those sciences as part of my agricultural production economics work over the years.

But, it has been approximately 50 years since I was an NDSU undergraduate studying the plant sciences in depth. Science moves on. When I was an undergraduate plant science major 50 years ago, it seemed that all the professors were greatly mystified by how life interacted with its surrounding environment. The basic explanation seemed to be that genes occasionally mutated as random events or even as accidents or mistakes, and, on occasion, though rarely, these mutations proved to be useful. The random genetic mutation made it possible to occasionally better adapt to a changed set of external conditions. But the ability of a living organism to adapt via changing its genetics happened rarely and randomly, if at all, and life forms often faced extinction if a chance mutation to deal with the change in the external environment did not happen.

The current view of how life forms interact with their external environments is very different from the old-school way of thinking. The current view is that life in nearly all its forms, plants, animals, bacteria and others, are relentlessly *opportunistic*. In this context, being opportunistic means the living organism immediately senses that something in the external environment has changed. As quickly as possible, a living organism adapts in an effort to take advantage of the change in the environment. Most of these quick adaptations do not need to rely on random gene-level mutations.

Take a polar bear, for example. The bear discovers the supply of easily-caught edible seals is not as great as it was some years back. The polar bear may go hungry, but hunger causes many polar bears to seek out a good alternative food source such as Canada Geese, geese which have recently started moving northward in their migration due to a warmer climate. No random genetic mutation was required to convince the polar bear to snack on the Canada Geese, merely the fact that the seals were in short supply.

In economics, we routinely see parallel behavior on the part of consumers at the meat counter. Say that the price of beef is rising, but the price of pork and chicken is stable or even declining. A low-income consumer, maybe even a high-income consumer, usually quickly adjusts to the changed external price environment by purchasing less beef and more pork and chicken and then changes the family menu to take full advantage of the shifts in relative prices. The human being also did not have a genetic mutation in order to adapt to the changed external environment. Indeed, its best to put the week's menu together *after* you see what is on sale at the meat counter.

What about a plant, perhaps a plant growing in an external environment that contains a significantly higher level of atmospheric carbon dioxide than was present 50 years ago? Plants might simply ignore the change in the external environment, but given how life in all forms attempts to adapt quickly to changes in the external environment, for a plant to simply ignore the rising carbon dioxide level would be very surprising. Given the critical role that atmospheric carbon dioxide plays in the chemistry of photosynthesis, it is quite likely that plants operating in new higher levels of atmospheric carbon dioxide would attempt to take full advantage of the new situation it faces. If human beings and polar bears can make quick opportunistic adaptations to changes in the external environment without genetically mutating, then so also do plants!

Here, the fossil record is very useful. It is well-known and accepted that the earth has gone through periods in which carbon dioxide levels were significantly higher than they are currently, even with recent industrialization. For human beings, one of the most important of these periods was the so-called carboniferous period, when carbon dioxide levels were not only higher than now but much of the world was a little warmer and wetter. Sound familiar? The carboniferous period sounds much like descriptions of what might happen to the earth under global warming, only perhaps less extreme.

During the carboniferous period, over much of the earth, plant life flourished with a combination of high carbon dioxide levels and a warmer, wetter environment. Plants are engineered to do well being warm and wet with lots of carbon dioxide within limits so long as it does not get too warm or too wet. It was during the carboniferous period that much of the organic material was laid down that has been and is being recovered by the fossil fuel industries. In short, the plants growing during the carboniferous period *sequestered* carbon dioxide that then remained underground as parts of longer-chain organic molecules, only to eventually be released again as carbon dioxide into the atmosphere as the fossil fuel is burned.

It is important to note here that the amount of carbon on the entire earth is fixed. We are not somehow getting carbon atoms nor carbon dioxide raining down from outer space. The only issue is where the carbon is at the moment, in a farm crop, pasture, or an orange grove, deep underground in coal, oil or natural gas, perhaps in the atmosphere, or even in the oceans. Fossil-fuel burning does not somehow create more carbon atoms, but perhaps changes their location at a particular point in time.

But plants have the remarkable ability to remove carbon dioxide from the atmosphere and make the carbon into plant parts. Indeed, this sequestering of carbon dioxide and converting these into food for humans is the very core of what a farmer does, big or small. A farmer might be thought of as an expert in carbon dioxide sequestering, employing plants that in one form or another converted atmospheric carbon dioxide into food for humans. In this regard, remember how happy plants were in the carboniferous period, breathing in generous amounts of carbon dioxide.

This leads me into the basic thesis of this article. This thesis is ***that much of the productivity gains for U.S. agriculture (both plants and animals), indeed agricultural productivity gains for in much of the rest of the world as well, can be directly or indirectly linked to the rising atmospheric carbon dioxide levels over a period of the last 50 to 75 years.***

The second part of this thesis might be even more controversial, especially with those who advocate drastic measures to reduce carbon emissions from burning fossil fuels. That part states that ***Efforts to use public policy and environmental regulations in order to combat climate change, if successful, may very well result in a significant decrease in the long term rate of growth in agricultural productivity, both in the US and worldwide, leading to significantly higher food prices both in the US and worldwide.*** **Higher food prices have the greatest negative impact on low-income consumers.**

Three separate mechanisms (lines of reasoning) lead to this conclusion. Each represents a separate, path, but all three theories lead to the same conclusion: the worldwide food supply will be jeopardized to a significant degree if efforts to slow the rate of increase in carbon dioxide emissions are successful.

***Mechanism 1*: The direct affects of gradually-rising levels of carbon dioxide occurring over the industrial era on plant growth, crop yields and biomass creation.**

This mechanism is grounded directly in the scientific basis for plant physiology, the chemistry of photosynthesis (the very *foundation* of life) and all of the biological mechanisms built into green plants. These mechanisms convert carbon dioxide from the atmosphere and mineral nutrients from the soil into all the complex organic chemicals plants need to grow, reproduce and make food for animals and humans. The energy source powering this is ordinary sunlight. These mechanisms are all well understood by agricultural scientists.

Any agricultural scientist will tell you that, at least within limits and with everything else held constant, a plant supplied with fertilizer nutrients will do better, grow bigger and maybe faster, and produce more seeds and biomass than a plant does not get the same fertilizer. Of course, too much fertilizer could make these systems shut down. Further, some nutrients are more important than others, with the so-called fertilizer nutrients, (nitrogen, phosphorus and potash) being the usual focus of attention by farmers.

Plants also take up many other soil nutrients, and some of these so-called micronutrients such as iron and zinc, if supplied to plants as fertilizer, could positively affect plant growth and crop yields. There is more debate among crop producers, however, on whether or not the application of micronutrients should be a normal part of producing field crops. There are advocates and non-advocates. Of course, legumes biologically remove atmospheric nitrogen (approximately 78 percent of the air we breathe is nitrogen) and fix that nitrogen within the plant, and these plants benefit much less from the application of fertilizer nitrogen in the soil, if at all.

One could think of atmospheric carbon contained in carbon dioxide as just another plant nutrient that happens to be obtained primarilyfrom the atmosphere. Remove all carbon dioxide from the atmosphere, and plants would die. Shortly thereafter, almost all plants and animals would disappear, as even meat-eating animals trace their lives back to the plant-eaters. The debate, of course, centers on whether or not plants supplied with additional carbon dioxide will grow faster and produce more seeds and biomass than plants in an atmosphere containing less carbon dioxide.

Many greenhouse growers have been experimenting with pumping additional carbon dioxide into the enclosed greenhouse in an effort to increase the production of greenhouse horticultural crops. The results have been somewhat variable, with some growers reporting what they believe are good results, while others being less certain.

The big question, however, remains unanswered, and very difficult to study under outdoor field conditions. The big question, of course, is ***What has been the impacts of gradually-rising carbon***

dioxide levels over the past 50 or even 100 years of industrialization (largely fueled by the burning of fossil fuels) on the ability of field crops to grow faster and produce more seeds and biomass?

Or more generally still, ***has industrialization accompanied by rising carbon dioxide levels raised the productivity of agriculture both in the US and worldwide simply because field crops producing seeds or pastures producing biomass do better because the chemistry of photosynthesis that relies entirely on carbon dioxide works better if more carbon dioxide surrounds the plant, within limits at least.*** If this were true, it would suggest that plants treat carbon as just another plant nutrient that happens to be in the air surrounding it and not in the soil. Carbon dioxide is the normal way a plant gets carbon, just as chemical fertilizer (nitrogen, phosphate and potash) is normally applied as a molecule (NH_3, P_2O_5 or K_2O).

Atmospheric carbon dioxide levels have gradually risen from the dawn of industrialization perhaps driven by gradual increases in the burning of fossil fuels. The real question is what impact has this gradual increase had on the production of widely grown field crops in the US and worldwide?

One view might be that plants that depend on photosynthesis to thrive and grow simply ignore this change to their external environment. To hold this view, however, seems to deny the well-known scientific knowledge about how the basics of plant physiology and photosynthesis work. Perhaps equally troubling for those who hold this view is that it denies what I believe to be the “core” modern theory of biology, which states that life in all its forms is very aware of the surrounding external environment. Further, life in all its forms is opportunistic in that to the maximum extent possible it will quickly attempt to take advantage of whatever the situation is. A human being might be happier eating a bigger steak dinner, but a plant may be happier with a little more carbon dioxide!

If you want to see an agronomist squirm, ask the agronomist what impacts rising carbon dioxide levels have had over the past 50 or 100 years on aggregate field crop and biomass production worldwide. Any agronomist understands very well the biochemistry of photosynthesis and the pivotal role of atmospheric carbon dioxide. The problem is that it would be difficult to construct a controlled experiment outdoors to study this. Even more difficult would be an experiment that looks at the long-term impacts of rising carbon dioxide levels on plant growth. Agronomists tend to squirm whenever they confront a puzzle not readily resolved by a controlled experiment of one sort or another.

Still, to conclude that rising carbon dioxide levels over the long term have had zero impacts on agricultural production seems to deny the science that is at the very core of the plant sciences, given how photosynthesis works. Such a conclusion conflicts with the modern understanding that life in all of its forms is constantly reacting to changes in its external environment and them making attempts to take full advantage on the new external environment if possible. Reacting to increasing atmospheric carbon dioxide levels by growing more seeds and biomass may be the plant version of the polar bear snacking on Canada Geese when the seals are in short supply, or even the plant version consumer at the meat counter, unhappy with the price rise in beef, quickly adjusts the week’s menu around chicken or pork, which is on sale.

Over longer periods of time, perhaps the industrial era comprising the last 50 or 100 years, plants may mutate on their own, and some of these genetic mutations may enable the plant to take fuller advantage of the rising carbon dioxide levels perhaps from the increased burning of fossil fuels. A plant geneticist interested in developing new varieties of field and forage crops is going to be in search of particular plants that do well not under the carbon dioxide levels that existed 50 or 100 years ago, but rather do the best under the current atmospheric levels. ***New varieties of plants are continually being developed for current field and carbon dioxide conditions, not the field conditions that existed many years ago***.

This means that ***the newest field and forage crop varieties may have built into their genetics whatever is needed to do well when planted right now, and this includes taking full advantage of whatever atmospheric carbon dioxide is present today, not what was there 50 or even 20 years ago.*** The mere process of developing modern varieties by plant geneticist has built into it a mechanism that may allow field crops to do well under higher carbon dioxide levels!

Mechanism 2: **Gradually rising carbon dioxide levels have led to growing seasons in the major crop-producing areas that are typically not only a bit warmer, but also somewhat wetter than was true 50 or 100 years ago, when carbon dioxide levels were lower.**

Earth has had periodic periods in its existence where carbon dioxide levels were significantly higher than they are currently long before industrialization or even human life occurred. The most heavily-studied period is the so-called *carboniferous* period. This period is important because the carboniferous period was the period where most of the organic material was laid down that under heat and pressure became the crude oil and natural gas that is currently being extracted and burned. Life in that period *sequestered* carbon dioxide from the air and ultimately put it deep underground. The fossil record provides more than ample evidence to suggest that the carboniferous period was warmer and wetter than today, and plant life flourished not only because of the ready availability of carbon dioxide but also because most plants like having a little more water and a little more warmth, and happy plants frequently respond to these external conditions by producing more biomass.

An often overlooked but very important point exists in the climate scientist's computer models that describe and forecast global surface temperatures. ***Carbon dioxide is not enough of a greenhouse gas to be able to, on its own, cause a significant rise in global temperatures. The gas exists in the atmosphere in only minute amounts and is very weak at holding in the warmth from the sun. The only way rising carbon dioxide levels from the burning of fossil fuels can be "blamed" for significantly increasing the global temperature is through an indirect effect on the amount of cloud cover! This increased average cloud cover, not the carbon dioxide gas, is what leads to the forecasts of global warming.***

In short, the basic climate science is that increased carbon dioxide levels interact with the atmosphere to provide additional cloud cover. Rainstorms do not happen a bright clear sunny day. If the day is cloudy, there *still might not be rain*. However, the *odds* that rain will occur increase if there are clouds in the sky.

At this point, I am going to take advantage of my experiences growing up on a farm in northwest North Dakota. Farming in Northwestern North Dakota, maybe even farming anywhere, is not unlike gambling using a roulette wheel. Sometimes, lady luck is with you, but often not. Farmers love being in situations where the odds of getting a good crop are enhanced for whatever reason. Ask a North Dakota farmer to choose among two options for a growing season. Option 1 is a growing season heavily dominated by days that are clear and sunny. Option 2 a growing season in which there are many days in which the weather is cloudy, and these clouds frequently turn into rainstorms. Which option will the farmer likely choose?

Of course, there are limits to all of this. Too much rainfall and plants do not do well because they are waterlogged and soon drown. Or a rainfall could turn into a hailstorm, and quickly destroy crops. However, the odds of getting a productive crop are improved with ample cloud cover on many days over what likely would have happened had there been a growing season with nearly all days clear and sunny. Ask a North Dakota farmer whether he or she sees additional cloud cover occurring because of rising carbon dioxide levels as a problem, or perhaps, an opportunity.

At this point, I use anecdotal information to further support the important point I am making. Growing up in Northwest North Dakota, times were often difficult. We would have occasional years of good crops, but these were mixed in with many years crops were not-so-good. Northwest North Dakota historically has an average rainfall of approximately 16 inches per year. The tricky part about farming on the northern Great Plains is that the 16 inches is not what falls consistently year after year, but is an average number over periods of maybe dozens of years. Some years the 16 was maybe 18 or even 20, and crop yields were above average. But equally important, some years the number was 12, or even 10, and crops were so bad they were not even worth harvesting. What sticks out clearly in my memory is a three-year period starting in 1959, when rainstorms were rare and wheat yields were often in the 5-10 bushel range. Even worse, pastures were poor, and there was little hay. We hauled hay in all the way from Wisconsin one year to keep our livestock alive over the winter months.

Owning a farm in North Dakota all these years since then, I observe that in recent years, periods in which drought affects the growing season in the manner it did 50 or more years ago are becoming increasingly rare. Indeed, this “concern’ that climate scientists seem to have that the burning of fossil fuels leading to increased cloud cover may indeed represent an advantage or opportunity for North Dakota farmers in which “lady luck” shines on them. In fact, in this case “lady luck” is embodied in the very “greenhouse gas” that the EPA has been known to refer to as a “harmful pollutant”. Go figure!

To the extent that increased carbon dioxide ultimately leads to chemistry that raises cloud cover and thus increases the odds of having a growing season with more rainy days, chances are, farmers will ultimately benefit. Maybe more so in the drier farming regions than in the wetter regions, those regions which already receive adequate rainfall in most years, regions where crop yields historically have been more consistent over time than on the upper Great Plains. But even in these regions a little more rain may improve crop yields. In the vast farming regions of the US where farmers make their living growing field crops and livestock, you find little enthusiasm for treating carbon dioxide as a harmful pollutant or for yet another environmental regulation aimed at reducing carbon dioxide levels. Farmers and all the rural people whose incomes ultimately come from serving farmers, merely act in their own self-interest, a self-interest that treats rising carbon dioxide levels largely as a benefit for the region, not a cost.

Climate-change scientists have unresolved issues with their model building. One of the issues relates to the fact that if Arctic ice is disappearing as fast as claimed (from increasing carbon dioxide levels that are coming from increased burning of fossil fuels via industrialization over many decades), then the oceans, but particularly the Atlantic ocean, should *already* be much higher than it is. But even now the ocean level is not nearly as high as the models would predict. If this were happening, then owners of Atlantic coast properties, fearful that their expensive properties would soon be permanently underwater, would be desperately trying to dispose of the property at heavily discounted prices in order to move into a less flood-prone area. But these properties are not being sold off in any significant way, and prices for ocean-front real estate is still very high often starting at a million dollars and going upward from there. The real estate market collectively does not believe that serious coastal flooding will occur any time soon, or prices would be heavily discounted as owners try to salvage part of their investment and move inland.

Let me use Wilmington Beach, North Carolina, as an illustration. The entire community exists on coastal land barely above sea level. Zillow® claims that the properties in Wilmington Beach are all in at least the high six-figure to seven-figure range. And life along the Atlantic coast for well-to-do property owners goes on pretty much as it always has for the past 50 years and longer. Properties only a few miles from the beach in the city of Wilmington proper go for far less money. But there is no mad dash of the wealthy into a property that would be less impacted by a rise in sea level. The same thing appears to be true for high-end real estate markets along most if not all of the Atlantic coast. Ask a real estate agent for these coastal properties if big discounts are now available because the properties will soon be permanently under water on account of sea level rise attributable to global warming and watch the response!

It is easy for an agricultural production economist to spot the flaws in the climate change model forecasting a big rise in sea level from the melting of ice. The basic explanation says that the total amount of water on the planet is all but fixed. Water can exist in many forms, including Arctic sea ice, seawater, moisture and cloud cover in the air, and as rainfall. Melted sea ice takes up less space than the frozen ice. The climate scientists are largely in agreement that rising carbon dioxide levels will lead to more cloud cover, and then logically, the odds of getting more rain on cloudy days are improved. The question is, if the total amount of water on earth is fixed, where does the moisture needed to generate the clouds and the rainfall come from. Think about this. Much of the earth's cloud cover forms over the oceans, and then moves inland with the prevailing winds. The moisture then precipitates over land in the form of rain and snow.

Many of the climate scientists seemed to believe that this additional precipitated moisture will almost immediately run off the land into streams and rivers and ultimately, back into the ocean, which then causes the oceans to rise. The problem is that when precipitation occurs, only a fraction of the water immediately goes back into a stream or river. A lot of the precipitation will stay in the soil, and that is how agricultural production takes place. To the extent that a plant gets more moisture and grows taller and with a greater seed yield, the plant pulling the water out of the soil, water that began as melted ice from glaciers, *sequesters* the water from the melting glacial ice. This same water soon ends up in a host of different agricultural products obtained from both plants and animals, and none of this water causes the sea level to rise.

As you sit down to your morning breakfast, consider that the food you are eating may contain the very water that originated when the glacial and cap ice melted! A few climate scientists, not many, have become aware of the fact that the big land masses are much more important in keeping the water from melting ice from raising the sea level by acting as a giant sponge. The real explanation is grounded in agricultural production economics, and production economists are not part of the so-called IPCC (Intergovernmental Panel on Climate Change) science.

Mechanism 3: **Increased Carbon Dioxide arising from industrialization and the increased burning of fossil fields has added days if not weeks to the growing season in temperate climates in both the spring and fall, and this is a benefit to agriculture, but particularly in regions where the short growing season traditionally limited what crops could be successfully grown.**

The first line of evidence on this issue is that any gardener realizes that the all-important maps of the US that delimit growing zones for gardeners have changed dramatically in recent years. Typically the zones have each moved about one zone upward, perhaps more, since the 1960s. The effect of this is that a North Dakota gardener can now plant crops that, 50 years ago could only be grown in Nebraska or maybe southern South Dakota but not further north.

The changes in the planting zones in large measure are directly tied to days added to the growing season in the fall without a killing frost, but perhaps also adding days to the growing season after the last killing frost in the spring in the spring, allowing earlier planting as well.

As a North Dakota gardener, I paid close attention in the seed catalogs to the data indicating the number of days to maturity for each seed variety. 88 days was pretty much OK. 95 or even 92 days was iffy. 100 days was completely out. As the growing season gets longer, even by only a few days, the options for what I can grow expand in a significant way. If I can count on a 100-day growing season in a normal year, I can plant a much more elaborate garden with a much greater variety of annual plants than I was able to grow with just an 88-day growing season, and that is only an increase of 12 days total. To the extent that the burning of fossil fuels increases the length of the growing season, my garden can produce more food.

What does this mean for commercial farmers? Here, I am relying on anecdotal evidence from my experiences growing up in North Dakota and comparing what we were doing as farmers then from what is going on today on the same farm. I grew up in the 1950s and the 1960s in northwestern North Dakota, where the average annual rainfall was about 16 inches, but with very large variation year-to-year variation. Even in the central north Dakota, where the average rainfall was an inch or two higher, crop production was what could best be described as a *near monoculture* in which the crops grown were nearly all small grain grassy cereals. Hard Red Spring and Durum wheat dominated, both crops planted in the early spring, but there was also spring-planted malting and feed barley, oats and fall-planted rye.

There were two reasons for this. First, the rainfall was too limited and the growing season too short to plant anything that needed more water or even a slightly-longer growing season. Such a plan to increase the diversity of the crops being grown would not be met with success in most growing years.

The second issue was that everything needed to be planted from seed in the spring. A few farmers were experimenting back then growing winter wheat. The problem was that the growing season was so short in the fall that many plants had trouble even getting a start in the fall before getting kicked by a heavy frost. Even worse, winter wheat can typically handle minimum temperatures that fall into the -20° F to -25° F range, but a few nights of -30° to -45°F and it was all over for the winter wheat plants! Fall-planted rye was more resistant to the really cold winter temperatures and usually fared better. That is why rye was the "go-to" fall-planted small grain on the Northern Plains. A problem with rye is that the market for it is that uses are limited and this market limited the opportunities to make money growing rye.

Since the 1960s and particularly in recent years, the number and diversity of plant species being successfully grown commercially by North Dakota farmers has exploded. There are three factors involved in this. First, plant scientists have built new plant varieties that are better adapted to the North Dakota conditions which involve short growing seasons, limited rainfall, and often very cold winter temperatures.

However, more importantly, all three of these issues in plant growth become less important with only a little extra carbon dioxide in the atmosphere. The extra cloud cover that the climate scientists worry about works very well to raise the odds of getting adequate rainfall for a crop that is not a small-grain cereal and improves the yields for the small grain cereal crops as well. The extra days added to both ends of the growing season makes it possible to successfully grow a diverse array of plant species commercially that would have never been possible 50 years ago. Whether you are a home gardener or a farmer, a few days added to either end of the growing season matter a lot in terms of what can be grown.

Take field corn production. Fifty years ago there was but one North Dakota county where corn was grown for grain in North Dakota successfully on significant acreage. That was Richland county, located in the very southeast corner of the state. In 1960, only 319,000 acres of corn was grown for grain in the entire state. The average corn yield was only 28 bushels per acre (*NASS*, *USDA*) The growing season was too short and the rainfall too limited to make the production of corn-for- grain commercially viable. But, corn varieties have gradually improved, rainfall on average is higher and the growing season has lengthened to make corn grown for grain as a significant commercial crop for North Dakota farmers. Corn-for-grain is even grown in the southwest part of the state, and area once thought to be suitable mostly as grazing land for beef and sheep. The transformation in what is being grown in the state over the past fifty years is nothing short of amazing.

For 2016, the acreage of corn grown for grain in North Dakota had increased to 3,270,000 acres, a ten-fold increase over 1960 acreage (*NASS*, *USDA*). The yield data are even more surprising, the 2016 North Dakota average corn yield was 158 bushels per acre (*NASS*, *USDA*)!

Compare acreage and yields per acre for North Dakota versus Indiana, a state in the middle of the Corn Belt. In 1960, the average corn yield for Indiana was 68 bushels per acre compared to the yield of 28 bushels per acre for North Dakota. The North Dakota yield was 41 % of the Indiana Yield. By 1990, the Indiana corn yield was 80 bushels per acre compared with 49 bushels per acre for North Dakota. North Dakota is beginning to catch up with Indiana, as the North Dakota yield is now 62 % of the Indiana yield.

But look at the yield data for 2016. The Indiana corn yield was 173 bushels per acre and the north Dakota average yield is 158 bushels per acre (*NASS,USDA*) The North Dakota yield is now over 91 % if the Indiana corn yield. And the rapidly rising corn grain acreage of 3.3 million acres is no longer that far below the Indiana acreage of 5.4 to 5.5 million acres.

What happened that makes North Dakota now a major corn-producing state, most of this happening over the past ten years? The production technologies used by corn farmers in both states with respect to inputs such as fertilizer, machinery and pesticides are likely similar. There may be some differences in varieties widely used in each state. But the primary reason for these gains for North Dakota probably relate to the probability that as carbon dioxide levels have risen, growing seasons have become longer in the spring and the fall, and the North Dakota climate is gradually becoming more favorable to corn production, on average a little warm and wetter. It is not surprising to me that climate change has favored agricultural states in the Northern Great Plains, where historically growing seasons were short and rainfall very limited.

Finally, even slightly warmer winter matters a lot if a farmer is attempting to produce a fall-planted crop such as Hard Red Winter (HRW) wheat. Fifty years ago, nearly all the wheat (Durum and HRS) was spring planted. Now the wheat acreage is increasingly being planted to fall-planted wheat. Agronomists have improved the hardiness winter wheat varieties over the years, but a major factor is that the winter lows nowadays are higher than they typically were 50 or 75 years ago. Together, all of this has made North Dakota farmers complain about the impacts of global warming all the way to the bank!

But, maybe these benefits only occur to farmers producing crops in “climate challenged” states such as those located in the Northern Plains. If so, then the benefits to global warming might be somewhat limited. What about agriculture in a state such as Indiana, a Corn Belt state that has a longer growing season, typically more rainfall but milder winters?

Shortly after I completed my doctoral degree at Purdue, I worked on a research project that utilized a computer model for assisting Corn Belt farmers in making a variety of production decisions. I worked closely with Purdue agronomists at that time along with other agricultural economists. A key feature of that model was the role of the planting date on farm profitability, particular for corn. Earlier planting means a significant increase in corn yields, and it is important for corn producers to get corn in the ground as early as possible to get the highest possible yields. On a farm producing corn, planting ordinarily occurs over a 2-3 week period, back in the 1970s, starting about April 15th. Earlier planting was infeasible mainly because the soil temperature was too low for germination. However, suppose that the planet has warmed to the point whereby a farmer could successfully get corn in the ground earlier, with planting beginning on April 5th or even April 10th, rather than April 15th. If this were the case, a greater share of the farmer’s corn would be planted at the optimal point in time from the perspective of maximizing both yields and farm profitability.

Another agronomic issue linked to climate change in Indiana involves double cropping. Double cropping involves planting two different crops in succession on the same field. This requires a growing season long enough for both crops to mature. In the Corn Belt the double crops often are a Soft Red Winter (SRW) wheat followed by soybeans. Soybeans are much like corn in that they yield best if planted early, but typically go in the ground after the corn is planted. The Highest-yielding soybeans probably went in the ground in Indiana around May 15th. Soybeans can be planted later, but, as the planting dates are delayed, the yields decline dramatically.

In double cropping, historically the wheat went in first, to be harvested in late June and early July. The soybean planting followed, with planting typically starting around July 15. These late-planted soybeans did less well yield wise (typically 25 bushels versus 45-50 bushels for single-crop soybeans), but the farmer had the income from the wheat as well, so the profitability of the land was greater than it would have been had the farmer grown the higher-yielding single-crop beans.

All of this analysis changes as a few more days are added to the growing season. Interstate 74 divides Indiana north from south through Indianapolis. In the 1970s, the standard view at Purdue was that double cropping of wheat and soybeans was feasible only south of I-74. But with even a slight increase in the length of the growing season moves the line of feasibility for double cropping northward, making farmers north of I-74 profitable double-croppers!

My general conclusion is that ***the farmers in North Dakota and in Indiana are benefitting from the increased carbon dioxide levels that lead to more consistent rainfall and an increased growing season. Further, much the same thing may very well be happening in other temperate farming regions both in the United States as well as in the other great agricultural regions around the world, but particularly for those located in temperate climates (MOST agricultural production takes place in temperate climates, climates similar to the conditions in states such as North Dakota and Indiana)!***

If this is true, then this also means that a significant share of the gains in measures of agricultural productivity since the dawn of the industrial age can likely be directly or indirectly a consequence as industrialization proceeds.

Currently, I am working with time-series measures of agricultural productivity. Dr. Eldon Ball (*Economic Research Service, USDA*) is recognized as the world's leading expert in developing methods and data series for measuring changes in agricultural productivity in the US and worldwide over time.

It is well known that over the industrial age, the agricultural productivity for both crops and livestock has increased dramatically, with significant year-to-year variation normally attributed to either favorable or unfavorable weather patterns occurring in each growing season.

One question that has puzzled agricultural economists looking at agricultural productivity (in the aggregate or for a specific commodity) is the specific forces pushing productivity generally forward over time. The usual answer to this is that farmers are gradually employing better and better production technologies. Each new technology boosts yields by an increment once the technology is widely adopted. These technologies include improved crop varieties, pesticides, the use of more and better fertilizers, better and more sophisticated farm machinery and others. Agricultural scientists both public and private like to claim credit for most if not all, of the productivity gains. But maybe this is not the complete explanation for the long-term production increases.

Could it be that commercially-grown plants such as corn and soybeans are taking advantage of the gradually rising carbon dioxide levels coming from human activity? Perhaps the newest and most recently-developed plant varieties from agronomists are exceptionally well adapted to the carbon dioxide levels in the current atmosphere, not the atmosphere that existed 50 or 75 years ago, when the atmosphere that contained significantly less carbon dioxide. If this is true, then part of the yield and productivity increase must be directly attributed to the extra carbon dioxide, the very thing that climate scientists rail against! Could it also be that pastures used for grazing do better with the additional carbon dioxide, more rainfall, a longer growing season and warmer winters as well? This, in turn, would lead to greater productivity from the livestock sectors as well. This could be controversial but what is not controversial is the critical role that atmospheric carbon dioxide plays in photosynthesis and plant growth.

Could it be that global warming has significantly increased the growing season in temperate climates, and that farmers and gardeners have already taken significant advantage of this to enable them to produce an ever more diverse array of higher-value crops? If this is true, this helps both the farmer and the consumer. With a longer growing season, pasture animals likely have more grazing days, and fewer hay-eating days. Further, hay production is increased with the longer growing season (maybe an additional alfalfa cutting would be one beneficial result). In addition, even slightly warmer winters makes it possible for farmers in more places to grow fall planted grains, and the fall-planted grains typically yield better than spring-planted grains.

If the climate scientists are correct in assuming that greater carbon dioxide levels lead to greater cloud cover (increasing the likelihood of rainfall on any specific day), could it be that farm-level productivity is gradually but steadily improving because there are simply fewer droughty growing seasons that there were 50 or 75 years ago? The snowpack melting that the climate scientists rail against may be in large measure responsible for the improved average rainfall conditions for agriculture.

I have been finding new ways to empirically test the general hypothesis that the increasing levels of carbon dioxide in the atmosphere has significantly pushed forward the productivity of U.S. agriculture. in a significant way. If this is true for the U.S., it is probably true also for agriculture worldwide as well. I have a long data series from Eldon Ball of the *USDA*, a series that measures the productivity of US farms over time.

The climate scientists are very fond of the atmospheric carbon dioxide data coming from the Mauna Loa observatory. I ran simple regressions using the *USDA* farm-level total factor productivity (*TFP*) data as the dependent variable (y) and the Mauna Loa carbon dioxide data as the independent variable (x).

The simple linear model is

$$y = a + bx + e$$

Where *y* could be either the *USDA* farm level productivity data or the Indian corn yield data and *x* is the carbon dioxide data from the Mauna Loa observatory. An improved model employs squared and cubic terms as a third-degree polynomial again with *y* as farm productivity (*TFP*) and *x* as carbon dioxide.

$$y = a + b_1x + b_2x^2 + b_3x^3 + e$$

The statistical results from the very simple models are very good. With the *USDA* farm productivity data, the explained variation (R-squared) for the third-degree polynomial runs over 98 percent. Figure 1 illustrates the results of this equation.

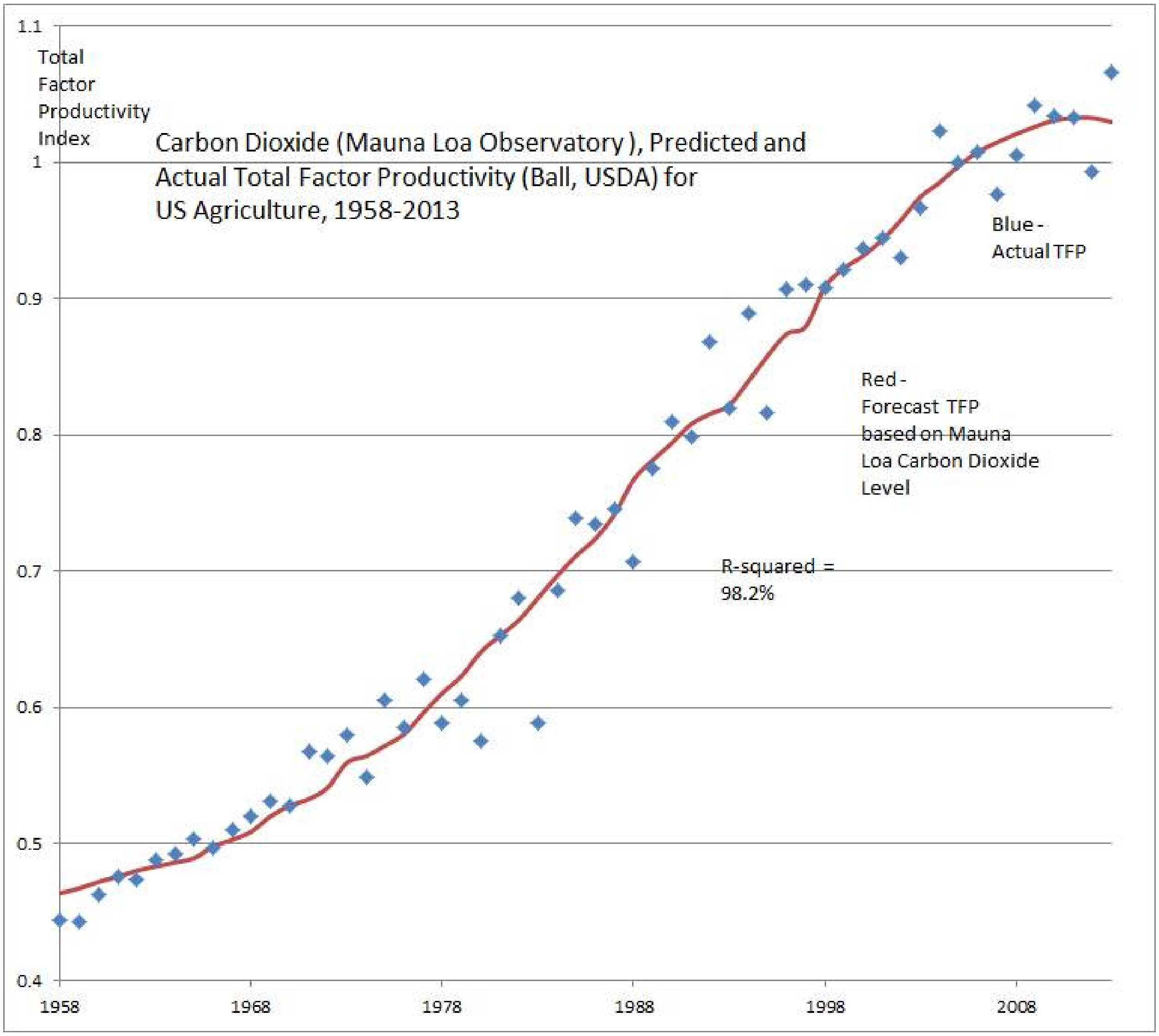

Figure 1. Source (calculated from data provided by Eldon Ball, *ERS*, *USDA*).

The general conclusion is that as atmospheric carbon dioxide levels have risen, so has the farm-level productivity of US agriculture, I do not truly believe that 98 percent of the gains in farm level productivity or even of crop yields are from the direct and indirect consequences of increased atmospheric carbon dioxide over time as a consequence of industrialization. I need to give some credit to plant and animal scientists and other improvements in farm production technologies unrelated to climate change. ***However, I also believe that the direct and indirect impacts arising from increased carbon dioxide levels are very important to farmers and consumers from an agricultural productivity perspective.***

I have also analyzed the yield data for wheat grown in North Dakota and corn grown in Indiana, and plotted to that data the carbon dioxide levels from the Mauna Loa observatory. The North Dakota data are in Figure 2, with the dots representing the North Dakota average wheat yield and the solid line representing the carbon dioxide data.

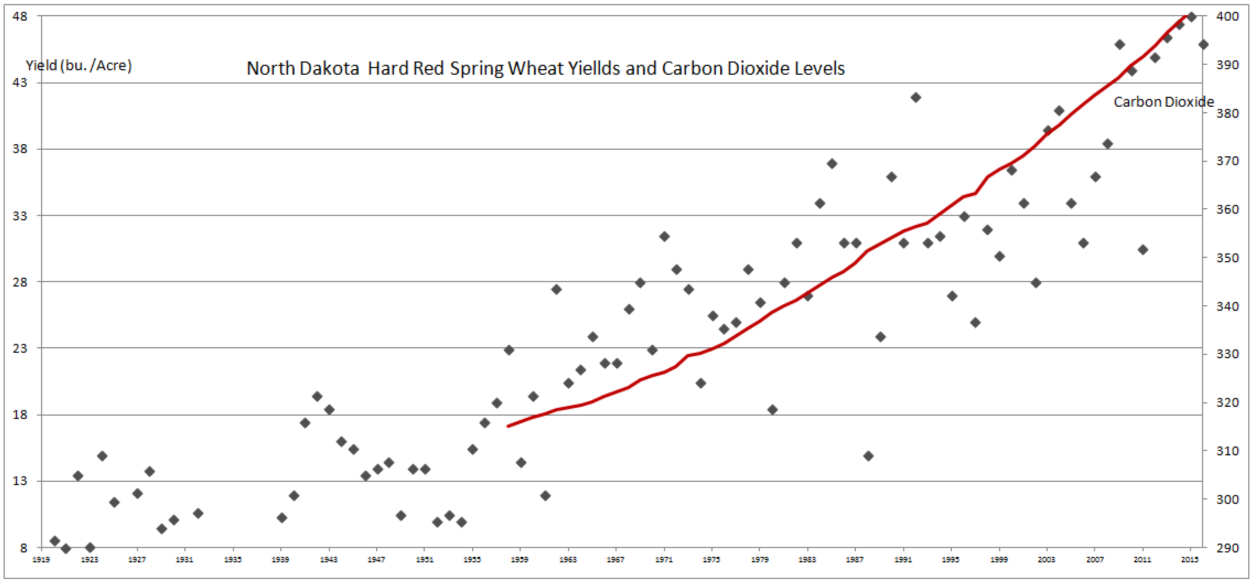

Figure 2. Source: *NASS* data base, *USDA*

The North Dakota wheat yield data extend back to 1919, and the carbon dioxide data from 1958. Most interesting is that the variation in the wheat yield data has come down substantially in the past 8 years or so, the specific period of time when climate change scientists have been complaining most loudly about rising carbon dioxide levels (Figure 2). I see in this graph a combination of more nearly steady rainfall amounts in recent years along with a gradually increasing growing season, allowing for earlier planting. And the wheat plants may be quickly adapting to the higher carbon dioxide levels and producing ever greater yields under adequate and better rainfall amounts as a consequence.

The Indiana corn yield data extends all the way back to 1866, and trace out three distinct periods. A long period of nearly stable yields extending from 1866 to about 1940, a period of somewhat rising corn yields extending from the 1940s through about 1960. This includes the period of time when farmers were rapidly moving toward hybrid corn and that is probably the major reason for the yield increases over that period. Then a third period, starting about 1960, when corn yields started increasing at a much more rapid rate. Interestingly, this period of rapid yield increases corresponds almost exactly to the period of time that has been identified with industrialization the rise in the burning of fossil fuels. Corn plants take advantage of the increasingly favorable carbon dioxide levels even as the average weather conditions warm (Figure 3). The dots represent annual Indiana corn yields and the solid line the carbon dioxide level as measured at Mauna Loa 1958-2015.

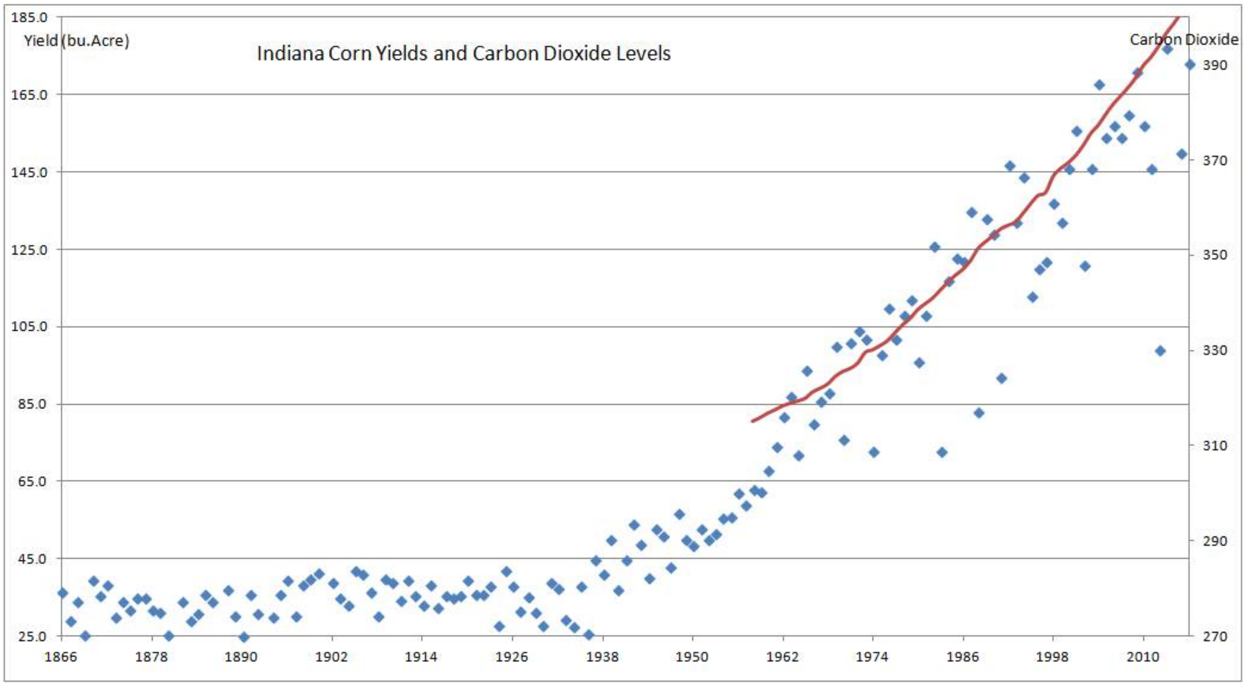

Figure 3. Source: *NASS* data base, *USDA*

My best estimate is that at least 20 percent of farm level productivity gains (and perhaps as much as 40 percent of the gains) can be linked directly or indirectly to gradually-rising atmospheric carbon dioxide levels. This would mean that still the largest share of farm-level productivity gains over time are unrelated to atmospheric carbon dioxide (60-80 percent), but mainly the good work of public and private agricultural scientists. Whatever the number, rising atmospheric carbon dioxide is clearly critical.

I conclude that the important role that atmospheric carbon dioxide plays in increasing farm-level productivity for the reasons cited in this paper can no longer be ignored in relation to the development of legislation and environmental regulations, particularly related to efforts directed toward limiting atmospheric carbon dioxide levels. Any new law or regulation needs to account for the potential adverse impacts on the farm-level productivity of agriculture and, ultimately, the food supply, both in the US as well as in the other important farming regions worldwide.

Climate-science policy has largely been driven by the idea that any warming of the earth's temperature was bad, that the increased burning of fossil fuels was the primary reason for the increasing atmospheric carbon dioxide levels, and that this was the premier if not the only reason that the earth was warming. There are enough people already critical of these conclusions that I do not feel compelled to add my own views to that criticism. However the direct and indirect effects of rising carbon dioxide levels on plant growth, rainfall and the length of the growing season, each leading to *increased* agricultural productivity have *been completely ignored* by the climate scientists.

My interest from a policy perspective is different. Given my understanding of plant physiology, I get agitated every time I hear the *EPA* refer to carbon dioxide as a harmful pollutant. In effect this characterization of carbon dioxide is itself a basic denial of the validity of the botanical sciences and a denial of the well-understood role that carbon dioxide plays in photosynthesis and the growth of plants. ***How can minute atmospheric levels of a harmful pollutant possibly also be the very molecule responsible for the life on earth as we know it, including human beings?*** It seems to me that the real science deniers are either employed by the *EPA* or by the *IPCC*!

This also suggests that it is important for the *EPA* to *not promulgate environmental regulations in any form without first doing a thorough benefit/cost analysis of each new regulation*. ***In the case of regulations that claim to reduce carbon dioxide emissions, drastic increases in costs to consumers need to be measured against the increased benefits to farmers and consumers of increasing food production for all of us.*** Too, the carbon dioxide arising from the burning of fossil fuels has probably been an important factor raising farm-level productivity to the point whereby ***world hunger is less than it would have been in the absence of the extra carbon dioxide emissions*.**

The climate scientists have been railing as to how the rising global temperature will adversely affect agricultural production worldwide. As a production economist looking at an array of agricultural data, I see no evidence of that whatsoever. ***Indeed, I conclude quite the opposite.***

Finally, consider that 2016 is supposed to have been the warmest year on record according to many climate scientists. Yet the U.S. corn producers, growing corn that thrived in the slightly warmer and wetter conditions coupled with the ready availability of atmospheric carbon dioxide, somehow produced a bumper-level crop of corn. Farmers are complaining that the harvest was so good that prices are way below profitable levels. Atmospheric carbon dioxide from the burning of fossil fuels directly and indirectly played an important role in why this all happened. Much the same was true in 2016 for many other field crops outside the Corn Belt and worldwide.

The result is that many basic food items at the grocery store are very cheap right now. Beef and Pork are cheaper than many fresh fruits and vegetables on a per pound basis. ***As you eat your next meal, consider that what you are eating is the carbon from the carbon dioxide that arose from the burning of fossil fuels, along with some of the water that started out as water from melting sea ice, went into the atmosphere as moisture, and then rained down of the great agricultural regions of the world!***

Executive Summary

The Role of Carbon Dioxide in Increasing Food Production and the Productivity of Agriculture for the US and Worldwide

Climate scientists have long warned that global warming, even if by only a few degrees, would play global havoc, with devastating negative impacts on the entire planet. In the climate science world, there are no positive impacts of a temperature increase, only negatives. Climate scientists frequently blame global warming almost entirely on the steady increase in the use of fossil fuels by human beings as the world becomes ever more and more industrialized. Climate scientists generally believe that drastic and costly steps must immediately be taken to curb the burning of fossil fuels in an effort to reduce the pace of global warming, even if these drastic measures have only a minimal impact on atmospheric carbon dioxide levels, if at all.

This paper takes an entirely different view grounded in both plant science and agricultural production economics. This has been largely if not entirely ignored by the climate scientists. The scientific basis is grounded both in agricultural production economics and the basics of plant physiology. ***The conclusion I reach states that to the extent the planet is warming, while there may be some measurable and reasonable costs, the same warming undeniably generates large benefits to agriculture. These benefits accrue to farmers and consumers.*** Farmers operating in the Northern Plains states have been and continue to be major beneficiaries. ***These benefits include not only the direct impacts of the carbon dioxide on plant growth, but also benefits such as increased rainfall associated with greater cloud cover, longer growing seasons allowing a larger diversity of high-value species to be grown, more lush pasture growth for livestock and warmer winters that allow more fall-planted and high-yielding plant such as winter wheats to thrive.***

The agriculture in states less prone to drought may also greatly benefit. Even slightly warmer and wetter conditions result in earlier planting dates, enabling a crop such as field corn to yield better than it would have without climate change, permit double cropping over a wider area and so on. A long list of climate change benefits to production agriculture have been ignored by climate scientists. A slight warming of the earth increases the productivity of agriculture and increases the food supply in the U.S. and worldwide. Indeed, this past growing season, was claimed by climate scientists to be one of the if not the warmest on record also generated near-record and even record corn yields for many farmers.

This warm weather the summer of 2016 was accompanied by generous rainfall in most agricultural areas of the US and a bumper crop for corn and other grains, leading an oversupply of many commodities and farmers claiming that as a result agricultural prices have dropped to unacceptably-low levels. The prices of basic food items at the grocery store are really cheap right now, but especially pork, chicken and grain-based food items such as breakfast cereals. The pork and chicken is being produced using a lot of cheap corn from the bumper harvest as the main feed. Even now, consumers are benefiting from the increased agricultural production in 2016 directly and indirectly linked to the warmer, wetter growing seasons in many states.

The anti-climate change lobby, loudly proclaiming that anyone who disputes their conclusions is a science-denier and calling any critics of climate change science as stupid-and-ignorant fools,

conveniently ignore the specific aspects of science that might potentially call into question any aspect of their anti-fossil fuel policy narrative. The *EPA* is in the middle of the controversy, labeling life-giving carbon dioxide as a *harmful pollutant*. Any plant physiologist will immediately tell you that not only is carbon dioxide definitely not a harmful pollutant, but carbon dioxide is required for photosynthesis. ***It is incomprehensible for the EPA to label carbon dioxide as just another industrial pollutant and then ignore the fact that carbon dioxide is essential to plant growth and ultimately all life on earth***. The *EPA* also conveniently ignores the any positive impact that increased carbon dioxide levels have on agricultural production, either direct or indirect.

An important mystery that the climate scientists seem unable to resolve is the issue of if industry has been spewing out ever-increasing amounts of carbon dioxide and the Arctic and Antarctic ice is melting into the ocean at a very high rate, this should be leading to a rapid rise in the oceans, but in particular the ocean along the Atlantic coast seaboard. Indeed, *NOAA* has published maps suggesting that much of the Florida peninsula will soon be underwater if we keep burning fossil fuels like we have in the past. Still, there is little evidence of a rise in the sea level because of global warming that has already occurred. According to many (if not most) climate scientists, this should have already happened!

The basic answer to this puzzle is right in front of the climate scientists. The climate scientist's methodology that links global warming to the increased burning of fossil fuels also argues that the increased carbon dioxide level leads to increased cloud cover which, in turn, holds in more heat from the sun. This indirect impact of more cloud cover ultimately leads to a rise in global surface temperatures. Conveniently ignored in this so-called "indisputable and settled science" is that if there is increased cloud cover, and the amount of water on earth is fixed, then moisture-laden clouds would normally form over the vast oceans to contain some of the moisture.

These clouds soon move over the great land masses of the world, dropping their moisture. This moisture usually precipitates as rainfall. Therefore, some of the rainfall that fell on the corn field of an Indiana or North Dakota corn producer, moisture that raised the farm-level field corn yield, probably started as melted sea water from the polar cap. This same water ended up as part of a corn plant and *not* as flood waters adversely impacting an expensive coastal property!

The real estate market for expensive coastal properties provides another illustration. Interestingly, the liberal-minded and wealthy individuals largely are the market-makers for these properties. They see their similarly-concerned neighbors as the good and socially-conscious people, but most of the people living in the vast center of the country as villains in climate change who are both naïve of climate science and socially irresponsible.

Yet, even these wealthy coastal property dwellers frequently make decisions and otherwise behave in ways inconsistent with their own values. If these expensive beachfront properties were in imminent danger of becoming permanently underwater because of flooding by seawater attributable to climate change, once high six-figure and seven-figure prices for these properties would be drastically reduced, as property owners feel compelled to retreat to relocate to higher ground less prone to coastal flooding from the seawater rise. After all, a house worth a million dollars or more cannot be worth nearly that if, in only five or ten years it will be permanently underwater. Remember, the coastal property owners who rail against climate change and believe that the people living in the middle of the US are the ones who need to bear the bulk of the costs for reducing fossil fuel use and reducing atmospheric carbon dioxide in part to protect their valuable real estate from recurrent temporary or permanent coastal flooding

Yet, life goes on in these high-end coastal areas, with seemingly little if any real concern for the possibility that the properties only a little above sea level will soon be permanently underwater, and the real estate markets in places such as Wilmington Beach, North Carolina, are not being discounted for this possibility at all!

A few climate scientists are beginning to recognize that the great land masses of the world act much like a giant sponge for any excess seawater from polar-ice melting, water which frequently becomes more rainfall on an otherwise parched agricultural area. This additional rainfall induced by climate change frequently greatly benefits not harms farmers and increases not decreases agricultural production.

The climate scientists apparently once thought that the water from this icecap melting-induced rainfall would quickly enter the streams and rivers and then soon make its way back to the oceans, raising the sea level. Instead, the global land mass is doing a good job of *sequestering* the additional water from the rainfall. Some of this water remains in the upper soil levels and is quickly taken up by plants that flourish in part because of the extra moisture. Some of the rainfall may go deep underground and help rebuild aquifers. Aquifers commonly are the water source for agricultural irrigation. The water thus taken up by all kinds of plants does not raise the coastal sea level!

As you sit down to your dinner table, consider that the food that you are eating is made up primarily of water and carbon-containing molecules. Some of the water in your meal may have first been from melted glacial or polar ice. Some of the carbon that makes up the organic materials found in all foods may have only recently been part of the exhaust from a coal-fired electric power plant.

The cost of the items in your meal is low in part because of the direct and indirect positive impacts of climate change. The *EPA* needs to stop issuing regulations to curb carbon dioxide emission without first measuring the benefits to food production—regulations that in the past have assume there are no positive impacts from climate change. Agricultural production directly and indirectly benefits greatly from increasing carbon dioxide levels. These benefits need to be measured in a standard Benefit/Cost framework, and weighed against any direct and indirect costs from the increased carbon dioxide emissions, not simply ignored as the *EPA* has been prone to do for years. The food supply not only for the US but for the entire world is the ultimate beneficiary. There is less world hunger in part because the use of fossil fuels has increased as the developed world has industrialized. ***Efforts to reduce carbon dioxide emissions via EPA regulations, if successful, could jeopardize the rate of growth in agricultural productivity in the US and worldwide, and lead not only to higher prices for food in the US and around the world, but also mean that such a misguided-and drastic regulatory policy could easily lead to increased world hunger!***

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David L.Debertin is Professor of Agricultural Economics at the University of Kentucky, Lexington, Kentucky. He retired after a career at UK that spanned 39 years, from 1974 through 2013. He was raised on a farm in northwest North Dakota located five miles west of Parshall, in what is now in the heart of what is known as the "Parshall field" within the Bakken. He attended elementary school for the first five years in a one-room rural school just a mile south of the farm. After that, schools were consolidated, and he continued his education at Parshall, graduating from Parshall High School in 1965. He then went to college at North Dakota State University in Fargo, ND, and graduated ranked number 1 in his senior class of approximately 1,200 students (*summa cum laude*), receiving a BS degree in agriculture with dual majors in agronomy (science option) and agricultural economics. He received a (competitive) Phi Kappa Phi fellowship to pursue graduate studies in agricultural economics, first an MS degree from NDSU in 1970, and then a PhD in agricultural economics from Purdue University, West Lafayette, Indiana, completed in 1973.

David was employed as a full-time faculty member in the Department of Agricultural Economics at the University of Kentucky (Lexington, Kentucky), first as an assistant professor (1974-76), associate professor (1976-79) and professor (1979-present) moving from assistant professor to professor in less than 6 years from the completion of the Purdue PhD. He has conducted research spanning a large array of issues relating specifically to agricultural production economics, public policy and rural economic development. His best-known work is probably the college textbook *Agricultural Production Economics* first published by Macmillan in 1986. The 1986 book has undergone many updates and additions, and is currently available in printed form from any bookstore, but the most recent version is also available online as a free pdf download. This book continues to be extensively read and used as a textbook not only in the US but in nearly every country offering programs in agricultural and applied economics. Many other writings written as academic journal articles or are also readily available as downloads either free at http://ageconsearch.umn.edu (98 separate publications at that location) or at other sites such as jstor.com (several hundred listed publications written or cited by in jstor) that store academic research digitally for access by researchers and students at university libraries. Simply Google "agricultural production economics" and the first link that will come up is a link for a free download of the Debertin book!

Since retirement, David has continued to write, focusing on issues relating to the linkages between agricultural productivity and specifically the usually positive role that carbon dioxide has in increasing food production in the US world-wide. He continues to maintain a residence in Lexington Kentucky only a short distance from the University of Kentucky agricultural economics department, a home in Plaza North Dakota as well as to the farmland he grew up on west of Parshall, North Dakota that he now owns and is underlain with many laterals from Bakken wells drilled between 2008 and 2014.