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# THE POTENTIAL OF THE NEW GREEN REVOLUTION

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## INTRODUCTION

With the anticipation of the global population reaching 9 billion by 2050, politicians and scientists are calling for a New Green Revolution (NGR) to meet projected food demands. Ultimately, the goal of a NGR is to end (not postpone) starvation and save lives, but like the first Green Revolution, humanitarian achievements will only be accomplished through the adoption of improved technologies. However, it is critical that technology is adopted while minimizing social and environmental consequences to sustain agricultural productivity beyond the $21^{st}$ century.

## HISTORY

As agriculturalists address the challenges of implementing the NGR, it is important that we consider all aspects of the Green Revolution. The Green Revolution is credited with saving over a billion lives through the adoption of new technologies principally in Mexico, Pakistan and India. In 1968, the United States Agency for International Development (USAID) termed the phenomenal increase in wheat yields in these regions the Green Revolution and credited the wheat breeder, Norman Borlaug, as the father. However, research to reach this milestone began over twenty years earlier following a visit to Mexico by U.S. Vice President Henry Wallace in 1940 (Kohler, 2007). As Secretary of Agriculture from 1933-1940 under Franklin D. Roosevelt, Wallace was instrumental in developing agricultural policies to aid American farmers during the Great Depression. Consequently, he recognized that addressing the subsistence farming in Mexico was the first point in addressing the countries widespread poverty and starvation. As a result, Wallace met with the Raymond Fosdick, president of the Rockefeller Foundation to discuss methods to improve agricultural productivity in Mexico (Kohler, 2007). In 1943, the Rockefeller Foundation began working with the Mexican Ministry of Agriculture, the United Nations and the Food and Agricultural Organization (FAO) on the Mexican Ministry Project to improve the yields of the principle crops of Mexico; specifically, corn, wheat, beans and potatoes. Borlaug's focus on dwarf wheat varieties led to the earliest yield improvements in Mexico and future global successes (Kohler, 2007; Conway, 1997). From 1948 to 1970, Mexican wheat yields increased 400% (Kohler, 2007). As conditions in Mexico began improving, Borlaug turned his attention to the widespread famine across Pakistan and India. Borlaug initially faced resistance from Asian farmers to adopt the Mexican dwarf varieties, but within five years, over 30% of the wheat in Pakistan and India was planted to Borlaug's dwarf varieties. The yield potentials of the new dwarf wheat varieties were enhanced by high levels of fertility and irrigation without the risk of lodging. Ultimately, the investments in agricultural research, especially in plant breeding, stabilized food supplies and minimized hunger and wasting, which provided the foundation for population growth throughout Mexico and Asia.

## A GROWING POPULATION

In December 2017, it was reported that the global population surpassed 7.6 billion, and it is estimated that the global population will reach 9 billion by 2050 (Fig. 1). Because of societal issues surrounding global population, the WHO established 16 Sustainable Development Goals targeting the 67 countries that comprise 75% of the global population. The first two goals are ending poverty and world hunger, and to accomplish these goals, the World Bank recognized that global improvements in agricultural prosperity are essential. In order to improve agricultural prosperity, global policy makers are calling for a NGR. However, increased investments in agricultural research as well as emphasis on the social and environmental costs of the Green Revolution must be addressed before global agricultural sustainability can be achieved with a NGR. Globally, the technology spill-over from the Green Revolution led to intensification of agricultural practices across many political and agroclimatic boundaries (Pingali, 2012). Although, Pingali (2012) noted that the agricultural achievements of the Green Revolution concealed agricultural inequalities in other geographic regions especially Africa. In 2008, the African leader Kofi Anan declared that the future of Africa to be dependent on a NGR (Ghana News, 2008), and the UN announced the Alliance for a Green Revolution in Africa (AGRA) to promote self-sufficiency in African regions with good precipitation and soils. While there are significant opportunities for agricultural improvement in Africa, the intensification of agricultural practices across vast geographic regions following the Green Revolution has resulted in soil degradation, depletion of aquifers, and aquatic dead-zones. A NGR must be responsibly implemented. Implementation of intensive agricultural practices without consideration of social and environmental imbalances has the potential to affect the success of 21$^{th}$ Century farming enterprises.

## SOCIAL AND ENVIRONMENTAL IMPACTS OF THE GREEN REVOLUTION(S)

Social impacts of the Green Revolution include increased life expectancies and increasing affluence (Kearney, 2010). With the intensification of agricultural practices during the Green Revolution, global starvation and childhood mortality rates declined increasing global life expectancies. In 1955, the World Health Organization (WHO) reported the global population was 2.8 billion, and the global life expectancy was 48. By 2015, the life global expectancy increased to 71.8 years, and the WHO estimates that the global life expectancy will increase to 73 by 2025. As life expectancies increase and the quality of life improves, high-calorie diets intensify the demands on global crop production. To meet the increasing food demands of a growing, more affluent global population, FAO estimates that agricultural productivity will need to increase 70% by 2050 with production in developing countries doubling to meet demands (FAO, 2009). A portion of this increase will be necessary to meet increasing demands for livestock feed as protein-based consumption increases; however, the increase in grain production does not clearly account for the usage of grain production diverted to bioenergy. Nonetheless, arable land expansion and further agricultural intensification are both considered options to increase agricultural productivity.

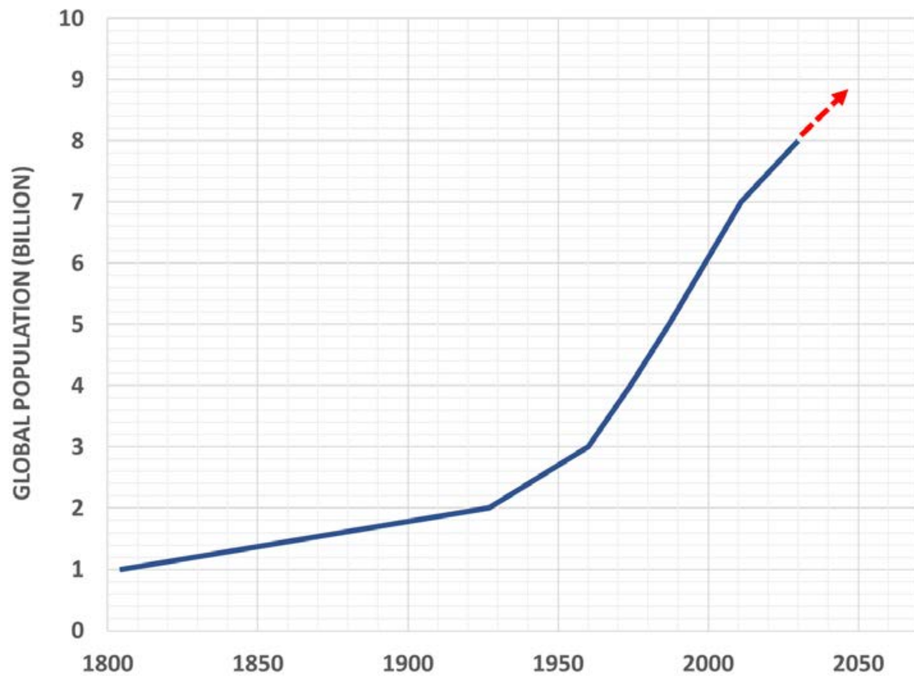


**Figure 1**. Increase in global population reflecting the projected increase in the global population to 9 billion by 2050.

Much of the world's uncropped arable lands are either marginal, forested, or located in water limited regions where land degradation and water shortages from irrigation are recognized as unintended environmental consequences of increased agricultural productivity following the Green Revolution. In 2016, Marris reported that more than half of the global population lives in areas with water shortages for at least one month a year (Fig. 2). Across the semi-arid U.S. Great Plains, 20$^{th}$ Century farmers adopted agronomic management including fertility, pesticide and irrigation programs for new high yielding varieties to reach their yield potential. In this region, the average annual precipitation does not meet the crop water demands to optimize production and economic returns so, crop production in the latter 20$^{th}$ century became increasingly dependent on irrigation from the Ogallala Aquifer. In the southern regions of the Ogallala Aquifer, groundwater withdrawals at rates greater than the recharge rates have resulted in the inability to maintain increases in crop productivity without a re-evaluation of cropping system paradigms and irrigation management to maintain farm profitability in addition to meeting the increasing global food demands (Fig. 3).

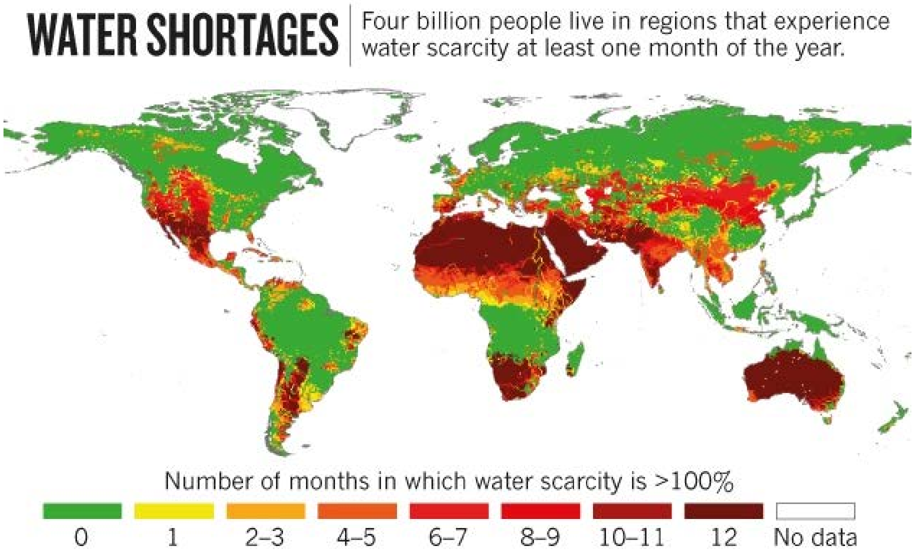


**Figure 2.** Global population that lives in regions with annual water shortages. *from* http://www.nature.com/news/water-scarcity-affects-four-billion-people-each-year-1.19370

In recent years, increasing global grain production (wheat and other coarse grains) has resulted in grain stocks ending the year at above average levels as reported by the International Grains Council (Schroeder, 2017). Despite increases in global grain production, a humanitarian crisis was unfolding across Africa with a famine affecting 20 million people in South Sudan, Somalia, Niger, and Yemen. The Washington Post reported this to be the highest level of famine since World War II (Bearak and Karklis, 2017). But this dire situation did not unfold over the course of one year. Historically, multifaceted challenges resulting from political instability, climate, reduced agricultural productivity and increasing population put pressure on what the UN defined in 2014 as a fragile food system (Munyang and Andrew, 2014). In 2005, in a form of assistance, G8 finance ministers dismissed Niger's $2 billion debt, but the government still refused to distribute free food because of potential socio-economic consequences created by disrupting markets and Niger's progression out of poverty (Vasagar, 2005). While a level of self-sufficiency is important for food security, importing crops may be necessary if land and water limit crop productivity (MacDonald, 2013). Meanwhile, record global grain production and above average global year-end stocks drove down 2017 U.S. commodity prices; a vicious cycle for the American farmer who needs to produce greater quantities of cheap grain to remain profitable. Global intensification of agriculture has progressed into the 21$^{st}$ Century with escalating grain production in South America. Global markets are currently producing more grain, but simply producing more grain is not the solution of the NGR. The NGR must avoid over-intensification of agricultural production in developing regions at the expense of long-term environmental sustainability in addition to avoiding a shift of agricultural instability and poverty from one region to another. The NGR must break political boundaries to establish markets that promote global agricultural and environmental sustainability while minimizing hunger and alleviating poverty. For the NGR to be successful, research in agronomics and irrigation management in addition to crop breeding will be the foundation for future food security.

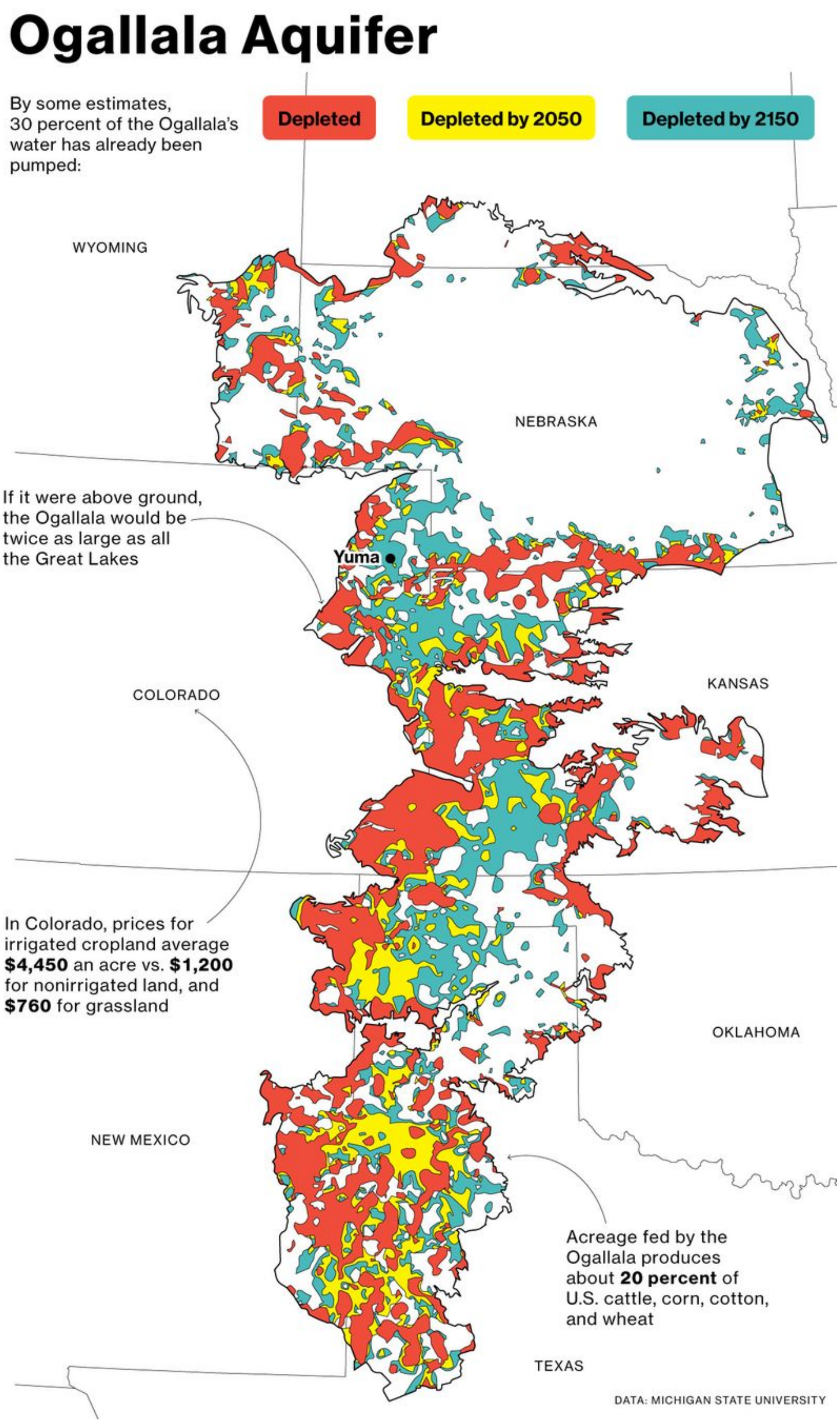


**Figure 3.** Current and Projected depletion of the Ogallala Aquifer from http://meridianintl.co/map-of-aquifers-in-the-us.html

## THE FUTURE AND THE NEW GREEN REVOLUTION

Breeding is responsible for providing high yielding varieties, but the yield potential of new varieties cannot be fully achieved without the adoption of improved agronomics and irrigation management. Irrigation enables producers to adopt high-value market-oriented production; consequently, irrigation helps alleviate poverty (Hussain and Hanjra, 2004). While the first Green Revolution was successful in countries with low agricultural productivity and incomes (Pingali, 2012), the NGR must focus on the development of regionally adaptable crop varieties and agronomic practices that optimize production and profitability in all regions to successfully meet global production demands. However, the success of a NGR is hindered by 1) the refusal to adopt genetically modified (GM) crops and 2) water shortages. A significant challenge of the NGR is to dispel fears surrounding modern GM crops. Refusal to produce and import GM crops inhibits the potential for food security in many of world's poorest countries. GM crops benefit the farmer and the environment by providing crop resistance to specific insects and diseases, which potentially minimizes pesticide usage and enhances crop productivity. Secondly, global water shortages can only be addressed through continual improvements agronomic and irrigation management. Agronomic management includes adoption of high yielding, water efficient and heat tolerant varieties in addition to management practices that maximize crop water and nutrient use efficiencies as well as minimize soil degradation. Accordingly, a renewed focus in soil science is also a critical component of the NGR.

If improvements in agricultural productivity are to remain viable to end poverty and hunger, profitability is a principal component of agricultural sustainability. Globally, the adoption of new precision technologies has the potential to minimize land degradation and optimize crop water use. Although research has shown that adoption of precision technologies has positive environmental and social impacts, the price of technology as well as data management and interpretation can affect technological adoption in some regions (Asad, 2015). For the NGR to be as successful as the first Green Revolution, financial constraints and political limitations must be addressed. Lack of funding for agricultural research limits the speed at which progress and a NGR will be achieved. Pingali accurately stated that the success of the first green revolution was the result of the combined investment in agricultural research, infrastructure, markets and policy (2012). In 2008, it was been reported that $6.1 billion will be needed to address the African Food Crisis (Sief, 2017). The ability for federal agencies and universities to address global disparities in agricultural production has been hindered by universal reductions in agricultural funding, but the demand for agricultural innovation and productivity is as great today as it was at the onset of the Green Revolution (Pinghali, 2012; Herdt, 2010). As a NGR is on the horizon, there is the potential for global markets to shift with agricultural progress. Consequently, the NGR must have a global footprint to ensure global agricultural sustainability. This is essential to minimize regional dependence on imports which can result in corruption as well as maintaining profitable export markets. Ultimately, the NGR is challenged with 1) producing more food with less water while minimizing the expansion of cropland and 2) address disparities in global markets. A New Green Revolution is necessary to not only improve the local basis for farmers in developed countries where narrow profit margins are forcing many farmers out of business but minimize poverty and hunger in developing counties.

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