

**THE FUTURE OF AGRICULTURE: HOW NEW WINE TECHNOLOGY AND
PRODUCTION METHODS ARE CHANGING THE FOOD PRODUCTION
LANDSCAPE**

Carlos Ernesto Vadillo Rodriguez

The Lauder Institute, University of Pennsylvania

A RESEARCH PAPER

Presented to the Faculties of the University of Pennsylvania in Partial
Fulfillment of the Requirement for the Master of Arts

April 2015

Faculty Advisor: Dr. Mauro Guillen

TABLE OF CONTENTS

Abstract	1
The Current Problem with Agriculture	2
Improving Agriculture	9
Development of Agricultural Technology in the 21st Century	10
Agglomeration Economies and their Technology	10
Wineries as a Hotbed for Innovation	14
A Prediction of Human Innovation and Perseverance	22
Bibliography	25

ABSTRACT

This paper will examine the role of technology and climate change on agricultural production methods and changes in the 20th and 21st century. Agriculture has been the cornerstone of civilization since the shift occurred from hunters and gatherers to agrarian societies. But relying on agriculture, civilizations throughout history have grown, flourished, and ran into problems. Each new civilization has been tested, and often times bested by Mother Nature, before human ingenuity has developed methods for continuing agrarian growth. With the arrival of the 20th and 21st century, along with industrialization, agricultural growth has grown exponentially. Society is currently able to produce higher quality food with fewer resources; yet, resources are still strained in many regions around the world. To explore the future of agriculture, it is imperative to understand the current global demands for food in the world and understand how agriculture is developing new technology to meet those needs. Additionally, it is important to understand how changing weather patterns will continue to create challenges to food producers and what food producers are doing in order to bridge the gaps between production and demand. Technology and new growth procedures are going to affect the way food is produced in the future and will undoubtedly have a role in shaping the way people 20 years from now grow and consume food. The world has a fixed number of resources that can be utilized to produce food and human population will continue to grow, it is estimated that the global population will reach 9.6 billion by the year 2050. As technology becomes cheaper and easier to utilize, it will help previously malnourished demographics gain access to cheaper and healthier food and will undoubtedly rise to the occasion and change the agricultural landscape by the year 2050.

THE CURRENT PROBLEM WITH AGRICULTURE

Thomas Malthus was the first political economist to delve into the world of food production and distribution. In his work *An Essay on the Principle of Population*, Malthus proposed that if population growth continued without hindrance, famine and disease could ultimately develop and create a Malthusian catastrophe, or the rapid contraction of a population due to resource scarcity. Malthus correctly understood that population growth is strictly controlled by resource scarcity and that populations increase when those resources are transcended—through production, or in this case, technology. However, Malthus was unable to see the future and understand how shifts in production frontiers could continue to incrementally increase food production. Malthus's importance in the field of agriculture is important specifically because if technology does not continually push food production into new production frontiers, a Malthusian catastrophe could potentially manifest itself in the near future.

Malthus would surely be surprised if he knew that as of December 2014, the International Food Policy Institute (IFPI) estimated that the world is home to over 570 million¹ farms. Incidentally, the geographic distribution of farms is not equal across the world as about three-quarters of the world's farms are located in Asia, and 60 percent² of these are located in China and India. From a Malthusian perspective it is important to analyze and interpret the current agricultural landscape in order to understand how technology can change global food production, and performance. According to the IFPI, agriculture is a family affair; 90 percent³ of farms worldwide are owned, managed, operated, and labored by families that have an economic stake on the performance of the farm. The reason the current state of agricultural production focuses on small farmers is that in many developing countries, agriculture continues to be the main

¹ Fan, Shегgen, Joanna Brzeska, and Tolulope Olofinbiyi. "Helping Small Family Farmers to Move Up or Move Out." *2014-2015 Global Food Policy Report*, no. 1 (2015): 26-31.

² Ibid

³ Ibid

source of employment, livelihood and income for between 50 to 90 percent⁴ of the population. Within this figure, the small farm sector actually make the up the majority of the agricultural industry, including between 70 to 95 percent⁵ of the farming population depending on the global region. Therefore, small farmers are therefore a significant proportion of the population that also traditionally survives on subsistence production. Although many of these farms can be small, normally less than two hectares of land, family farms are global businesses that produce up to 80 percent⁶ of the world's food. Within this demographic, many small crop producers in the last two decades have experimented with export crops with occasional initial success but many disastrous failures. Many of the crises that have occurred in the global agricultural sector can be sourced to the application of industrialization and or implementation of export orientated government policies, which have had little to no positive effect on small crop producers. Because the majority of the farmers are small crop producers, their power of influence in global economics cannot be marginalized. In a lot of instances, government policies and regulations relating to farmers have only exacerbated the income gaps in societies that rely on farming as a means of economic development.

As technology has developed into the 21th century, societies and nations worldwide have been able to increase food production to meet the demand of their constituents. However, the continued population growth, two percent⁷ annually, still pushes many countries and nations to pursue effective, but detrimental solutions to the food production problem. A perfect example of these detrimental practices is the use of pesticides. Reliance on pesticides as a means to eradicate entire insect species began with the introduction of Paul Müller's, DDT

⁴ R. Eastwood, M. Lipton, and A. Newell, "Farm Size," in *Handbook of Agricultural Economics*, Vol. 4, edited by P. Pingali and R. Evenson Amsterdam: Elsevier, (2009).

⁵ Ibid

⁶ Ibid

⁷ S. Fan, J. Brzeska, M. Keyzer, and A. Halsema, "From Subsistence to Profit: Transforming Smallholder Farms." *Food Policy Report* No. 26 Washington, DC: International Food Policy Research Institute, (2013).

(dichlorodiphenyltrichloroethane) in 1939. Since then, the use of detrimental pesticides increased by a factor of 50 since 1950⁸. World reliance on pesticides is very large; according to a study by the EPA, the world as a whole used approximately 5.2 billion⁹ pounds of pesticides, with herbicides constituting the biggest part of world pesticide use at 40¹⁰ percent. The EPA also estimates that the US used 1.1 billion pounds of pesticides in 2007 and accounts for 22¹¹ percent of total world usage. The problem with pesticides stems not from their effectiveness, but instead stems from their contamination of the goods produced and destruction of the environment. As pesticides become more common, in emerging economies, natural enemies of pests and traditional pollinators being eradicated while increasing pest resistance to pesticides.

Pesticide overuse is one of the many problems with current agricultural production. Resource mismanagement or lack of accessibility to modern agricultural methods by food producers can also lead to waste and ineffective crop production. Compared to developed countries, the developing world is extremely inefficient in agricultural production. According to the UN's Food and Agriculture Organization (FAO) annual report, emerging markets often produce less crops because those governments offer weaker legal protections and ownership rights are less enforceable. Additionally, less developed typically tend to have fewer market opportunities, resulting in products and methods for agriculture that are not as technologically advanced when compared to their developed country counterparts. One example is the lack of advanced irrigation systems in developing countries.

Another problem facing crop producers is the growing of crops outside of their native climates. Crops that are grown outside of their native geography—such as wheat, rice, and

⁸ R. Eastwood, M. Lipton, and A. Newell, "Farm Size" p. 42

⁹ Kindall, Henry, and David Pimentel. "Constraints On The Expansion Of The Global Food Supply." *Ambio* 23, no. 3 (1994): 345-400.

¹⁰ Ibid

¹¹ Gilliom Barbash, Jennifer Crawford, George Hamilton, Et al. "The Quality of our nation's waters: Pesticides in the nation's streams and ground water", *US Geological Survey Journal* Vol. 124 No. 2 (Washington DC: US Geological Survey Journal 1992-2001.)

barley—require a higher investment in technology, have a higher cost of harvest, and face higher volatility in market fluctuations relative to native crops. These problems in developing markets are only exacerbated when food producers in these economies also face total crop failure due to foreign pests, disease or inadequate agronomic practices is much higher than in traditional crops. Another problem facing developing food producers is that, as with access to economic markets, acquisition of technology is biased towards large tract farmers that can afford to purchase technology or know-how from developed economies. In this scheme small-scale producers normally rely on subpar resources, technology, and services, which therefore diminishes crop performance. Finally, crop producers need to ensure crop quality and standardization across markets, creating problems for both small and large tract farmers across the world. Small crop producers may have the knowledge to grow and distribute within their local markets; however, appearance and taste demographics that apply in a local market may not be the norm in established distribution centers. As such, standardization and quality is a barrier to export and distribution beyond the home market for the small crop producers unable to meet quality standards.

Current solutions to the inefficiencies seen in the agricultural sector are varied and some have been successful in allowing global producers to bridge the gap between supply and demand in their respective markets. Innovative technology has served as the most important tool in allowing food producers to continually increase their production performance in spite of Malthus's predictions. Perhaps one of the greatest agricultural innovative leaps of the 20th century was the development of the Green Revolution in the 1960's. Under the tutelage of Norman Borlaug, known as the father of the Green Revolution, new varieties of cereals, improved irrigation methods, crop management techniques, hybridized seeds, and development

of synthetic fertilizers and pesticides were pioneered and successfully developed in this time period. Dr. Borlaug's research has been credited with providing food for over a billion¹² people through his research. In fact, thanks to Dr. Borlaug's research, world grain output increased two fold¹³ from the 1950's to the 1980's.

Unfortunately, Malthus' prediction that sustained population growth without innovation in food production would strain food resources has once again has fulfilled itself. Currently, per capita production of basic cereals and staple produce has slowed and is actually in a period of decline of three percent¹⁴ year on year as compared to food production in the 1980's. In order to continue sustaining population growth and the ever growing demand for food, farmers and producers can either farm more land, or farmers can use technology to increase the productivity that each unit of land can sustain. Given that humans are approaching the limit of farm land expansion in the world, only 10 percent¹⁵ of the land on earth is arable, continued innovation in the agricultural technology to increase the productivity of land is the only solution. Out of the world's total arable land area of 15 million km², most of the productive land is already exploited and the remaining land is too steep, too wet, too dry, or too cold for agriculture. As an example of the rapid expansion of human agriculture, 80 percent¹⁶ of the arable land in Asia is already under agricultural use. However, although there are diminishing amounts of arable land left in the world, not all land is created equal. Net land production in different parts of the world can be far more productive than others depending on geographic location, climate, resources, access to irrigation, and a myriad of other factors. For example, Chernozem is one of the most fertile soils

¹² Henry Miller. "Norman Borlaug: The Genius Behind The Green Revolution." Forbes. January 12, 2012. Accessed April 6, 2015. <http://www.forbes.com/sites/henrymiller/2012/01/18/norman-borlaug-the-genius-behind-the-green-revolution/>.

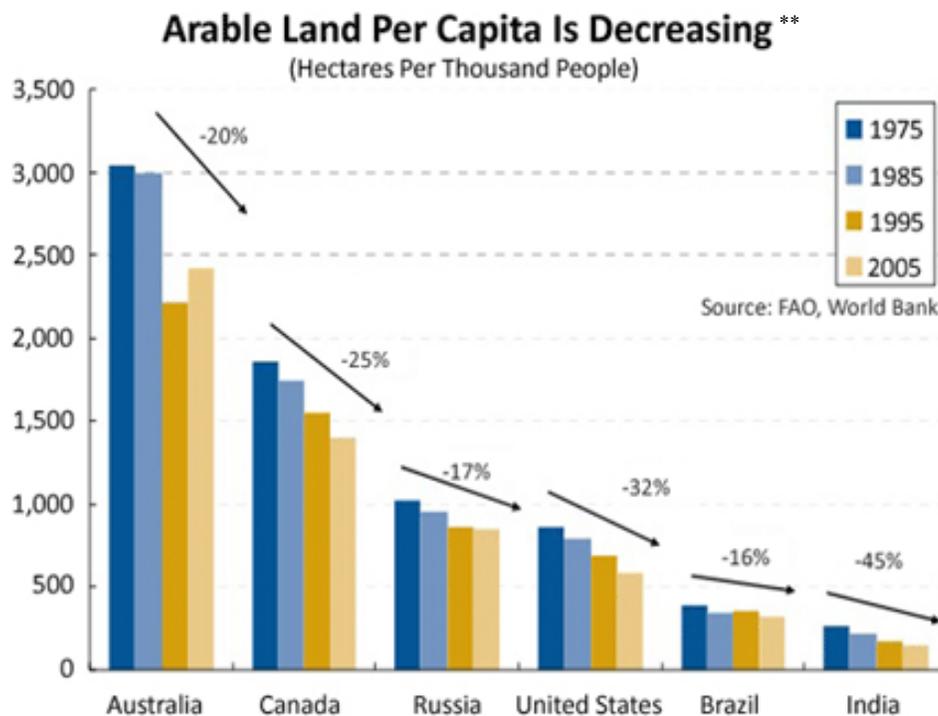
¹³ Ibid

¹⁴ Fan, Shегgen, Joanna Brzeska, and Tolulope Olofinbiyi. *Helping Small Family Farmers to Move Up or Move Out*.

¹⁵ Ibid

¹⁶ Ibid

present in the world. The high percentage of humus¹⁷, or organic matter found in the soil, is usually between 7 to 15 percent¹⁸, and high percentages of phosphoric acids, phosphorus, and ammonia make it an extremely sought after soil. Yet, this sought after soil is extremely limited to two particular zones or belts in the world in Europe and parts of the United States. By contrast, other land, which has been repurposed for agriculture—such as that present in the tropics and is actually highly productive for native plant species—is highly unproductive when used for agricultural purposes. Lastly, as population growth continues in parts of the world, agricultural land is redistributed or reutilized for urbanization, this further reduces the amount of fertile and usable land for agricultural purposes and activities.



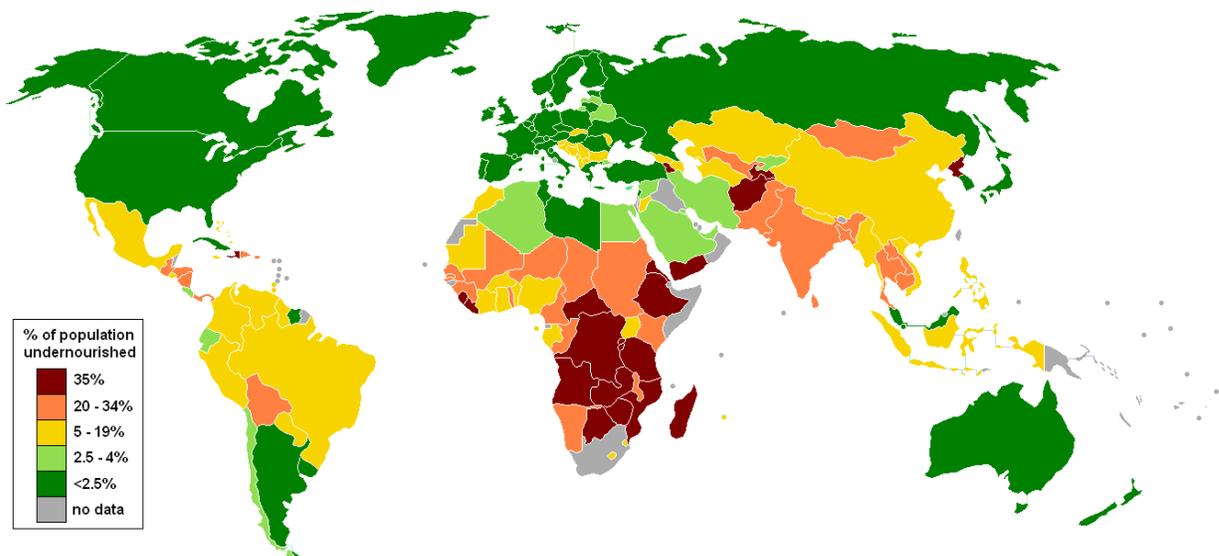
¹⁷ Originally coined 1790–1800; from the Latin humus: earth, ground

¹⁸ Fan, Sheggen, Joanna Brzeska, and Tolulope Olofinbiyi. *Helping Small Family Farmers to Move Up or Move Out*.

** Voelz, Wayne. "NAWAPA, Agriculture, and the Food Crisis." Map Aggregated By: Lyndon LaRouche PAC. March 23, 2011. Accessed April 4, 2015. <http://archive.larouchepac.com/node/17776>.

Given the diminishing amount of arable land and the increasing demands for higher and better food production, the only way to increase food production and quality is to follow in Dr. Bourlag's steps. Continued innovation and development upon existing agricultural techniques will further push food production frontiers. It is imperative that this trend continue as the top 20 countries that currently have the highest population growth rates in the world also have the lowest agricultural productivity. Additionally, all of these countries are also developing economies with significant economic, social, and political challenges. However, an "apply all" method for these economies is to stabilize their food resources and foster food security could be extremely beneficial. If these economies can benefit from easily accessible technology that will not pollute their environments and help them increase the productivity yield of their arable land while controlling population growth, Malthus could be proven wrong.

Population Nourishment as a Result of Agricultural Productivity for Year 2013¹⁹



¹⁹ Shepherd, Beatrice. "Child and Adult Malnutrition." Restless Beings. January 1, 2009. Accessed April 11, 2015. <http://www.restlessbeings.org/projects/dhaka-street-children/child-malnutrition>.

IMPROVING AGRICULTURE

As aforementioned, progress and innovation pioneered during the Green Revolution served to help bridge the gap between population growth and the food resources necessary to sustain society. Despite, the progress of agricultural technology, the effects of pesticide and insecticide use are still not fully understood and need to be brought under control in order to prevent pollution and other detrimental effects on the global environment. Research and development in the industry will improve yields and quality through better agricultural practices in land management, pest control, irrigation, and the development of more crisis resistant crops.

Perhaps the best technology for helping produce higher quality crops is to rely on science for creating crops that can grow faster and larger while utilizing fewer resources. However, this approach can be very complicated and fraught with many questions about what modifying and redesigning crops can mean for the food that people eat. Instead, the application of computer and technology can achieve a similar production increases in food production with less controversy. The approach of integrating technology into existing agricultural processes should not be too difficult. While the world is home to a vast amount of edible plants and animals, few are actually easy to domesticate and mass-produce and therefore achieve economies of scale through mass production. In fact, according to the UN's FAO, 90 percent of the world's food is derived from just 15 plant and 8 animal species²⁰. Cereals, such as wheat, rice, maize, millet, and sorghum provide about 70 percent²¹ of daily calories and up to 90 percent²² of all protein consumed by the world's population.

²⁰ "Innovation in Family Farming." *The State of Food and Agriculture 2014*, Vol. 70, no. 3 United Nations Food and Agriculture Organization (2014): 67-90.

²¹ Ibid

²² Ibid

While on a sustenance and food security level agriculture is extremely important, from a business perspective it functions much like any traditional business of production inputs and outputs. Crop yields are the direct result of resource management, weather forecasting, and proper use of artificial or additive materials. However, making sense of all of these inputs and outputs—up until the 21st century—has been difficult due to the lack of computer penetration in developing and emerging markets. The introduction of smart phones has allowed many rural farmers to have access to communication, education, and processing power. Much of what the future of agriculture is centered on is predictive statistics alongside understanding soil composition and weather patterns. While all of these technologies are still not in the market, by the year 2050 farmers and crop producers world wide will have access to the technology and education necessary to allow them to make better farming and resource allocation decisions.

DEVELOPMENT OF AGRICULTURAL TECHNOLOGY IN THE 21st CENTURY

Agglomeration Economies and their Technology

Technological innovation is usually the result of economies of agglomeration. The term, coined by urban economists, is used to explain the phenomenon and benefits that firms obtain by locating operations or business centers near each other. The theory surmises that economies of scale and network effects take place when businesses within the same industry or field are close to each other. As the number of firms related fields cluster within a geographic area, costs of production may decline significantly because of the residual effect of their economic decisions. For example, although firms could have competing multiple suppliers, greater specialization and division of labor, the direct effect of their operations influences the geographic area surrounding the cluster creating economies of scale. In such an environment, technological innovation by one

of the market player can mean the escalation of technological development that often results in cheaper prices for consumers. Even when competing firms in the same sector cluster, there may be advantages because the cluster attracts more suppliers and customers than a single firm could achieve alone. As societies develop, cities form and grow to exploit economies of agglomeration; the expansion and exploitation holds true for agriculture and technology. In order to predict how agriculture will be shaped by technology it is important to understand what innovations and trends are occurring around agricultural and technologically centered economic clusters.

California is an established agricultural, technological, and educational powerhouse in the United States. The state by itself produces more than half of the fruits and vegetables consumed in the United States and has a total combined market value of \$17 billion²³ for the largest staple foods grown in the state. These crops include lettuce, grapes, almonds, nursery plants, strawberries, and walnuts. However, the state's most important crop happens to be wine grapes. Vineyards in California are considered a different industry within themselves and they produce a total of 90 percent²⁴ of the wine consumed in the United States and according to the California Wine institute. In fact, if California were a nation, it would be the fourth leading wine-producing country in the world behind France, Italy and Spain. The state currently has 570,000 acres²⁵ of wine variety grapes that require surveillance, irrigation, fertilizer, and pesticides. Wine is California's most valuable finished agricultural product and comprises an economic institution worth more than \$45.4 billion²⁶. The relationship between California's grapes in relation to global agricultural technology might seem a bit stretched; however, aside from being the nation's top producer of food, California is a hot bed for technology and experimental farming. Many

²³"California Department of Food and Agriculture." CDFA STATISTICS. January 1, 2015. Accessed March 23, 2015. <http://www.cdfa.ca.gov/statistics/>.

²⁴ "Innovation in Family Farming." *The State of Food and Agriculture 2014*, Vol. 70, no. 3 United Nations Food and Agriculture Organization (2014): 67-90.

²⁵ Sidney Cox, *Information Technology: The Global Key to Precision Agriculture and Sustainability*

²⁶ United Nations Food and Agriculture Organization, *The State of Food and Agriculture 2014*

new technologies in irrigation, monitoring, and management are pioneered in California's Central Valley. The state has been known to utilize aerial analysis for crop production—mostly focusing on satellite and fixed wing imagery—with a nascent quadrotor cottage industry being developed. Additionally, new irrigation methods are currently being developed in the state. Furthermore, the United States has a share of 13 percent²⁷ of R&D expenditures within the agricultural sector, making this a technological market of \$4.364 billion²⁸. These industries have a direct influence on California agriculture; most agricultural firms are willing to invest in new technology. This sophisticated market of early adopters can help refine agricultural products and technologies and expand them beyond grape production. Additionally, the high number of agricultural firms could mean that collaboration between firms and industries is possible.

Similar to California, the Latin American agricultural market is an agglomerated economy where technology has continued to develop. Although Latin American farmland comprises only 4 percent²⁹ of total world farmland, the region is still one of the most robust agricultural regions in the world. According to a United Nations study, Latin America produces \$104 billion³⁰ worth of agriculture annually, which is 16 percent³¹ of the world's total. Additionally, the region has highly valuable crops and has a high investment in R&D in the agricultural sector with a 10 percent³² share, making it a \$3.36 billion³³ market. Latin America is also one of the world's largest wine producers, with Argentina and Chile making up a \$3.429 billion³⁴ market in terms of raw grape production, and \$42 billion³⁵ market in terms of wine

²⁷ "California Department of Food and Agriculture." CDFA STATISTICS. January 1, 2015. Accessed March 23, 2015.

<http://www.cdfa.ca.gov/statistics/>.

²⁸ Ibid

²⁹ Ibid

³⁰ Ibid

³¹ Ibid

³² Ibid

³³ Ibid

³⁴ Ibid

³⁵ Ibid

production. Latin America also shares many cultural ties with North America and farmers normally spend money in acquiring equipment to improve their costs.

Chile, Argentina, Uruguay, Paraguay and Brazil have economies that are growing at a projected rate of 3.6 to 4.1 percent³⁶—collectively—in the year 2015. The fast paced economic growth could translate into more disposable income for farmers to invest in agriculture. According to the Inter-American Development Bank, agriculture in the region suffers from slow growth in productivity. The annual rate of growth of total productivity in the region grew only 1.9 percent³⁷ between 1961 and 2007 compared with 2.4 percent³⁸ in OECD countries. Chile is one of the top producers of grapes in the world with a total annual production of \$1.82 billion³⁹ in raw tonnage and a total wine production of \$21.9 billion⁴⁰. Grapes are also Chile's primary export fruit, with grapes and wine accounting for 33 percent⁴¹ of all Chilean exports. Given the reliance on grape production, the propensity to invest in new technology, and the key relationships with the United States, Chile is also another global agricultural region for technology development and innovation in agriculture to occur. Argentina is the fifth largest producer of wine in the world and has been the largest exporter in Latin America since the year 1990 with more than 1,500 wineries⁴² sending their wines abroad. Argentina's most popular wine region is Mendoza, which is home to some of the country's largest vineyards and vintners as well as some of the most expensive Argentine wines. Currently, Mendoza has an estimated 360,974 acres⁴³ of wine producing land within its region with Malbec being the most popular

³⁶ "FAOSTAT." FAOSTAT. January 1, 2015. Accessed February 23, 2015. <http://faostat.fao.org/site/339/default.aspx>.

³⁷ Ibid

³⁸ Ibid

³⁹ Ibid

⁴⁰ Ibid

⁴¹ Ibid

⁴² Ibid

⁴³ Ibid

grape among wine producers. The total Argentine wine market has an estimated size of \$19 billion⁴⁴ annually and it is projected to grow at a rate of 17 percent⁴⁵ for the year ending in 2015.

Wineries as a Hotbed for Innovation

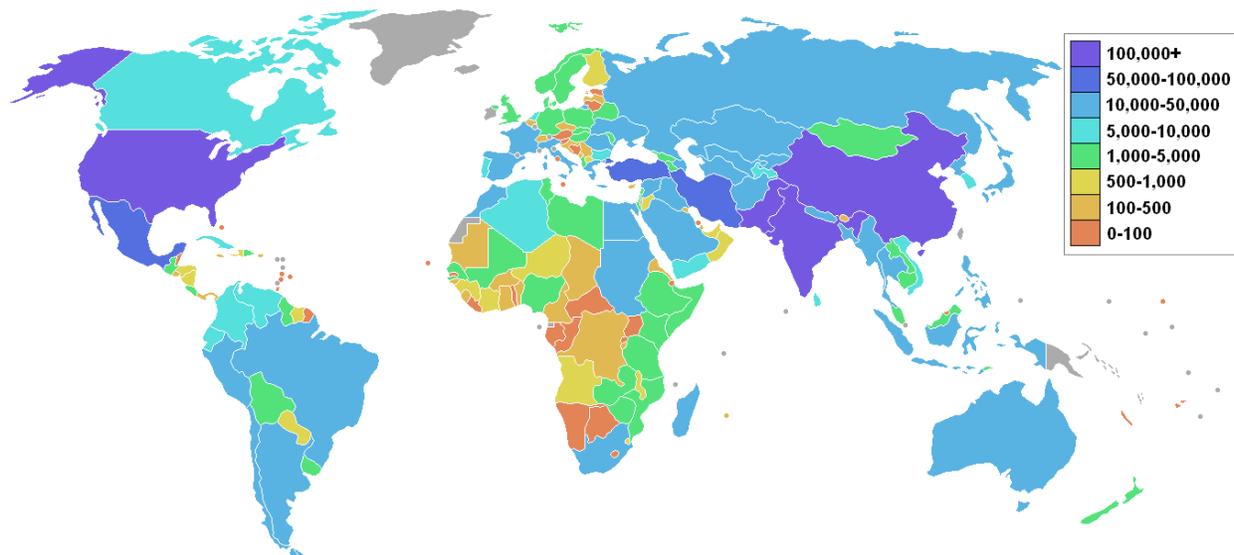
Wineries in California, Chile, and Argentina are the ones responsible for helping foster advances in agriculture that look into implementing computer technology into production instead of looking for innovation in pesticides, insecticides, or genetically modified food. Instead, wine growers are concerned with how to best utilize these resources with the power of data analytics, resource conservation, and natural approaches to difficult problems. The reason for viticulture as one of the birthplaces of agricultural innovation is due partly to agglomeration economies. Wine making is also a highly profitable business in these regions, leaving many wine owners flush with cash to invest in R&D which is then used

Winemakers are responsible for many of the modern innovations in irrigation such as drip irrigation and soil moisture monitoring. These innovations arose because winemakers know that soil moisture is key to growing quality wine grapes, but accurately monitoring the soil's water content is a difficult and expensive task. Technological companies and research institutions are currently developing methods for the wine industry to measure soil moisture levels—which also work in conjunction with drip irrigation systems—to help winemakers determine what rate of soil moisture is perfect for creating smaller grapes. Some of these different technologies involve in ground sensors and predictive statistical models, while other innovations rely on electromagnetic pulses to determine moisture levels in different layers of soil. Universities, such as UC Berkeley see these technologies as disruptive because the technology required is no longer cutting edge, but rather relies on the economies of scale and the

⁴⁴ Cox, Sidney. "Information Technology: The Global Key To Precision Agriculture And Sustainability." *Computers and Electronics in Agriculture* 36, no. 2-3 (2015): 93-111.

⁴⁵ Ibid

cost reduction they bring. When winemakers are able to consistently grow smaller grapes that have a higher skin-to-juice ratio, they are able to consistently produce finer and consistent tasting wines. Yet, the real benefit of the technology is reducing energy, water use, reliance on pesticides, and increasing predictability during harvests. The big data components of these innovations also help wine growers save money. By correlating soil moisture with vine growth, wine growers can predict what kind of spacing to use for the vineyard. This information would allow farmers to cut further costs in irrigation and pesticides by spacing vines at optimal intervals. Aside from monitoring soil moisture content and temperature, the sensors can be utilized to monitor other important soil aspects such as nitrogen content, acidity and PH levels. This information, which is gathered worldwide in various different vineyards, helps the winemakers decide how to better adapt their land for optimal production. Understanding the chemical and water saturation properties of soil is imperative to knowing which crops will perform best when planted.



Amount of irrigated land⁴⁶ throughout the world in km²

⁴⁶ "FAOSTAT." FAOSTAT. January 1, 2015. Accessed February 23, 2015. <http://faostat.fao.org/site/339/default.aspx>

While it might not seem like much, this incremental use of technology in the wine field can lead to greater implications for other food producers across the world. As the cost of technology continues to decrease, instead of relying on eyeballing or traditional irrigation methods, traditional farmers can rely on sensors or studies to better understand their fields. If one compares the map of malnourished people on page 8, with the above map, which highlights irrigation in square kilometers, it is easy to understand to draw the correlation that inadequate irrigation is one of the leading problems with agriculture in many developing and emerging economies. Yet, as with wine producers, the better that a food producer understands the inputs necessary to grow a successful crop, the probability of them producing higher quality and yielding crops increases exponentially. Furthermore, as technology continues to not only increase in power, but also reduce in cost, the application of this technology will become much more accessible to those food producers that truly need it. Producers living in regions of the world that are susceptible to droughts or other environmental disasters will be able to use the power of big data to better understand how to farm their fields. Other forms of technology that were initially developed strictly for the wine industry, such as satellite imagery with multi-spectral cameras, have also moved onto analyzing other forms of crops. For example, the company Precision Hawk currently utilizes small airplanes equipped with various types of cameras to help farmers map their fields. The different light spectrums of each camera allow the company to make estimates on plant health measurement, water quality assessment, vegetation index calculation, and plant counting. While the average cost for this kind of analysis is still out of reach for many of the world's farmers, it is possible for regional and national governments to invest in this kind of technology. With the backing of a regional or national government, small producers could gain access to the benefits these analytics provide.

While Latin America and California gave rise to the technological side of agricultural innovation seen thus far in the 21st century, the French wine region of Provence is also shaking things up in the agricultural revolution by returning to the roots of agriculture. Aside from creating some of France's more diverse wine blends, Les Baux-de-Provence was the first French appellation to require all vineyards to be farmed biodynamically; meaning that vineyards should be self sustaining that they treat soil fertility, plant growth, and livestock care as ecologically interrelated tasks. This rule has created quite a stir in the region, but has ultimately resulted in the conversion to more organic viticulture. Les Baux-de-Provence has successfully eliminated the use of most chemicals that could easily dispersed from the vines by the strong winds of the region.

Biodynamic agriculture and organic agriculture have a lot in common, but are actually entirely different approaches to farming. Organic wine makers, just like organic farmers, focus on producing wines that are free of any synthetic additives and from grapes that are exclusively grown through an organic method, meaning that no sulfites are ever added to the wine. By contrast, biodynamic farming looks at the vineyard as a small part of the environment necessary for production. By acting in the best interest of the ecosystem—in conjunction with other technological advancements such, as sensors or satellite imagery—producers are able to better plan for challenges that their crops might face by having all resources on hand. For example, pests are fought by introducing natural predators and by utilizing non-environmentally detrimental solutions, such as nets that prevent birds from eating grapes, or introducing snakes to keep rodent populations in check. Additionally, biodynamic production also implements the organic methods for wine making that were mentioned previously. Although these methods are new, and seen as a step backwards in terms of innovation, the approach is actually showing quite

positive results that can be translated into success stories for farmers and food producers worldwide. By treating the land, local environment, and the region's microclimates as bio-diverse entities much waste and pollution has been reduced in France⁴⁷.

Pollution as well as resource cost cutting is one of the reasons that the biodynamic movement is expanding beyond the Les-Baux region of France. As more and more wine producers implement these changes on their own farms, communities as a whole are also noticing huge changes to the natural environment. One example is the decreased demand for top soil in vineyards across the south of France⁴⁸ as the biodynamic methods utilized are helping the soil of local farms to preserve the nutrients that make it a stable for grape growing. Another agricultural method pioneered by the biodynamic movement and implemented in the south of France, also recently adopted in California vineyards, is the presence of mustard during the winter months. The reason for the presence of the wild growing yellow flowered plant in vineyards is because mustard actively suppresses nematode population. Nematodes are a type of roundworms⁴⁹ that damage grape vines through invasion of root systems, causing root knot⁵⁰ and spreading viral diseases across plants. However, mustard contains a cocktail of natural pesticides that are toxic to nematodes known as biofumigants⁵¹. As a result many vineyards in the south of France and in California's Sonoma and Napa Valleys have adopted the practice of planting mustard, with some vineyards having created their own varieties that are specifically bred to have high levels of biofumigants to further deter nematodes. Though systems of crop rotation and pest control have existed since the Middle Ages, understanding the science behind why these methods of agriculture work are extremely important. Given the prevalence of roundworm

⁴⁷ Cox, Sidney. *Information Technology: The Global Key To Precision Agriculture And Sustainability*

⁴⁸ "The Magic of Mustard in the Vineyards." Sonoma County. March 12, 2012. Accessed January 23, 2015. <http://www.sonomacounty.com/articles/magic-mustard-vineyards>.

⁴⁹ Ibid

⁵⁰ Cox, Sidney. *Information Technology: The Global Key To Precision Agriculture And Sustainability*

⁵¹ Ibid

nematodes in farms throughout the world, utilizing mustard instead of pesticides or insecticides to combat the worms is a technological innovation that can also help food producers turn an extra profit when they sell the mustard they produce along with their staple crops.

Another innovation born of the biodynamic agricultural movement is the development of alternative fuels by using the waste that the winemaking process creates. As mentioned before, California, Chile and Argentina are home to some of the most robust wine production regions in the world. As a result, in California alone there are over 90,718 metric tons⁵² of grape skins that are wasted every year. While traditionally most of this material is disposed, the biodynamic movement has taken aim to find a useful purpose for the grape waste and that solution is creating alternative fuels. According to Frédéric Mistral, the wine master of Chateau Romanin, the sugar in left over in the grape skins can actually be converted into energy and biofuel. The grape waste is dried to create what is known as grape pomace. The pomace is then used as the main food for bacteria and other microbes that consume the sugars in pomace and turn them into raw oxygen and hydrogen.⁵³ Once the process is complete, the raw hydrogen and oxygen can then be utilized to create different kinds of fuel mixtures or energy resources. The process has been so successful in the south of France that Mr. Mistral explains that his winery has adopted the practice and many others are following suit. However, the trend isn't limited to just the French wine market, researchers from Penn State and UC Davis have also teamed up with wineries in Napa Valley and Sonoma County to implement a similar biofuel infrastructure that relies on utilizing grape waste to make hydrogen and oxygen. Furthermore, in an effort to leave no part underutilized, Danish chemist Dr. Yi Zheng is currently developing method for digesting cellulose from the skins and seeds of grapes into ethanol. This research, though initially grape focused, can have

⁵² Morganstern, Adam. "Wine Quality, Organic Viticulture and Vine Systemic Acquired Resistance to Pests." *Organic Wine Journal* RSS. November 1, 2008. Accessed April 3, 2015. <http://www.organicwinejournal.com/index.php/2008/11/wine-quality-organic-viticulture-and-vine-systemic-acquired-resistance-to-pests/>.

⁵³ Ibid

huge ramifications for the role that plant waste could have on energy policy around the world. If Dr. Zheng is successful in his research, agricultural waste around the world could become the next source of cheap energy for emerging and developing countries. The current advantage of applying this technology is that the vineyards are able to produce their own biofuels, and therefore energy, through their waste. Hydrogen powered generators are allowing some wineries to rely less on technologies that create carbon deficits and come a little closer to becoming carbon neutral. Additionally, the end result of the process is normally hydrogen, oxygen, and natural wastewater, which can then be used to re-irrigate the wine fields. If the same technology could be achieved with potato skins, orange peels, or other staple fruits, farmers worldwide would benefit from selling their crops as well as from energy independence.

The last reason for implementing a biodynamic strategy in vineyards is that the quality of crops produced under a biodynamic farm seems to outperform that of crops grown with traditional methods. However, this is a topic that has continually been shrouded in controversy. For example, at during a tasting competition, put forth by the Les-Baux region, biodynamic wines were tasted and compared to conventional wine varieties. According to the participants of the tasting the biodynamic wines won eight out of ten times and had one tie.⁵⁴ That means conventional grapes only outshone biodynamic ones one out of 10 times in that blind taste test. Frédéric Mistral, wine master of Chateau Romanin, agrees with the results and explains that the improved flavor and complexity of wine throughout the Les-Baux region as a result of biodynamic agriculture can also be translated into the growth of tourism in the region. The Les-Baux regional government has created a well-developed marketing campaign highlighting the adoption of biodynamism in grape production resulting in tourists and wine producers visiting

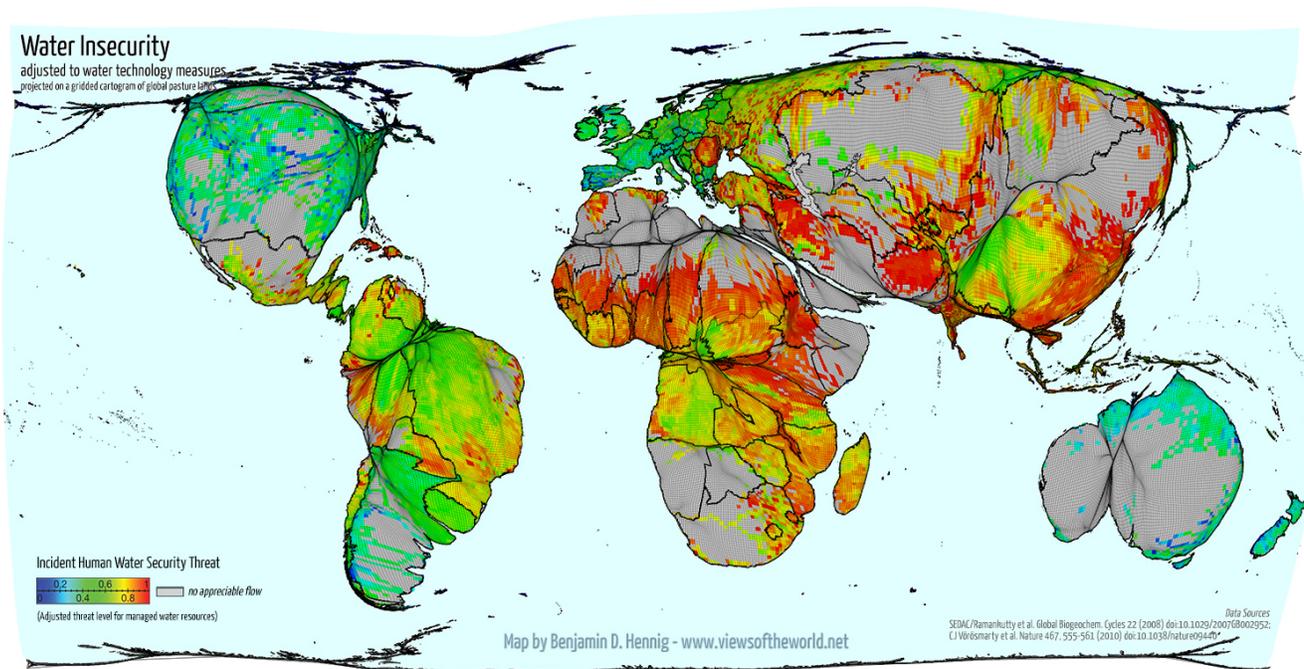
⁵⁴ Morganstern, Adam. *Wine Quality, Organic Viticulture and Vine Systemic Acquired Resistance to Pests*.

the region to not only taste the wines, but also learn about how France is at the forefront of implementing biodynamic agriculture to a very traditional industry. According to Mr. Mistral, the wine flavors of Provence have fundamentally changed since the edict on biodynamic farming. Flavors are now more vibrant and wines exhibit a more natural and holistic composition. Mr. Mistral also mentions that the edict on biodynamic farming meant that many vineyards had to invest in their own vineyards to meet the new requirements, but the investments have resulted in better resource management, energy policies, and higher quality produce. Higher quality and better tasting produce could be a soft benefit to biodynamic agriculture, but if it were a result of implementing new processes, it would be a welcome benefit.

Wineries throughout the world serve as a hotbed for agricultural innovation. While in the short-term technology developed for wineries is extremely focused towards the processes seen in a vineyard, as technology and knowledge diffuse, technology restricted to a particular use can gain a wider adoption. Agriculture in other parts of the planet can benefit from drip irrigation systems and the water conservation that they promote. Sensors and computer technology can help farmers better understand their fields and the inputs that drive their agricultural outputs. Another benefit of sensor technology is also resource conservation and the reduction of pesticide and insecticide pollution caused by over use. Lastly adopting biodynamic practices in conjunction with advancements in irrigation and computer technology will help all food producers better manage their crops and resources while also deriving more value from them. Natural pest prevention, such as the appropriation of mustard to fight nematodes or using grape pomace to create biofuels, can reduce the usage of chemicals and energy in farms throughout the world. Agriculturists worldwide will one day thank wineries for the technology that will be available to them in the near future.

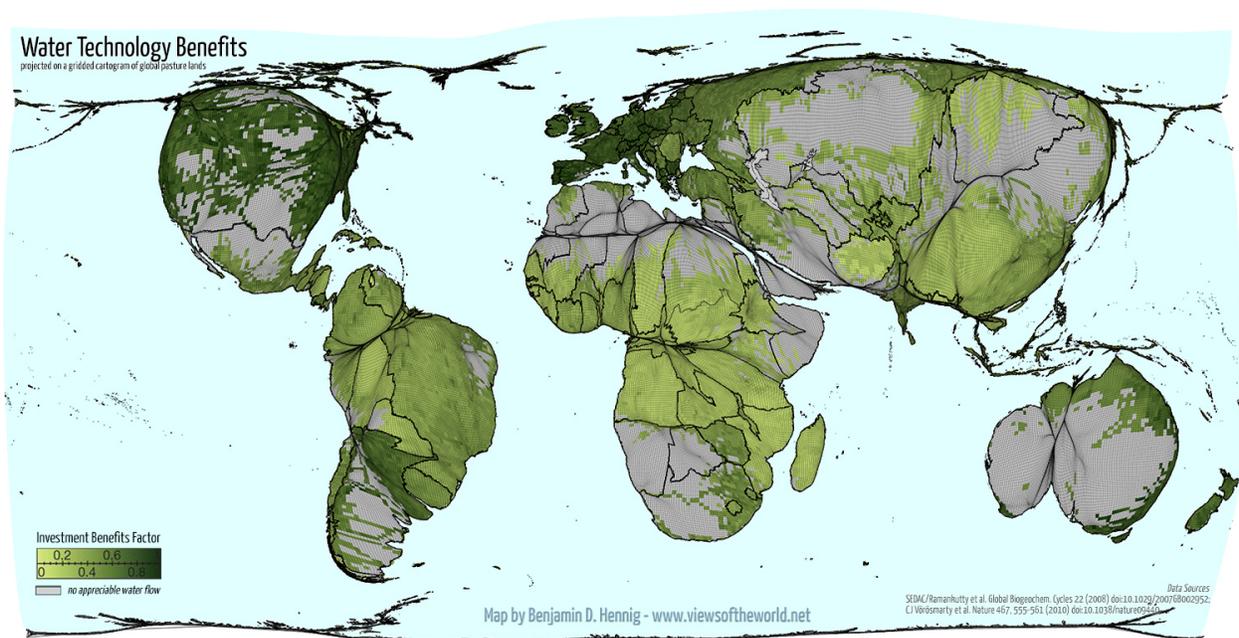
A PREDICTION OF HUMAN INNOVATION AND PERSEVEARANCE

The world as it is now is much different than it was in the late 19th and early 20th century. Human activities are having a lasting impact on the environment and climate of the earth, as highlighted by Dr. Neil deGrasse Tyson in the 2013 documentary *Cosmos, A Space Odyssey*. According to Dr. Tyson, carbon dioxide emissions are reaching new records—approximately 300 billion tons yearly—of emissions into our atmosphere. This amount of CO² in the atmosphere is having detrimental effects on short-term weather patterns. Furthermore, the world's arable land supply is steadily decreasing, affecting how many of the world's agrarian societies currently do business. According to Benjamin Hennig, Senior Research Fellow in the School of Geography and the Environment at the University of Oxford, water insecurity will be one of the major points of conflict in the coming century. However, there are solutions to preventing future conflict and that is adopting better water policies. For example, since 2011



⁵⁵ Hennig, Benjamin. "World Water Insecurity." Views of The World. September 30, 2010. Accessed March 29, 2015. <http://www.viewsoftheworld.net/wp-content/uploads/2010/09/GlobalWaterInsecurityadjustedMap.jpg>.

California has been at the mercy of a prolonged period of drought that is crippling agriculture. Farmers—both industrial and family sized—are opting to leave fields fallow instead of incurring the high costs of using ground water for irrigation. Yet, among the economic slow down among agricultural producers, wineries are actually the best prepared to face off against the weather conditions created by the drought. By relying on irrigation, imaging technology, and data aggregation, wineries are actually water neutral food producers. By looking at another map composed by Mr. Hennig, it can be inferred that water security is a global problem, regardless of whether it is caused by climate change or not. In the future farmers will require equipment to better manage their water resources if they are to successfully meet their food production needs.



Aside from population growth and the looming Malthusian crisis predicted by Thomas Malthus, the world beyond the year 2050 is likely to have many weather, energy, and food production related problems. However, given the pace with which technology grows, expands,

⁵⁶ Hennig, Benjamin. "World Water Insecurity." Views of The World. September 30, 2010. Accessed March 29, 2015. <http://www.viewsoftheworld.net/wp-content/uploads/2010/09/GlobalWaterInsecurityadjustedMap.jpg>.

and diffuses, it is not hard to stipulate that current nascent technology developed in vineyards will eventually make its way into the channels that demand it. As the cost of production continues to decrease, and humans become more knowledgeable about agricultural processes, the landscape of agriculture will change with it. Farms in the future will use sensors to predict crop yields, weather patterns, and sicknesses before they occur, thereby allowing communities and governments to better plan and distribute resources. Additionally, farms will be a source of clean energy as biofuel technology continues to be developed and expanded beyond grapes. The increase in clean energy will have benefits beyond giving power to people in developing nations. Access to clean energy will help communities gain access to clean water and sanitation, as better health care, and education that will continue to reinforce agricultural norms. The world of the future will no doubt bring with it many challenges; however, human ingenuity will raise to the occasion and meet those challenges head on.

Bibliography

Fan, Sheggen, Joanna Brzeska, and Tolulope Olofinbiyi. "Helping Small Family Farmers to Move Up or Move Out." 2014-2015 Global Food Policy Report, no. 1 (2015): 26-31.

Hennig, Benjamin. "World Water Insecurity." Views of The World. September 30, 2010. Accessed March 29, 2015. <http://www.viewsoftheworld.net/wp-content/uploads/2010/09/GlobalWaterInsecurityadjustedMap.jpg>.

Morganstern, Adam. "Wine Quality, Organic Viticulture and Vine Systemic Acquired Resistance to Pests." Organic Wine Journal RSS. November 1, 2008. Accessed April 3, 2015. <http://www.organicwinejournal.com/index.php/2008/11/wine-quality-organic-viticulture-and-vine-systemic-acquired-resistance-to-pests/>.

"The Magic of Mustard in the Vineyards." Sonoma County. March 12, 2012. Accessed January 23, 2015. <http://www.sonomacounty.com/articles/magic-mustard-vineyards>.

"California Department of Food and Agriculture." CDFA STATISTICS. January 1, 2015. Accessed March 23, 2015. <http://www.cdca.ca.gov/statistics/>.

"FAOSTAT." FAOSTAT. January 1, 2015. Accessed February 23, 2015. <http://faostat.fao.org/site/339/default.aspx>

"California Department of Food and Agriculture." CDFA STATISTICS. January 1, 2015. Accessed March 23, 2015. <http://www.cdca.ca.gov/statistics/>.

United Nations Food and Agriculture Organization, *The State of Food and Agriculture 2014*

"Innovation in Family Farming." *The State of Food and Agriculture 2014*, Vol. 70, no. 3 United Nations Food and Agriculture Organization (2014): 67-90.

Shepherd, Beatrice. "Child and Adult Malnutrition." Restless Beings. January 1, 2009. Accessed April 11, 2015. <http://www.restlessbeings.org/projects/dhaka-street-children/child-malnutrition>.

Voelz, Wayne. "NAWAPA, Agriculture, and the Food Crisis." Map Aggregated By: Lyndon LaRouche PAC. March 23, 2011. Accessed April 4, 2015. <http://archive.larouchepac.com/node/17776>.

Henry Miller. "Norman Borlaug: The Genius Behind The Green Revolution." Forbes. January 12, 2012. Accessed April 6, 2015. <http://www.forbes.com/sites/henrymiller/2012/01/18/norman-borlaug-the-genius-behind-the-green-revolution/>.

R. Eastwood, M. Lipton, and A. Newell, "Farm Size," in *Handbook of Agricultural Economics*, Vol. 4, edited by P. Pingali and R. Evenson Amsterdam: Elsevier, (2009).

S. Fan, J. Brzeska, M. Keyzer, and A. Halsema, "From Subsistence to Profit: Transforming Smallholder Farms." *Food Policy Report* No. 26 Washington, DC: International Food Policy Research Institute, (2013).

Kindall, Henry, and David Pimentel. "Constraints On The Expansion Of The Global Food Supply." *Ambio* 23, no. 3 (1994): 345-400.

Gilliom Barbash, Jennifer Crawford, George Hamilton, Et al. "The Quality of our nation's waters: Pesticides in the nation's streams and ground water", *US Geological Survey Journal* Vol. 124 No. 2 (Washington DC: US Geological Survey Journal 1992-2001.)