Argentine Desertification Assessment: Land Degradation through Agriculture

By

Mary Pukenis

An Undergraduate Thesis Submitted in Partial Fulfillment of
Bachelor of Arts
In
Environmental Science: Conservation and Ecology

Department of Environmental Science
Carthage College
Kenosha, WI
May 2015
TABLE OF CONTENTS

LIST OF FIGURES........................................................................................................ 3

LIST OF ABBREVIATIONS................................................................................................ 4

CHAPTER

1. ABSTRACT.................................................................................................................. 5

2. INTRODUCTION
   2.1. Thesis Statement................................................................................................. 6

3. LITERATURE REVIEW
   3.1. Desertification................................................................................................... 7
   3.2. The Evolution of the Land.................................................................................. 8
   3.3. Rising Food Demand........................................................................................ 10
   3.4. Argentina: Breadbasket of the World............................................................... 11
   3.5. Productivity and Progress.................................................................................. 12
   3.6. Crop Agronomy.................................................................................................. 13

4. METHODS.................................................................................................................. 16

5. RESULTS.................................................................................................................... 18
   5.1. Statistical Analysis............................................................................................ 18
   5.2. Graphical Analysis............................................................................................ 19

6. DISCUSSION............................................................................................................... 23
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Argentina soybean planted area since mid-1970s</td>
<td>10</td>
</tr>
<tr>
<td>Figure 2</td>
<td>A visual description of yield</td>
<td>16</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Map of focus area with soil overlay</td>
<td>17</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Yield Estimations from 1969-2013 (using CERES models)</td>
<td>20</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Graphical depiction of Argentine maize yield gap</td>
<td>21</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Graphical depiction of Argentine wheat yield gap</td>
<td>22</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Graphical depiction of Argentine soy yield gap</td>
<td>23</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>CERES</td>
<td>Crop Environment REsource Synthesis</td>
<td></td>
</tr>
<tr>
<td>GDP</td>
<td>Growth Domestic Product</td>
<td></td>
</tr>
<tr>
<td>GMO</td>
<td>Genetically Modified Organism</td>
<td></td>
</tr>
<tr>
<td>GYGA</td>
<td>Global Yield Gap Atlas</td>
<td></td>
</tr>
<tr>
<td>GYGA-ED</td>
<td>Global Yield Gap Atlas Extrapolation Domain</td>
<td></td>
</tr>
<tr>
<td>IUCN</td>
<td>International Union for Conservation of Nature</td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>Parent Materials</td>
<td></td>
</tr>
<tr>
<td>OM</td>
<td>Organic Materials</td>
<td></td>
</tr>
<tr>
<td>RWA</td>
<td>Reference Weather Stations</td>
<td></td>
</tr>
<tr>
<td>SIIA</td>
<td>Sistema Integrado de Información Agropecuaria</td>
<td></td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
<td></td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
<td></td>
</tr>
<tr>
<td>UNCCD</td>
<td>United Nations Convention to Combat Desertification</td>
<td></td>
</tr>
<tr>
<td>UNCOD</td>
<td>United Nations Convention on Desertification</td>
<td></td>
</tr>
</tbody>
</table>
1. Abstract

Farming is the center of civilization, and the implementation of tools first achieved in Mesopotamia five thousand years ago was the beginning of it. One of consequences of such advanced technology is that the earth is not a continuously recyclable resource, and without proper management the land becomes degraded. This eventually can lead to the condition of desertification, after becoming aridified by the combined changes in climate that is occurring around the world and anthropogenic action. This is an investigation into whether the only sub-humid region in Argentina has become less productive with the increased global demand for the grains it produces. This is determined from a yield gap assessment using data provided by the Global Yield Gap Atlas (GYGA) group and Sistema Integrado de Información Agropecuaria (SIIA). Yield gap being defined as the difference between the water limited yield potential and the actual yield collected from that site in tons. From the results over a six year period from 2006-2012, the yield data does not show a significant trend overall, with no significant relationship between yield gap and time. In conclusion, from the limited analysis it will be assumed that the land is not degrading currently but more variables and a longer study period would be necessary to make a more complete judgment.

2. Introduction

Farming is the center of civilization, and the implementation of tools first achieved in Mesopotamia five thousand years ago was the beginning of it. Throughout history, the workers of the land are almost forgotten but are key elements of imperial success. This can be seen in the North winning the American Civil War and the defeat of the Russians in World War I. Settlement of the land would not be possible without the use of technology to provide large enough harvests and storage to last winter seasons. This advanced use of the land also contains a price, the land is only able to maintain so much life at its surface, and is only able to rejuvenate itself with time. As is commonly said, the land is a precious resource. Throughout the world this is becoming a larger issue with now increased land degradation and aridification of the land leading into desertification.
This project is an investigation to determine if desertification is occurring in the most prosperous and most intensively farmed region of Argentina located in the Buenos Aires-Pampas region. Located in South America, Argentina is one of the largest semi-arid regions in the world. It was chosen to be used as a case study in identifying and learning more about desertification conducted by the United Nations Convention to Combat Desertification (UNCCD) that was recently finished in 2009. Almost the entire country, approximately ¾, is degraded and or naturally arid except for a humid region located near Uruguay. This humid region called the Pampas is an ecoregion that was once more similar to the ancient tall grass prairies in the United States and now contains the highest population density in Argentina (Asner 2003). With a great portion of its land mass within Buenos Aires province, this is where the majority of agricultural products are grown. There have been major changes of the climate of this region such as increased precipitation and longer growing seasons which has been linked to global climate change (Davies 2013; Viglizzo et al. 2011). It is thus expected that climate will have an impact on the crop productivity, and that due to a large increase in areas being cleared for agriculture and the recent change of policies within the last decade that there will be increased degradation beyond natural changes occurring. The amount of degradation is being determined by using yield gap assessments of the three most productive and commonly grown crops in the region: corn, soy, and wheat. Argentina is the number one exporter of soybean products and the fourth largest exporter of raw soy. The large amounts of soy products being produced in the region has only occurred in the last 30 years. It also is a global player in the production of corn and wheat. Corn and soy are more massively produced because of the change in the use of GMOs (genetically modified organism) by farmers throughout the country. Yield gap’s technical definition in this project is the difference between the actual yield produced (harvest) by any crop and the predicted yield under water limited conditions. This assumes that the actual yield is the highest possible amount possible to be harvested based on soil conditions, climate, growing degree days, evapotranspiration, nutrient availability etc. It predicted that in this project that there will be an overall trend of increasing negativity of yield gap.

3. Literature Review

To explain what exactly is being implied by using yield gap values as an indicator of land productivity and thus the healthiness of the system, a background of desertification, the creation of soils,
global food demand, the socio-political background of Argentina, and the agronomy of the crops in this study, corn, soy, and wheat will be presented.

Desertification

As an ecological condition, desertification affects every continent on the globe with current statistics suggesting that 35% of land is at risk of becoming desert. The most sensitive to climatic change, arid regions, are defined as having less precipitation than humid regions (having an average rainfall of less than 10 inches or 250mm per year) but this does not necessarily make them deserts (Maliva 2012) at least in the most stereotypical sense. These areas contain 850 million people or about 1 in 3 people on earth are directly affected by this change in the land (Murphy 2011). The United Nations Convention to Combat Desertification (UNCCD) defines desertification as “land degradation in arid, semi-arid, and dry sub-humid areas resulting in various factors, including climatic variations and human activities. Land degradation is in turn defined as the reduction or loss of the biological or economic productivity of drylands” (MEA 2005). UNCCD is a convention that was established in 1974 as a response to a catastrophic famine in the Sahara region of Africa due to a persistent drought throughout the late 60s. Almost immediately after the initial research for the first conference, the scientists and the data to support taking action in many regions has almost disappeared (Thomas 1994; Bauer 2009). Due the expansive duties, and the number of committees tasked with the investigation of desertification and other climatic issues the original goals and concept of the conference has been lost. In general it has been felt that, “Science has been left the scapegoat of the unsuccesfulness of the prior conference that began the plan from 1977-2000” where real progress has been stalled by the political campaigns of individual groups (Bauer 2009). Today the issue has evolved with the establishment of this decade (from 2010-2020) as the focus of the UN to mitigate and educate people about desertification and its causes.

This is an expansive field due to no singular symptom is able to be accessed as a cause, it is a global phenomenon with local conditions that make each case of this type of land degradation unique. Desertification is what these types of projects use projections in the hopes of avoiding rapid land degradation. From personal experience, understanding the context of soil and what it is made of, and the development of it was an important factor in thinking about desertification.
The Evolution of the Land

The changing of the land into a more arid region is natural but the process of desertification is not because even the change in climate during the recent millennia has been artificially altered. Naturally areas become more arid over time due to conditions such as having consistent high atmospheric pressure, being located in a mountain’s rainshadow, being near cold ocean currents, and/or continentality causes by continental winds. Air masses rise from the equator when they become warmer due to the loss in water molecules when it rains. As they continue to rise they continue to spread over the earth’s surface losing precipitation along the way, resulting in the rainforest conditions between latitudes of 15 degrees north or south of the equator (0 degrees). The air that is brought from the equator is so warm and dry that it does not allow for the formation of new rainclouds resulting in very low amount of precipitation between latitudes of 15 degrees and 30 degrees north or south of the equator. An example of this loss of moisture can be seen in the desert region of the Sahara in northern Africa.

One of the largest contributing factors to soil loss is erosion. Water moves freely cutting through land forms to get to the destination of the largest body of water possible. It is much easier for rivers to create new paths, and for flooded regions to push soils aside when there are not root systems in place to hold the soil. This is becoming a major issue throughout the agricultural sector in climates that experience seasonality. It is common not to use cover crops which has detrimental effects such as large amounts of soil are carried down river when there are heavy rains and when these areas dry up cause soil to be blown away by the wind.

Understanding the land and what it is made of is one of the first steps in analyzing productivity of the things that are grown from it. Soil, being defined as a having horizons, or having differentiating layers between the parent material and the surface, as well as being able to support rooted plants in a natural environment (USNRCS 1999). The soil is like water, hosting large amount of microbial life forms that if they are not able to function normally in their ecosystem, the soil could become entirely functionless. The percolation of rainfall and the movement of groundwater, as well as, the organisms in the soil (such as nitrogen loving bacteria) that cycle nutrients breakdown parent materials (PM) in the lowest horizons of the soil overtime. Parent materials are rock formations that were created under extreme pressure and heat millions...
of year ago; some of this is volcanic for example. Statistically it can take over 500 years for 2.5cm of soil to form from this process which would approximately fill half a coffee mug in terms of depth for a single area (FAO Land Degredation 1993; USNRCS 1999; IFAD 2009). The soil then settles into layers called soil horizons that separate the different types of soil textures into sections built overtime. Organic matter (OM) consists of decaying plants and animals which is the surface layer of the majority of soils called the O horizon. This is an extremely important part of soil formation and functionality because OM allows more precipitation to be absorbed as well as adding nutrients back into the soil (which regenerates it). After the O horizon, as depth increases, more and more of the original bedrock or PM is present. The hard bedrock in layers C, and R and not affected very much by the actions of the surface and only begin to degrade ‘quickly’ once large portions of the other layers begin to disappear which is the case in arid regions (USNRCS 1999). The major soil types in the Pampas are Mollisols and Vertisols. These are all categorized as well drained soils, that then to have lower soil moisture content. Mollisols have high calcium content due to the bedrock (PM) erosion occurring at a faster rate than other areas with the same PM. Many plant species are unable to use the calcium to help them grow, which decreases species biodiversity in the areas this occurs. Plants are then also unable to storm as many other nutrients that would help them grow because they have already absorbed so much excess calcium.

The land produces only so much as it is capable of based on the elements it is formed from. The world is becoming a place where technology is the key to survival and for many farmers exporting and selling the majority of their crops makes them the most money. Thus they need to be able to meet the rising demand of the market they are joining, which is only possible with technologies since using the simplest tools cannot match the demand. This is especially important for countries that have 10% of their economy’s gross domestic product (GDP) based on the success of their crops like Argentina.

Rising Food Demand

The need for farming to be more productive without expanding into more territory is growing, and is it calculated that harvest would to need to double in order to meet global needs by 2050 (Ray et al. 2013; Sanjani, Koocheki, and Nassiri Mahallati 2012; van Wart et al. 2013).
There are much larger uses for many of the cereals grown around the world such as biofuels, increased animal feed, sweeteners etc. This has caused a great increase in exportation of corn, and soy specifically over the past 30 years (Grau, Aide, and Gasparri 2005) which can be seen in Figure 4.

![Figure 1: Increased soy production since 1970 (Viglizzo et al. 2011)](image)

With this in mind, in order to be more productive, the soils and other climatic conditions have to improve or the plants themselves need to be adapted to the specific environments they are being grown in. To employ these techniques comes at a high cost monetarily but it can limit on the taxation on the environment, and it would lower the amount of habitat destruction because efficiency would be able to increase in regions already being used. This is highly dependent on the soil type that is present in the areas that are being used for the primary growth of these agricultural products. The soils themselves have limits that can be found in their amount of water it can hold and how quickly it percolates through the system. Agriculture causes a large strain on the environment and it takes away already limited resources such as minerals and nutrients that are key components for growth. Nitrogen (N) and phosphorus (P) are particularly limited as they come from sources that naturally take a long time to degrade. Phosphorus’s main source is [10]
bedrock that is located deep under the earth’s crust, and is brought up to the earth’s surface by the capillary effect when water moves through bedrock. Nitrogen is most plentiful in its gas form in the atmosphere and is one of the most commonly found gases in our atmosphere. Plants and the microorganisms in the soil cannot use the gas directly so, the bacteria that live in the soil metabolize it in their bodies and change the form of the gas into something usable for other organisms which is where the majority of applied nitrogen is from. These bacteria process much of this nitrogen from detritus (decaying OM). To increase soil productivity fertilizers, genetically modified (GM) crops, and single season monocropping is used in order to gain the highest yields of a single crop. This exhausts the soil beyond its limits which can lead to soil erosion, and water pollution (bioaccumulation, mutation of water organisms, algae blooms etc.) when these farming techniques are not used in moderation.

Argentina: Breadbasket of the World

It all began with the settlement of the European colonists and their desires in the expansion of the land. The Pampas the only sub-humid region in Argentina is home to large expanses of tall grass prairies that provided the fertility of the soils used for agriculture in this region today. This area is located at a latitude of 33 -35 S, and a longitude of 62 - 64 W, which covers about 60 million hectares (124 million acres) and is part of one of the largest prairies of the world. The soil type consisting majorly of Mollisols provides the storage of nutrients necessary for the intensive farming required. Agriculture is 10% of the growth domestic product (GDP) of Argentina’s economy, and is cultural baseline for the countries’ people as it is not subsidized. The country has 31 million hectares of land being used for agriculture with 13 million being used for the sole purpose of harvesting soybeans. The amount of soy, corn, and wheat produced and exported from this region is second only to the United States and 4th in the world. These plants are nutrient loving, and require land regeneration between growing seasons (Goodwin 1895). The management of these cereals is very extensive, and is overall more sustainable than the current model used in the United States. The use of fertilizers, pesticides, and herbicides increases as the overall middle class gains more funds but still is significantly less than that of the United States (Lavado and Taboada 2009; Austin, Piñeiro, and Gonzalez-Polo 2006; Schnepf, Dohlman, and Bolling 2001). They also have strict no-till policies throughout the country due to large amounts of soil erosion that occurred in 1980s causing a huge upset of the Argentine economy (Viglizzo et al. 2011). With
no-till being the technology applied, the soil will have more time to recover as it is not turned over every season to bring nutrients to the surface. These methods can occur because the land has generally been self sustaining for the past 100 years and has been able to create sufficient nitrogen and phosphorus naturally. The use of fertilizers is also not as effective in this region of the world, the soils do not keep hardly any of chemicals and are almost entirely excess (Lavado and Taboada 2009; Austin, Piñeiro, and Gonzalez-Polo 2006; Schnepf, Dohlman, and Bolling 2001). This may be due to also growing legumes between crops causing a greater negative net gain of nitrogen as well as potassium and phosphorus. Soy is also used as a double crop after wheat’s growing season to prevent soil erosion. This technique is growing in popularity as planting soy and wheat together at the same time is both profitable, and stabilizes the soil for future crops and seasonality. Overall, these techniques have allowed for Argentina to be nitrogen neutral since the year 2000 but this does not explain the entirety of the soils current condition.

To provide more background, some of the social and political history must be understood in the development of modern farming in the Pampas as well as the surrounding country. The European colonists displaced the indigenous people and constructed canals and other irrigation methods throughout areas that could not provide water sustainably (Abraham and Torres 2014). The immigrants also introduced several key domesticated species of cattle, and sheep that are still in use today. There also was an increase in many other European settlers at this time such as the Irish, and Italians that began herding sheep and expanding the most modern agricultural methods that has caused great amount of degradation throughout the country as well (Lewis 2001; Goodwin 1895). This has lead to a large increase in non native species being brought to the area where large mammals had not been introduced before (Rodriguez and Jacobo 2010; Medan et al. 2011; Bisigato and Laphitz 2009; Tadey and Peco 2006; Kerley and Whitford 2000). When the land was being taken under the name of protecting the public’s resources under the newly forming Argentina (as a formal nation) thousands of the indigenous people were killed in this military campaign lead by General Roca in 1878. The majority of the people were displaced to the more arid lands in Patagonia; located in the southern half of the country. This is why many of the local people are distrustful of the investigation of desert regions mostly due to terminology causing miscommunication (Solis 2002). “Desertification, drought, and declining agricultural yields are major drivers of poverty and hunger among these populations” (Mayrand, Paquin, and Dionne
Almost everything that is grown in the country is exported to foreign markets causing an increase in domestic products and economic success is completely dependent on the demand of the global economy (Kandell 2015; The Economist 2009, 2006).

**Productivity and Progress**

To compete in and accommodate the growing global market and the demand for food products traditional forms of agriculture cannot create the outputs necessary to support this venture. In the 1950’s Argentina began to specialize in a smaller range of crops and began growing: maize (corn), soya (soy), trigo (wheat), sunflower, and cotton almost exclusively throughout the country. Over 90% of the original grasslands have been converted to agriculture or cattle-raising (Medan et al. 2011). This led to a decrease in productivity in other fields of agriculture such as animal husbandry (cattle-raising and dairy farms), as well as the growth of crops purely used domestically. The economy of Argentina became solely dependent on the value of its exports to the global market. This has made it very sensitive to inflation and the eventual collapse of its economy in 2000-2001. Much of this was also been due to the acceptance and wide use of genetically modified (GM) crops that began to be issued in the 1990’s specifically corn and soy (Schnepf, Dohlman, and Bolling 2001). The crops became increasingly profitable economically with significantly higher yields than prior years, and have allowed the country to recover from its $65 million debt (Kandell 2015). The International Union for Conservation of Nature (IUCN)’s Global Drylands Initiative reported that this isn’t a sustainable option, “Quite a lot of degradation comes from farming practices considered to be the best option economically but actually are not – not even in the short term,”(King 2013) . With this in the mind, the health and productivity of the soil has decreased because of the higher tax on its resources these unnatural crops and herbicides induce. The GM crops are resistant to a specific herbicide called glyphosate created by the agrochemical and agricultural biotech firm Monsanto. This has led to complete dependency on the corporation to provide and to have seed that performs well, which limits the biodiversity of the crops causing increased risk of disease or pest damage. Officially the country is prosperous, with President Cristina Fernández de Kirchner creating longer lasting contracts with Monsanto as part of her Agribusiness Strategic Plan (PEA), despite growing discontent coming from working farmers (The Economist 2006; Kandell 2015; Davies 2013). This has caused the farmers to revolt politically and is currently winning party
votes in even the opposing working parties (Kandell 2015). This investigation focuses on the results that these actions have on productivity in numbers.

*Crop Agronomy:*

To better compare the different crops that are being investigated, maize, soy, and wheat, an understanding of their general agronomy and biological potential is needed. The plants’ general historical context, geological range, and cultural production will specifically be discussed. These crops are not only being compared because they are the highest produced crops in the region but many times are grown in a two year crop rotation where corn is grown first followed by wheat and then a final rejuvenating crop of double-crop soybeans and wheat is grown (Lee 2009). Wheat following soybean generally yields more than wheat following corn (Beuerlein, Lipps, and Lentz 2005; Lee 2009).

Maize is a tropical grass that is well adapted to many climates but originates from Mesoamerica. The scientific name for maize is *Zea* mays and it is commonly known as corn. Maize is one of the world’s most important cereal crops after rice and wheat, and because of increasing global demand for stock feed, especially as China develops a greater demand for meat, it is predicted that maize demand will continue to rise (Verheye; Belfield and Brown 2008; Yara). Maize is grown globally from 50°N to 40°S with optimum temperatures for maize growth ranging from 18 to 32 °C. Like soybean, maize is not drought tolerant. Nutrition is extremely important when growing a maize crop as it has a high demand for nutrients, which the soil cannot always provide. Maize yields vary a lot depending on the soil type where the crop is grown. Maize is also a demanding crop for phosphorus (P) and is quite sensitive to low P availability, especially in the early growth stages (Belfield and Brown 2008). If the farmer is growing hybrid seed it must not be harvested and kept for sowing the next season. This raises costs when seed has to be bought each season but due to Argentina law, seed is allowed to be kept for up to two seasons (Belfield and Brown 2008; Romig 2014).

The soybean (*Glycine max*) is a species of legume native to East Asia. Although classified as a bean, a soybean is actually an oilseed like the peanut. Soybeans are highly versatile, and the beans can be processed into oil, flour, and meal. Cultivated primarily in warm
and hot climates, soybeans were originally used as nitrogen fixers in early systems of crop rotation (Beuerlein and Dorrance 2005; Tiller 2007). Today soybean cultivation occupies more than half of Argentina's productive land (The Economist 2006). The proportion of genetically modified soybeans used under current farming practices has jumped from about 8% in 1997 to 89% by 2006 (Austin, Piñeiro, and Gonzalez-Polo 2006; Tiller 2007). Soybeans grow best in temperatures between 68 – 86 °F, and can grow in a wide range of soil types. Soybeans have the highest yields when grown in soils of pH between 6.0 - 6.5. Sulfur, phosphorus and potassium are some of the key nutrients that are usually added to the soil with fertilizers for soybean crops (Beuerlein and Dorrance 2005).

Wheat (Triticum spp.) is a cereal grain that originates from the Near East and it is currently the 3rd most produced crop in the world (Yara; Shewry 2009). Globally, wheat is the leading source of vegetable protein in human food, having a higher protein content than other major cereals, maize (corn) or rice. Wheat is most commonly ground into flour for use in the baking of breads; it is also eaten as a porridge-type cereal. A balanced inclusion of the thirteen common nutrients with increased importance on these eight: N, P, K, Mg, S, Mn, Cu, Zn is essential for the most productive growth of the plant (Yara; Beuerlein, Lipps, and Lentz 2005). Wheat thrives in temperate zones throughout the world where seeds are able to germinate at temperatures of 39°F or higher. Temperatures between 54° and 77°F are considered optimum for rapid germination and growth. Commonly wheat is grown in the winter and is often referred to as winter wheat. This is done because the plant has to focus more on reproducing which produces more of the grains that humans wish to harvest. At cooler temperatures wheat plants begin a phase called vernalization which is the process of changing from vegetative to reproductive growth. The main stem and leaves are smaller and less full in order for the plant to prepare for winter. This state has to be induced for a specific length of time and the temperatures needs to be below 50°F for best results (Lee 2009).

4. Methods

Agriculture one of the key components of the nation’s culture and economy was studied using yield gap as an assessment for land degradation and general soil quality. The larger the yield gap value, the less productive the land is which will suggest that it is not sustainably being
used on average. Due to the limitations of available data this analysis assumed large yield gap values generally represents and includes low nutrient/soil quality, less precipitation, less genetic diversity, low quality of seed, and a large variance in temperatures etc. or a combination of these factors that lead to this result. Yield gap being defined as the difference between the water limited yield potential and the actual yield collected from that site in tons. Thus it was assumed that the actual yield is the highest possible amount possible to be harvested based on soil conditions, climate, growing degree days, evapotranspiration, nutrient availability etc as can be seen in Figure 2.

![Figure 2: “A deficiency of any single nutrient is enough to limit yield” (Yara International ASA). The idea is that a full bucket is desired but if any part is weaker or limited, the water will come out, and the result will not be as robust.](image)

For the initial analysis, the three most productive crops, soy, wheat, and corn were studied by comparing the yields gap values of each crop:

\[ Y_G = Y_A - Y_W \]

(The yield gap equals the water limited yield potential subtracted by the actual yield)

The water limited yield potential was generated by using CERES for maize and wheat, CROPGRO for soy by the Global Yield Gap Atlas (GYGA) group. These long term climate models are a better representative for variations in temperature, solar radiation, and rainfall over time (van Wart et al. 2013). In order for precipitation limitations to be included in this data the GYGA group had 16 weather stations record their data which were located at the sites indicated on this map:
The 16 (15 for corn) reference weather stations (RWS) were chosen by the GYGA group due to these areas containing the highest concentrations of each crop growing there.

Two groups were created that categorize each province as either ‘wetter’ or ‘drier’ based on climate zone data calculated using the GYGA Extrapolation Domain (GYGA-ED).
ED is a hybrid approach that was created to have a “bottom-up” approach in determining location specific climate zones without being based on a grid system. To do this aridity, mean temperature, and growing season data was combined. The two groups (“more wet” and “more dry”) will be the collective average from 8 of the 12 provinces that plant maize, soybeans, and wheat, where 78, 81, and 70% of the crop land is represented (%s in order as listed) (Monzon 2013). These results will then be compared to the national average production for the years between 2006 and 2012. All the yield data is provided by the Sistema Integrado de Información Agropecuaria (SIIA) and the GYGA group.

A one-way analysis of covariance (ANCOVA) was used to determine the statistical significance of climate on the crops and determined if the crops are having similar yield gaps overall. This test was used to eliminate the influence of time as much as possible so that the yields can truly be comparable. ANCOVA is a combination of an ANOVA test and regresional analysis used on two or more groups that are being compared. The climate zone data will be tested as the independent variable and the yield gaps as dependent variables with a control of time. In addition to the regular ANCOVA test to see beyond if the means of the two climate groups were different, a post-hoc t test was applied to see how the crops differentiated from each other as well.

5. Results

Based on the analysis performed the data does not support my original hypothesis that the yield gaps would increase in negative value overtime. It was also found that climate was insignificant with the data sets sampled from for this analysis. The groups that were split into groups arbitrarily by climate zone number were assumed to be the same. There wasn’t a significant relationship found between yield gap and time either.

Statistical Analysis:

Climate is not significant in determining the yield gaps of the crops overtime F (1, 322) = 0.036, p = 0.849. This suggests that the climate was not varied between the two groups that were arbitrarily created and thus does not have a noticeable impact on the crop values differing. The pairwise comparison climate values changed after performing a post-hoc test indicating that some of the data could have properties that have biased the test. It was found that there was a
statistical significance between the three crops studied, $F(5,323) = 8.552, p = 0.000$ according to Laverne’s Test of Equality. In general it was found that the crops are not all the same, rejecting the null hypothesis that assumes them all to be the same. The crops themselves have significantly different yield gaps from one another except for the relationship between soy and wheat which was found to be insignificant using a Sidak comparison $F(2, 322) = 52.639, p = 0.00; p = 0.996$. To be more specific the wheat and soy crops were found to be the same with corn having different values, which allows the group to be statistically different overall but similar in individual comparison. There is also a noticeable variation between the pairwise comparisons of the crop data before and after applying a bootstrap post-hoc test. This would indicate that parts of this data could be biased for this version of the test as well.

**Graphical Analysis:**

It can be seen from Figures 3-6 that the variation between the regions productivity are not visually significant. The results also indicate that wheat has had the best performance in the last 5 years but soy has a more consistent crop. Corn is the most unstable as well as having the largest yield gap within this seven year period.

![Graph showing Argentine Crop Yield Estimations (1969-2013)](image)

**Figure 4: Yield Estimations from 1969-2013 (using CERES models). This shows the increased trend in crop production based on SIIA estimates in only the last 20 years.**

[19]
Unlike what the research suggests, corn has significantly larger yields than soy and wheat even though the majority of the land is planted with soy. This is another indication to show its uniqueness quantifiably than the other two crops which can be seen in the statistical analysis.

Maize or corn has some of the largest variation between its smallest to largest value of yield gap of the three crops studied. It also has the largest negative value of yield gap. Although no indicated trend overall, it appears that the productivity or the yield gaps had a very large increase in positive yield gap between the years of 2011-2012.

Figure 5: The averages of the maize yield gap (YG) data from the ‘drier’ region vs. the ‘wetter’ region vs. the national average. Timescale is from 2006-2012.

[20]
Wheat Regional Yield Gap Averages

Figure 6: The averages of the wheat yield gap (YG) data from the 'drier' region vs. the 'wetter' region vs. the national average. Timescale from 2006-2012.

Wheat is the only crop to have positive yield gap values. It also remains relatively neutral except during the period between the years 2010-2012. Instead of performing within ±3 tons per hectare during this time it increased +6.5 tons per hectare. It doubled its productivity in this 3 year span.
Figure 7: The averages of the soy yield gap (YG) data from the 'drier' region vs. the 'wetter' region vs. the national average. Timescale from 2006-2012.

Soy is the most neutral of all the crops remaining in the range of ±2 for the majority of the study period. It also has the most variation between the two climate groups and the national average at this scale. The period between 2010-2012 shows the largest positive increase in productivity (tons per hectare harvested) like the other two crops but does not show the drastically and sudden increase unlike the other crops.

6. Discussion

As was found in the results, the yield gaps that were found in this data do not support the conclusion that the land is current degrading. This is including the assumption that the yield gap values represent some of the variables that were not included in this investigation. Some of the variables include low nutrient/soil quality, less precipitation, less genetic diversity, low quality of seed, a large variance in temperatures. Some of the reasons that may explain why the yield gaps had no visible trend, and did not support the hypothesis of this project include nutrient availability being highly variable from season to season, less seasonal effects in this region, and that all the sites that were sampled were well maintained fields. The soil is almost a living thing and causes high variability even from month to month due to the organisms that use it live and
die changing the composition. The sample sites that were used in this study were in a humid climate which is stable and has precipitation year round. This type of environment allows for changes in the soil to be a very slow process or much slower than those in desert or arid climates. There was not information provides from farmers about how they keep their farms or the size so these could be well established and maintained systems where degradation is less likely to occur.

From the design perspective of this project, in order to have a more controlled experiment, a much longer study period would have to be used to better estimate the influence of climate overtime, and for the highly variable soil quality to be constant. This is the type of research that could take a whole life time, especially if many of the economic and political motivations for some of these changes were also investigated more closely. Sadly, the resources to make this possible are not currently available at an undergraduate level of study located outside the intended focus area. Overall, what is discussed in this paper can lead to a more focused approach on variables, and which variables in particular have the most impact on determined “productivity”. It can also open doors to the investigation of areas that appear to be constant and unchanging in terms of a human life time, but over a much longer period of time this could be more varied.

In a larger awareness of what was being tested, some of the results can be explained to why they were or were not significant statistically. For example, the fact that there was no distinction found amongst the two climate groups that were created was because the split was arbitrary and that the number were rather similar to each other only ranging from a continuum of 5502-7402 where a majority of the numbers were in the middle range. As can be seen in Figure 3, the RWS all are in the range of similar soils, and in the same climate region. Although it had been desired to find data for regions outside of this sub-humid zone that was not possible.

Another discussion point from the data is the significance from maze and the other two crops. Maize has the highest yield of all the crops as can been seen in Figure 4, and also has some of the largest variation from year to year of the three crops. It also is most commonly grown on its own as a monocrop, and as a plant takes up much larger quantities of nutrients from the soil to support its high yields. All these factors may have led to the significance of corn whilst soy and wheat are grown together often as a drop crop. Since soy is a legume it provides N back into to the soil and maintains some of the quality that is lost during former seasons growing the other
crops. This also links to the neutrality that can be seen in the yield gap values depicted in Figure 7. These consistent yields can also be due to the mechanical nature of major food production that exists in the country. As one of the largest producers for all its main crops many human factors are eliminated. It would also partially explain why there were no significant trends or relationships found in the data between time and the yield gap values.

There have been no other experiments like this trying to compare agricultural productivity with the specific type of land degradation of desertification. Although small parts of other reports mention the effects that this has on the overall management of ecosystems. To make this topic more relevant to compare with other cases would be to pick more specific factors and study how yield gap affects them or what could change the yield overtime. This could have results that could be paired with reports made in the late 80s and early 90s (Viglizzo 1989).

One of the factors that were desired to be focused on the most was agriculture specifically animal husbandry in the other regions of Argentina where real time land degradation has been occurring for some time. It is one of the reasons that there has been so much bloodshed. In the attempt of some to remove the more impoverished people more and more from this rich farming region, the Pampas. It would have been very interesting to discuss more in detail how the international community, has influenced changes in the global market, and caused greater degradation globally because there is a lack of global policy about this issue, the condition of desertification. It is almost a myth in that it is a concept so large that it really cannot truly be proven, and that many of its causes are highly plausible correlations at best. Just like climate change, it is generally agreed upon that it is a condition and we as people of the international community need to work on turning this whole thing around. The UN’s subcommittee and convention, the UNCCD, had hoped to eliminate desertification by the year 2000 when it established itself in 1969. Yet it persists onward to this day, 50 years from the tragedy that inspired the UN to act. In 2010, the UN declared that this is the decade to battle desertification. There has been a growing amount of reports that indicate education about land degradation and desertification is helping to alleviate poverty in arid areas of the world.


Beuerlein, Dr. Jim, Dr. Pat Lipps, and Dr. Ed Lentz. 2005. Small Grain Production. In *Ohio Agronomy Guide: The Ohio State University*.


Lavado, R. S., and M. A. Taboada. 2009. The Argentinean Pampas: A key region with a negative nutrient balance and soil degradation needs better nutrient management and conservation programs to sustain its future viability as a world agroresource. *JOURNAL OF SOIL AND WATER CONSERVATION -USA* 64 (5):150A-153A.


Malina, Robert Missimer T. M. 2012. Arid lands water evaluation and management.


Murphy, Jessica A. 2011. Sand dunes conservation, types, and desertification.


Tiller, Alex. 2007. *An Introduction to Soybeans*.


Yara. *Winter Wheat*. Yara International ASA.