Agricultural and Resource Economics
UPDATE
GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS • UNIVERSITY OF CALIFORNIA
V. 17 no. 3 • Jan/Feb 2014

The Cost of Delaying Approval of Golden Rice

Justus Wesseler, Scott Kaplan, and David Zilberman

More than 250,000 children go blind every year because of Vitamin A deficiency. Vitamin A intake can be enhanced by consuming Golden Rice—a genetically engineered variety of rice. It was available for commercialization in 2002, but approval has been delayed. We estimate that this delay has resulted in 600,000 to 1.2 million additional cases of blindness.

Between 250,000 and 500,000 children go blind every year because of Vitamin A deficiency, and more than half die within a year of becoming blind. A total of 125 million children under the age of five suffer from Vitamin A deficiency, which has resulted in increased vulnerability to common childhood infections, higher likelihood of anemia, and poor growth.

There is sufficient evidence that people who suffer from these nutritional deficiencies are much less productive, more likely to remain poor, and die young. Many of the people who suffer from Vitamin A deficiency subsist on rice as a staple food. Rice produces beta-carotene that contains Vitamin A. However, it remains in the leaf and is not found in the grain people consume. One avenue to address Vitamin A deficiency is to add Vitamin A to rice, which is the idea behind Golden Rice.

By taking advantage of our better understanding of the genome of rice, and inserting only two genes into the genome of rice, which contains a total of 37,544 genes, a modified variety called Golden Rice was introduced. The more "golden" the rice is, the higher the concentration of beta-carotene, and since the prototype was developed in 1999, improved lines of Golden Rice have been generated.

The objective is to reach the recommended daily allowance of Vitamin A by consuming 100-200 grams of rice containing beta-carotene. A recent study found that a daily intake of 60 grams (one-half cup) of Golden Rice is sufficient in preventing Vitamin A malnutrition. From its inception, the technology has encountered major objections, mostly from environmental groups. In early versions of Golden Rice, there was a concern that it required a large intake of rice to meet daily allowances. However, over time the concentration of Vitamin A in Golden Rice increased substantially, and relatively modest consumption of Golden Rice can lower the risk of Vitamin A deficiency.

Another criticism was that Vitamin A deficiency could be avoided by distributing supplements to the poor, is a nice idea in theory, but has not been put into action. Likely, the real concern of opponents was that Golden Rice would act as a "Trojan Horse" that would lead to large-scale expansion of the adoption of genetically engineered (GE) food in developing countries.

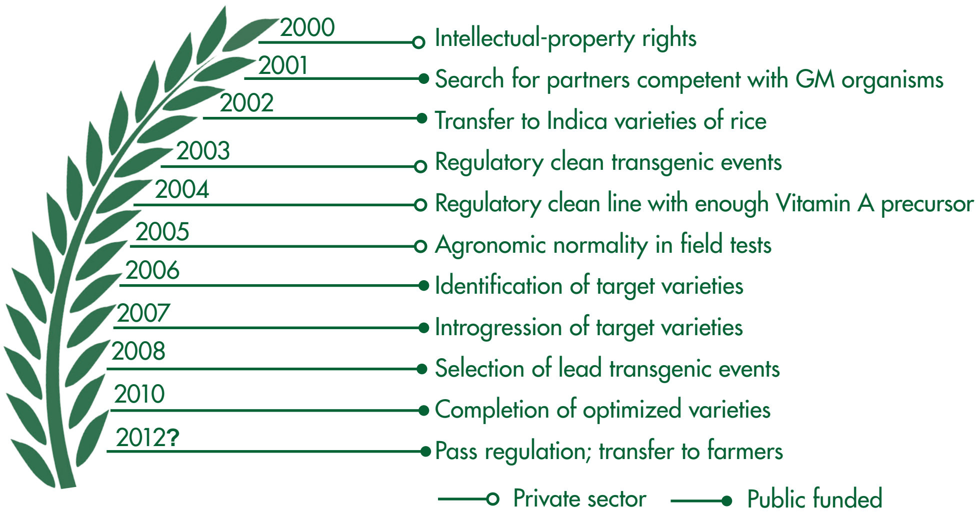
The proof of concept of Golden Rice has existed since the late 1990s, and it was expected that the first commercial variety would be available in 2002. In 2000 a public-private partnership started between the Golden Rice Humanitarian Project and the Syngenta Corporation that aimed to pass the regulatory approval process and bring the product to market. However, the regulatory bodies in India and Bangladesh have not approved thus far, even though there is a large body of evidence that suggests Golden Rice and other GE varieties do not produce greater health or environmental risks than non-GE varieties, clearly the primary reason for the delayed decision is objection from environmental groups.

Assessing the Impact of Delaying the Approval of Golden Rice

To assess the economics of regulating Golden Rice, we quantified the logic of the regulatory process. A regulator can approve the use of a new technology, ban it, or delay the decision in order to obtain new information. In the case of Golden Rice, regulators in countries

Also in this issue

Figure 1. A Decade of Regulatory Hurdles for Golden Rice



Source: Transgenic Plants for Food Security in the Context of Development

where Vitamin A deficiency is a major problem (e.g., India and Bangladesh) have decided to delay the choice.

The rationale for such a decision is that the gains from improved knowledge through delay are greater than the cost of the delay. The benefit from delay is the perceived cost of uncertainty about the outcome of a technology that may be reduced by delaying approval. In the case of a regulatory decision, this perceived cost quantifies the magnitude of the political pressure by people opposing the technology.

The costs of delay are the net benefits from adoption of Golden Rice that are lost. These net benefits are the sum of the discounted net benefits of reduced incidents of Vitamin A deficiency-induced health problems minus the cost of the introduction and adoption of the technology.

To derive the foregone benefit, had Golden Rice been adopted in India in 2002, we assume a gradual adoption of Golden Rice and estimate that the overall adoption would be around 30%, which is modest. The unit of measurement of foregone benefit is the disability-adjusted life year (DALY). These disabilities include blindness, measles, and mortality of children and pregnant women.

We estimated the number of DALYs lost because of the lack of availability of Golden Rice since 2002 to be between 1.4 and 2 million. We assume a very low value of a DALY (USD $500) in our initial calculation. The cost of the introduction of Golden Rice includes maintenance and breeding as well as social marketing of the new variety, which are much smaller than the benefit from improved health because of Golden Rice.

Based on these conservative assumptions, we estimated that the net present value of a 10-year delay in the introduction of Golden Rice to be USD $707 million. Note that $500 per DALY is a very conservative assumption. In the United States, it may be something like USD $20,000 or higher. If we increase the DALY to USD $2,000, the net loss is approximately four times as high.

The delay of approval by more than 10 years reflects that the cost of the various perceived risks associated with the introduction of Golden Rice is greater than the perceived benefits by a significant amount. Our calculation of these accumulated perceived risk costs estimates them to be at least USD $1.7 billion since 2002. The annual perceived cost of risk associated with the adoption of Golden Rice in India, alone, is estimated to be USD $199 million. The transition from annual cost was calculated based on a discounting factor that took into account the uncertainty about the magnitude of the risk. These estimated perceived costs of introduction provide an economic rationale for the delay. Of course, much of these costs really reflect the political pressure against its adoption.

An alternative approach to assess the policy-making process is to recognize that every year, between 250,000 and 500,000 children go blind, and in India alone, more than 70,000 die because of Vitamin A deficiency. If we assume global adoption of 20%, from 2002 until today, we could have prevented 600,000 to 1.2 million cases of blindness, and in India alone, about 180,000 deaths of children.

The Perceived Cost of Golden Rice

Whether viewed in monetary terms or the costs of blindness and death avoided, the delay of the introduction of Golden Rice was very costly. We know that the scientists fighting river blindness, a disease that affects millions of people and blinds about 300,000 in Africa, are justifiably treated like heroes. Thus, the perceived costs of Golden Rice must be very high to delay its introduction.

But where are these costs coming from? A 2012 publication of Greenpeace titled "Golden Illusion: The Broken Promises of 'Golden' Rice," states: "if introduced on a large scale, golden rice can exacerbate malnutrition and ultimately undermine food security." The concern is that Golden Rice may accelerate the adoption of other GE crops in developing countries, which is perceived by Greenpeace and others to be very dangerous.

However, the reality is quite different. A growing, large body of literature indicates that GE varieties have produced a significant amount of real benefit throughout the world, and its curtailment is a source of potential social loss.

Agricultural biotechnology applies the tools of modern biology to agricultural production. Genetic engineering has been a crucial element in developing medicine that is based on better understanding of biological processes, and is serving the same role in agriculture. For years, we have been modifying varieties by crop breeding, but GE technology increases precision and enables altering only a few genes.

Because of strict regulation, the adoption of GE has been limited. GE varieties have been introduced in corn, soybean, and canola mostly in the U.S., Canada, Brazil and Argentina, and to a large extent with cotton. There is significant adoption of GE varieties in papaya, and some application in rice and tobacco. Even though GE has been introduced in few crops, its impact on agricultural production is immense because it has increased productivity substantially. Furthermore, its impact on productivity has been higher in developing versus developed countries. Because of limited adoption in most of these regions, its potential has not been realized.

Without adoption of GE, soybean prices are estimated to have been 33% higher and corn prices 13% higher. Even though these crops are used to support livestock, the poor are consumers of meats, and they are affected significantly when there are food shortages.

The food crisis of 2008 is a good indicator of the consequences of high food prices. Without the contribution of GE varieties, we would see much more frequent food shortages. Our research suggests that if GE was adopted by European and African countries and introduced in grains, food prices would decline much more substantially, and the land footprint (total land acreage in production) would decline because of higher yields.

The higher yields associated with GE varieties have a significant positive environmental effect because of the reduction in use of fertilizer, water, and energy in agriculture. Some of the land-saving effect is because of the ability to use double-cropping to produce soybeans.

GE also benefits the environment because it allows certain toxic chemicals to be replaced, and there is evidence that it has already saved lives in developing countries. Of course, it encounters some problems with pest resistance and changes in use of herbicide, but the overall environmental effect is quite positive. Because GE provides a powerful mechanism to develop new varieties in a systematic manner, it can play an important role in providing strategies to adapt to climate change, which can significantly benefit developing countries that may face some of its most dire consequences.

GE was introduced in cotton in India in 2002, and has been adopted by over 90% of cotton farmers. As we know, adoption of technologies in India and other developing countries tends to be slow, and the high rate of adoption is one indicator that farmers perceive it to be beneficial. Studies have shown that farmers, including very poor ones, gain a significant share of the benefit as a result of high aggregate adoption. In some cases, it increases their income by 50% or even more.

The drastic increase in cotton yield because of GE increased the Indian share in world cotton production and benefitted its economy. The high rate of adoption of GE cotton and other varieties (when available) in India and other developing countries suggests that if Golden Rice would have been introduced, it would have been widely adopted.

If Golden Rice had been adopted, it might have led to further acceptance of GE technology and adoption of other traits in rice. While some groups may be concerned about it, based on evidence from China and the cases of cotton and corn, it seems that GE would increase the productivity of the rice sector and free up land and other resources for alternative uses.

Conclusion

Our analysis suggests that the delayed introduction of Golden Rice for over a decade has been very costly both in monetary terms as well as the hundreds of thousands of cases of blindness and child deaths. Political pressure by opponents to GE technology is likely to be one of the main causes for this delay. The irony of the situation was not lost on some of the individuals who opposed GE technologies. For example, Patrick Moore, one of the co-founders of Greenpeace, recognized that the poor have paid the majority of the price of the fight against GE technologies, and founded an organization called the "Allow Golden Rice Society." Golden Rice is an extreme case that illustrates global social loss from the heavy regulation of GE technology, and reevaluation of policies assessing these technologies is needed.

Suggested Citation:

Wesseler, J., S. Kaplan, and D. Zilberman 2014. "The Cost of Delaying Approval of Golden Rice." *ARE Update* 17(3):1-3. University of California Giannini Foundation of Agricultural Economics.

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For additional information, the authors recommend:

"Allow Golden Rice Now." www.allowgoldenricenow.org/component/content/article?id=29

Greenpeace. 2012. "Golden Illusion: The Broken Promises of 'Golden' Rice." Amsterdam:Greenpeace International. www.greenpeace.org/international/Global/international/briefings/agriculture/2012/GoldenRice/GoldenIllusion.pdf.

ARE Faculty Profile: Dalia Ghanem

Dalia Ghanem
Assistant Professor
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Dalia Ghanem has recently joined the faculty at the University of California, Davis as an assistant professor in the Department of Agricultural and Resource Economics (ARE). Her fields of interest are econometrics and environmental economics. Her work in econometrics is focused on improving existing methods for using longitudinal or panel data for economic and policy analysis. Her environmental research examines air pollution in China.

Dalia's country of origin is Egypt. She grew up in Alexandria, where she attended the German School in Alexandria. She received her B.A. in Economics and Political Science at the American University in Cairo (AUC). At AUC, Dalia volunteered for an international human rights lawyer and thought that she would pursue a career in that field, until she took her first course of econometrics. She simply got "hooked" and decided that a Ph.D. in econometrics was the right dream to pursue.

Before embarking on her journey to pursue a career in academia, Dalia first worked as a research analyst at the Egyptian Center for Economic Studies, a think-tank in Egypt. She also worked as a special assistant to Egypt's former minister of trade and industry, Rachid M. Rachid. These experiences still inspire how she sees her role as an academic in the "greater scheme of things."

The Ph.D. journey started with an M.Sc. in Econometrics at London School of Economics, followed by a Ph.D. in Economics at the University of California, San Diego, which she completed in June 2013. Her dissertation examined identification and estimation issues in nonlinear panel data models. Panel data are becoming widely available in many fields, including ARE. They allow empirical researchers to identify the effects of policies or changes in economic conditions on different states, firms, farms, or individuals. Since we usually lack experimental control in many policy settings, we worry about unobservable heterogeneity in our data that may confound our effect of interest. In the main chapter of Dalia's dissertation, she examines this identification question thoroughly and provides the empirical researcher with ways to test for whether his or her data can identify the effect of interest.

In another chapter of her dissertation (co-authored with Junjie Zhang), she applies the tests developed in her main dissertation chapter to examine the manipulation of air pollution data by Chinese cities. The Chinese central government has been monitoring air pollution of over 100 Chinese cities since 2001. Chinese local governments have been required to report their air pollution index (API) on a daily basis. This self-reported data enters the performance evaluation of local officials. Dalia and her co-author examine the incentive for manipulation in such a policy environment. They find evidence of manipulation for about half of the cities in their sample. Their results indicate that manipulation is more likely to occur on days where visibility is high and wind speed is low. It is intuitive that these conditions would be conducive to manipulation, since it is hard to be suspicious of a good API score when visibility is high. In addition, when wind speed is low, the pollutants are not simply "gone with the wind."

Currently, Dalia is continuing her empirical work on issues related to air pollution in China. She is collaborating with UC Davis professors Colin Carter and Shu Shen. Her current econometrics projects include developing new methods to measure the degree of data manipulation. She is also working on improving existing methods for inference in nonlinear panel data models. Next spring, she will be teaching econometrics to the first-year Ph.D. students, where she hopes to inspire them to learn and use state-of-the-art quantitative methods.

In her free time, she loves spending time with her husband, Sean Riordan, and their son, Fareed. They love going to the countless Davis parks, the rock-climbing gym, and the Davis Farmer's market, where Fareed rides the bicycle-powered carousel. On weekends, they enjoy exploring Sacramento and the Bay Area. They also love traveling to San Diego and Alexandria to visit family and friends.

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Managing International Migration in the Americas

Philip Martin

The number of international migrants, defined as persons outside their country of birth at least a year, reached 232 million in 2013, making 3.2% of the world's people international migrants. The United States is debating what to do about 11–12 million unauthorized foreigners, Canada is modifying its point-selection system to reduce brain waste, and some Latin American countries are attracting home citizens who emigrated.

The number of international migrants more than doubled between 1980 and 2010, from 103 million to 214 million, and the stock is projected to continue rising faster than population, doubling to over 400 million in 2050. Each international migrant is unique, and each migration corridor has unique features, but there are four major migration flows, often summarized as S-S, S-N, N-N, and N-S (Table 1):

- South-South: The largest flow of migrants, 74 million or 34% in 2010, moved from one developing country to another, as from Indonesia to Saudi Arabia or Nicaragua to Costa Rica.
- South-North: The second-largest flow, 73 million or 34%, moved from a developing to an industrial or more-developed country, as from Morocco to Spain, Mexico to the U.S., or the Philippines to South Korea; one-third of international migration involves south-north movement.
- North-North: Some 55 million people, or 26% of international migrants, moved from one industrial country to another, as from Canada to the U.S.
- North-South: Over 13 million people, or 6% of migrants, moved from industrial to developing countries, as with Japanese who work or retire in Thailand.

Most of the world's countries participate in the international migration system as countries of origin, transit, or destination, and many participate in all three phases of international migration.

This article explains why people cross national borders, the effects of international migration on sending and receiving countries, and the struggle to improve migration management in North America, Europe, and Asia.

Migration, Inequalities, and Revolutions

Migration is the movement of people from one place to another. Migration is as old as humankind wandering in search of food, but international migration across defined and policed national borders is a relatively recent development. It was only in the early 20th century that nation-states developed passports and visas to regulate the flow of people across their borders.

International migration is the exception, not the rule. The number-one form of migration control is inertia—most people do not want to move away from family and friends. Second, governments have significant capacity to regulate migration, and they do, as evidenced by long lines of people outside consulates seeking visas and large agencies that patrol borders and check on foreigners inside countries.

International migration is likely to increase with globalization and the creation of new nation-states. There were 193 generally recognized nation-states in 2000, four times more than the 43 in 1900.

The major reasons to expect more international migration are two inequalities coupled with three revolutions. The demographic inequality is simple: almost all population growth occurs in the world's 170 poorer countries, while the population of the 30 richer countries is expected to remain at 1.2 billion through 2050. The economic inequality is also straightforward. Worldwide GDP was $62 trillion in 2010, an average $9,000 per person a year. The 30 high-income countries had a sixth of the world's people but two-thirds of the world's economic output—an average $39,000 per person per year—ten times more than the $3,800 average in the poorer 170 countries. Many young people are motivated to try to cross national borders to earn ten times more.

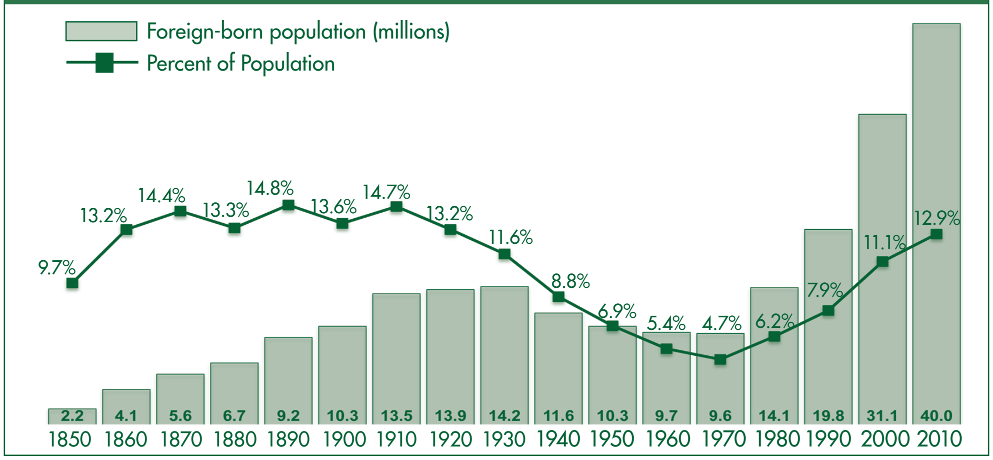
Demographic and economic inequalities are like battery poles, providing the potential for migration but not necessarily laying out a path for people to cross borders. Migration bridges or networks connect the demand-pull factors that attract migrants with the supply-push factors that motivate migration, and they have been

Table 1. International Migrants in 2010

Origin	Destination: Industrial	Destination: Developing	Total
	----------------millions--------------		
Industrial	55	13	68
Developing	73	74	147
Total	128	87	215
	------------percent of total-----------		
Industrial	26%	6%	32%
Developing	34%	34%	68%
Total	60%	40%	100%

Source: UN Population Division. 2010. International Migration Report. http://esa.un.org/migration/

Figure 1. Foreign-born Population and Immigrant Share of U.S. Population, 1850–2010



enlarged by revolutions in communications, transportation, and rights.

The communications revolution highlights the ease with which information flows over national borders. In the mid-19th century, when literacy rates in rural areas were often low, the so-called American letters sent to friends and relatives in Europe describing opportunities took weeks or months to arrive, and then the recipient would have to find someone literate to read the letter and draft a response. Today, mobile phones and the internet transfer information much faster and cheaper over national borders.

The transportation revolution refers to the ever-lower cost of travel. In the mid-18th century, many migrants to what became the U.S. could not afford the one-way fare, so they signed indentured-servant contracts that obliged them to work four to six years for whoever met the ship and paid the captain. Today, the one-way cost of traveling legally to almost anywhere in the world is less than $3,000, and even migrants who pay smugglers $20,000 or more to get into higher-wage countries can usually repay this cost in less than two years.

The rights revolution refers to the expansion of political, social, and economic rights in most countries over the past half-century. UN human rights conventions grant basic civic rights to all persons, labor conventions call for all workers to be treated equally in the workplace, and national laws often grant at least some political, social, and other rights to all residents. Once inside a country, governments may have difficulty removing foreigners who want to stay.

Policy makers grappling with unwanted migration can do little in the short-term to reduce demographic and economic inequalities, and they do not want to roll back communications and transportation revolutions. The instrument most readily available to alter migration flows quickly is rights, and adjusting migrant rights is the policy tool often used to deal with migration crises.

For example, as welfare rolls climbed alongside federal budget deficits, President Bill Clinton pledged to "end welfare as we know it." Immigrants loomed large in the 1990s welfare reform debate as some wealthy U.S. residents sponsored their elderly parents for immigrant visas and, after their arrival, enrolled them in welfare programs. Children born to unauthorized foreigners in the United States are U.S. citizens, and some were enrolled in cash assistance and health-care programs—one factor in California voter approval of Proposition 187 in 1994.

Congress debated two broad options to deal with immigrants and welfare: admit fewer needy immigrants and maintain their access to the welfare system under the theory that first, reduce welfare costs by admitting fewer needy immigrants and second, continue admitting the same number and type of immigrant but restrict their access to welfare benefits. Congress elected the second option, and denied federal welfare benefits to most immigrants who arrived after August 22, 1996, until they became naturalized U.S. citizens or worked in the United States 10 years. As a result, 45% of the expected savings from welfare reforms came from denying benefits to the immigrants who were 11% of U.S. residents.

Adjusting migrant rights to manage migration generates heated reactions from those who advocate a rights-based approach to migration. Under this theory, all persons in a country have fundamental rights by their presence, and those employed have the right to equal wages and benefits and the other entitlements granted to local workers. Many advocates of a rights-based approach to managing migration want both more international migration and more rights for migrants, and do not acknowledge any trade-off between migrant numbers and migrant rights.

United States

The United States is a nation of immigrants. Under the motto "e pluribus unum" (from many one), U.S. presidents frequently remind Americans that they share the experience of themselves or their forbearers beginning anew in the land of opportunity. Immigration is widely considered to be in the national interest, since it permits immigrants to better themselves as it strengthens the United States.

For its first 100 years, the United States facilitated immigration, welcoming foreigners to settle a vast country. Beginning in the 1880s, certain types of immigrants were barred, including prostitutes, workers who arrived with contracts that tied them to a particular employer for several years, and Chinese—beginning an era of qualitative immigration restrictions. In the 1920s, quantitative restrictions or quotas were added that set a ceiling on the number of immigrants accepted each year.

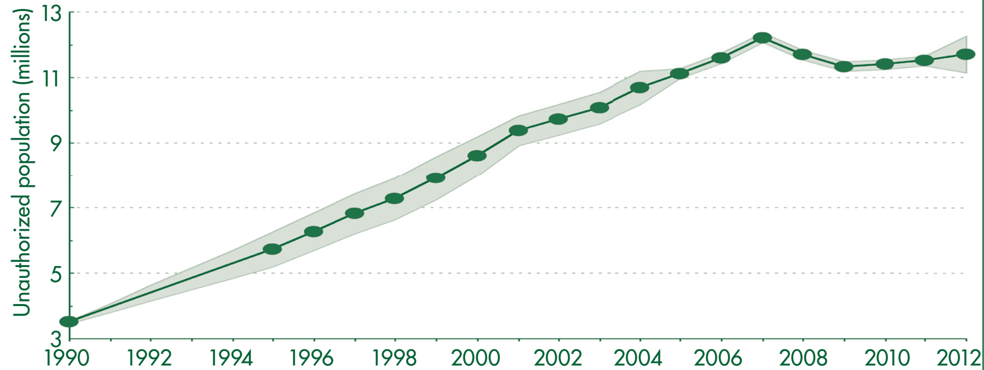
Immigration law changed in 1965. Qualitative and quantitative restrictions were maintained, but national origin preferences that favored the entry of Europeans with U.S. relatives were replaced by a selection system that favored the admission of foreigners who had U.S. relatives or were requested by U.S. employers. During the 1970s, the origins of most immigrants changed from Europe to Latin America and Asia.

U.S. immigration has occurred in waves, meaning peaks and troughs (Figure 1). The first wave arrived before records were kept beginning in 1820, when most of the newcomers were English-speakers from the British Isles. The second wave was dominated by Irish and German Catholic immigrants in the 1840s and 1850s, and the third between 1880 and 1914 brought over 20 million immigrants to the United States, an average 650,000 a year at a time when the United States had 75 million residents. Third-wave European immigration was slowed first by World War I, and then by numerical quotas in the 1920s.

The fourth wave began after 1965, and has been marked by rising numbers of immigrants, mostly from Latin America and Asia. The United States admitted an average 250,000 immigrants a year in the 1950s, 330,000 in the 1960s, 450,000 in the 1970s, 735,000 a year in the 1980s, and over a million a year since the 1990s.

The major immigration debate today is what to do about the 11–12 million unauthorized foreigners in the United States (Figure 2). The Senate approved a comprehensive immigration reform bill (S 744) in June 2013 that increases enforcement to prevent illegal migration, provides a path to legal immigrant status and U.S. citizenship for most of the unauthorized foreigners, and expands and creates new guest worker programs. The House is expected to debate bills that would increase enforcement, provide a path for some unauthorized foreigners to immigrant status but not U.S. citizenship, and expand and create new guest worker programs.

Figure 2. Estimates of the U.S. Unauthorized Immigrant Population, 1990–2012



Source: Pew Hispanic Trends, Passel, Cohn and Gonzalez-Barrera, 2013. Shaded area represents 90% confidence interval.

Canada

Canada is an immigration exception among industrial countries, with high levels of immigration, generous social welfare programs, and significant public satisfaction with immigration policies. Many analysts trace this satisfaction to Canada's point selection system that favors the entry of young and well-educated foreigners who know English or French and have Canadian work experience.

Canada differs from the United States because over half of the legal immigrants include a family member who achieved enough points to obtain an immigrant visa. The point selection system ensures that the average educational level of adult immigrants arriving in Canada exceeds the average educational level of Canadian-born adults.

Many adult immigrants have college degrees, but some cannot find Canadian jobs that use their education, resulting in brain waste, as when an immigrant doctor drives a taxi because he cannot obtain a Canadian medical license.

Canadian immigration patterns mirror those of the United States, and its policy changes were similar until the 1970s. For example, the United States barred Chinese immigrants in 1882, and Canada limited Chinese immigration in 1885. Immigration to Canada peaked between 1895 and 1913, when 2.5 million newcomers arrived in a country that had a 1913 population of 7 million.

Canada is a bilingual and multicultural society. The goal of achieving unity between English and French speakers has been the focus of Canadian politics for much of the past half-century, and many of the policies that make Canada a bilingual and bicultural society also affect immigration. For example, the provinces play a role in selecting immigrants, so the Quebec government selects immigrants to bolster the number of French speakers.

Mexico

Until recently, Mexico was Latin America's major emigration country, sending up to 500,000 people to the United States each year. Mexico-U.S. migration slowed during the 2008–09 recession, and Mexico also became a destination for migrants from poorer Central American countries. Some Americans, often Mexicans who have lived in the United States, retire to Mexico.

Mexico-U.S. migration, both legal and illegal, remained low until the 1970s, when the Mexican peso was devalued, making higher U.S. wages more attractive. Ex-Mexican guest workers, known as Braceros, crossed the border illegally with their relatives and friends in the 1970s, and there were no penalties on U.S. employers who hired them. The stream of Mexican migrants turned into a flood in the 1980s, and the United States responded with the Immigration Reform and Control Act of 1986 (IRCA), which legalized 2.7 million unauthorized foreigners—85% Mexicans. IRCA had the unintended consequence of encouraging more Mexicans to move illegally to the U.S. in anticipation of another amnesty and to spread Mexicans throughout the United States.

Mexico in 1990 proposed the North American Free Trade Agreement (NAFTA). NAFTA lowered trade and investment barriers between Canada, Mexico, and the United States after 1994, and was expected to reduce Mexico-U.S. migration as Mexico sent tomatoes rather than tomato pickers to the United States. Instead, there was a Mexico-U.S. migration hump, as increased free trade eliminated jobs in Mexican agriculture faster than investment could create new nonfarm jobs. During the late 1990s, as Mexico recovered from another peso devaluation and the United States was creating 10,000 net new jobs every work day, Mexico-U.S. migration peaked at over 700,000 a year.

Mexico fared better than the U.S. during the 2008–09 recession. The combination of improving economic conditions in Mexico and stepped up border and interior enforcement in the United States slowed net Mexico-U.S. migration to almost zero, meaning that as many Mexicans returned to Mexico as arrived in the United States. The unknown questions include whether Mexico-U.S. migration will increase again with U.S. economic recovery and what effects a new U.S. legalization program would have on Mexico-U.S. migration patterns.

Central America, Caribbean, and South America

The seven countries of Central America, with 44 million residents, sent few migrants to the United States until civil wars erupted in the mid-1980s. Fighting displaced tens of thousands of Guatemalans, Nicaraguans, and Salvadorans, some of whom migrated to the United States. The U.S. government initially granted asylum to Nicaraguans, who were fleeing a government the United States opposed, but not to Guatemalans and Salvadorans fleeing governments the United States supported.

Most Central Americans in the United States became immigrants, and family unification and unauthorized migration followed. Natural disasters allowed unauthorized Central Americans in the United States to receive "Temporary Protected Status" (TPS) so they could work legally and send home remittances to help in rebuilding. TPS has been renewed since, and there are there are now large communities of Guatemalans, Hondurans, Nicaraguans, and Salvadorans in the United States.

The 15 independent Caribbean nations and dependencies have 42 million residents and some of the world's highest emigration rates, as over 10% of persons born in Cuba, Dominican Republic, Haiti and Jamaica have left—usually for the United States. Immigration to the U.S. from the Caribbean averages 100,000 a year, including one-third from the Dominican Republic and one-sixth each from Haiti, Cuba, and Jamaica.

South America's 400 million residents are two-thirds of the 600 million people in Latin America. A century ago, Italians and Spaniards migrated to Argentina and Brazil and Japanese to Brazil and Peru. During the 1990s, some of their descendents of these immigrants returned to Italy, Spain, and Japan in search of better economic opportunities, but migration from South America to Europe and Japan reversed in recent years, as some South Americans abroad returned.

Conclusions

The number of international migrants, people living outside their country of birth or citizenship, reached an all-time high of 232 million in 2013. The number of migrants is likely to continue increasing because of demographic and economic inequalities between countries, and revolutions in communications and transportation that enable migrants to learn about opportunities abroad and travel to take advantage of them. Policy makers often react to migration crises by restricting the rights of migrants, drawing protests from advocates who urge a rights-based approach to managing migration.

Every one of the world's 200 countries participates in the international migration system as a source or destination for migrants or a country through which migrants transit. Many countries participate in all three ways. Most migrants do not move far from home, and each of the world's continents has a migration system with unique characteristics, including the large number of unauthorized migrants in the United States, the point selection system of Canada, and high emigration rates in many Latin American countries.

Suggested Citation:

Martin, P. 2014. "Managing International Migration in the Americas." *ARE Update* 17(3):5-8. University of California Giannini Foundation of Agricultural Economics.

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For additional information, the author recommends:

Hollifield, J., P. Martin, and P. Orrenius, Eds. 2014. *Controlling Immigration. A Global Perspective.* Stanford University Press. www.sup.org/book.cgi?id=22520

Migration News. http://migration.ucdavis.edu

Buffer Zone Regulations and Alternatives to Pre-plant Soil Fumigation: Using Steam in California Strawberry Production

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The number of regulations regarding pre-plant soil fumigation is increasing. Buffer zones are required for methyl bromide and chloropicrin applications. Choosing application blocks, methods, and rates to maximize profits is becoming a difficult challenge for growers. One consideration is the management of the buffer zone. We consider the costs and returns of using steam for pre-plant soil disinfestation in a non-fumigated buffer zone.

California strawberry growers face an increasing number of regulations regarding preplant soil fumigation. Buffer zones are required for methyl bromide applications under state and federal rules, and for chloropicrin applications under the EPA's Phase II regulations (implemented December 2012). Additional state regulations regarding chloropicrin are currently under consideration by the California Department of Pesticide Regulation (CDPR).

Broadly speaking, growers may take one of four approaches to buffer zone management. First, the buffer zone may be left fallow but it will not produce any revenue and may incur costs, such as weed management costs. Second, an alternative crop that does not require pre-plant soil fumigation could be planted, which makes the logistics of farming the site more complex and less efficient. Third, the buffer zone could be planted in strawberries even though it is not fumigated. This could create a pathogen and pest reservoir that would affect production in the interior of the field. Finally, the buffer zone could be treated with a non-chemical alternative that is not subject to buffer zone requirements. We consider the costs and benefits of treating a buffer zone with pre-plant soil disinfestation using steam.

Current Fumigants and Regulations

In 2011 chloropicrin (CP) was used on 94% of all pre-plant soil fumigation of strawberry acreage. Of the total acres treated, 51% was treated with 1,3-dichloropropene (1,3-D) + CP, 33% with methyl bromide (MBr) + CP, 10% with CP alone, 4% with metam sodium, and 2% with metam potassium, according to CDPR's Pesticide Use Reporting database.

The December 2012 U.S. Environmental Protection Agency (EPA) Phase II regulations for CP include two sets of buffer zone requirements which are on all product labels: buffer zones surrounding difficult-to-evacuate sites (DES) and general buffer zones intended to limit exposure in order to protect human health. The EPA defines DES as including pre-kindergarten to grade 12 schools, state-licensed daycare centers, nursing homes, assisted-living facilities, hospitals, inpatient clinics, and prisons. For these sites, no fumigation with a buffer zone greater than 300 feet is permitted within one-quarter mile, unless the DES is unoccupied for 36 hours following the start of the fumigation. For buffer zones of 300 feet or less, the minimum distance from a DES is one-eighth mile.

For the second set of buffer zone requirements, EPA selected buffer zone distances to protect bystanders from exposure to CP. The minimum allowable buffer zone distance is 25 feet. The distances vary based on the product applied, the application rate, the application block size, application equipment and methods, and, if applicable, credits for use of emission-reduction measures such as the use of tarps. Table 1 illustrates these differences by presenting the buffer zone distance requirements for the application of Pic-Clor 60 at 210 lbs/acre, with totally impermeable film (TIF) using two application methods, drip and broadcast, for four field sizes.

Activities are restricted in the buffer zone from the start of the application through a minimum of 48 hours after the application is complete. All non-handlers are excluded from the buffer zone except for purposes of transit, including agricultural workers not involved in the fumigation. If the buffer zones overlap, a minimum of 12 hours must elapse from the end of the first application to the beginning of the second.

In some cases, the buffer can be extended outside the treated field so that all field acreage can be treated. In other cases the buffer cannot extend outside the field, which reduces treated acreage. We refer to the latter case as a "binding" buffer zone. In order to provide a sense of how much acreage can be lost due to binding buffer zones, Table 2 presents the share of field acreage that

Table 1. Buffer Zone Distance by Application Block Size and Treatment Method

Application Block Size (Acres)	EPA buffer (feet) for TIF drip	EPA buffer (feet) for TIF broadcast
5	25	30
10	45	64
20	78	92
40	132	158

Pic-Clor 60, 201 lbs/ac, Totally Impermeable Film

Table 2. Buffer Zone Acreage and Share of Field Acreage in Buffer Zones								
Field Size (acres)	5		10		20		40	
Buffer Zone Width	Buffer Zone Acres	Percent of Field Acres	Buffer Zone Acres	Percent of Field Acres	Buffer Zone Acres	Percent of Field Acres	Buffer Zone Acres	Percent of Field Acres
25	0.3	5%	0.4	4%	0.5	3%	0.8	2%
50	0.5	11%	0.6	8%	1.1	5%	1.5	4%
100	1.1	21%	1.5	15%	2.1	11%	3.0	8%
200	2.1	43%	3.0	30%	4.3	21%	6.1	15%

is part of the buffer and, hence, not part of the application block for a range of field sizes and buffer distances.

Possible Responses to Buffer Zone Regulations

If the buffer zone distance cannot extend outside the field, then the grower has an incentive to reduce it. One response to the buffer zone regulations that growers could elect to pursue is to divide fields into multiple, smaller application blocks in order to qualify for smaller buffer zone distances. Another response would be to treat the same ground multiple times using lower application rates (and perhaps different products) in order to reduce buffer zone distances. However, both actions would extend the period of calendar time required to complete pre-plant soil fumigation of the eligible acreage. This, in turn, can delay planting and, ultimately, harvest. On the other hand, if a buffer zone can extend outside the treated field, there is no reason for a grower to reduce the buffer zone distance further and increase the time required to complete fumigation.

Table 3. Steam Applicator Cost Estimates	
Price to Operator	$207,717
Application Rate	15.5 hrs/ac
Equipment Life	7 years
Annual capital recovery cost	$35,573
Annual repairs	$4,154
Annual steam machine cost/treated acre	$253

The extent to which buffer zone regulations reduce strawberry acreage eligible for pre-plant soil fumigation is unknown, but there will be acreage losses in some cases. Growers will have to manage buffer zones. As noted above, there are four basic choices, each with its challenges: fallowing, planting an alternative crop, planting strawberries without fumigating, and treating with a non-chemical alternative to fumigation. We evaluate the economic feasibility of pre-plant soil disinfestation using steam utilizing data from two separate field trials: comparing net returns on a per-acre basis to an untreated control, and comparing net returns on a per-field basis to fallowing the buffer zone or planting strawberries in an untreated buffer zone.

Economic Viability of Steam on a Per-acre Basis

One of the key determinants of economic viability is whether or not pre-plant soil disinfestation using steam provides effective control of pathogens, pests, and weeds. The extent of control influences production costs and yields. A field trial conducted in the 2012–13 growing season evaluated steam's efficacy.

The trial included four strawberry varieties. Different genetic stock may have different levels of tolerance for important pests and pathogens, which in turn, can affect the efficacy of pre-plant soil disinfestation using steam. The varieties included the University of California variety Albion and three proprietary varieties—referred to as P1, P2, and P3 here. Two treatments, steam and steam + mustard seed meal (MS), were applied to each variety and each variety had an untreated control.

Results show that the treatments provided effective control. These results were then used to evaluate the economic returns for the two treatments. Net returns were calculated using *2010 Sample Costs to Produce Strawberries,* cost information regarding the steam applicator (Table 3), and price data from the USDA Agricultural Marketing Service. The average shipping point price for California nonorganic strawberries for flats containing eight 1-lb. containers was $9.99 during the trial period.

Net returns are reported in Table 4. Of the four strawberry varieties, P1 had the highest net return for both treatments and the control. Comparing the treatments, steam yielded the highest return for each strawberry variety. However, net returns varied considerably across the four varieties. This comparison suggests that growers who are considering using steam to treat buffer acreage should consider the performance of varieties when soil is treated with steam, rather than fumigants, prior to planting.

Additional analysis confirms that the net revenues of the treatments are sensitive to the strawberry shipping point price, fuel price, and the speed of the steam applicator. A higher shipping point price, lower fuel price, and faster applications generate higher net profits. The relative importance of variations in these factors depends on yields. Higher yields generate a larger effect on net

Table 4. Net Revenues per Acre			
	Steam	Steam+ MSM	Control
Albion	$7,381	$5,395	-$5,231
P1	$10,109	$9,464	-$1,296
P2	$9,349	$8,838	-$3,979
P3	-$2,308	-$4,820	-$4,430

Table 5. Net Revenues by Buffer Zone Treatment: 20-acre Square Field, 78-foot Buffer on One Side

Buffer treatment	Field-level Net Revenue
Steam	$10,799
Untreated	$9,752
Fallow	$5,312

revenues for any given change in price.

The non-treated control had negative returns for all varieties. This result suggests that planting strawberries on untreated buffer zones may not be economically attractive.

Buffer Zone Steam Treatment for a Fumigated Field

Apart from its per-acre performance, steam can affect total returns to a field by increasing net revenues, as well as providing better control of pests and pathogens in buffers that cannot be fumigated prior to planting. We illustrate this possibility using the example of a 20-acre square field. Where permitted by regulation, the field is treated with Pic-Clor 60 (56.7% of CP and 37.1% of 1,3-D) through drip application at the application rate of 250 lbs./acre with totally impermeable film.

As reported in Table 1, this treatment requires a 78-foot buffer. In the example, the buffer zone is entirely within the field on one side, so that only 18.33 acres may be fumigated and the 1.67 acres in the buffer zone may not. Data regarding weed control and yield for steam, Pic-Chlor 60, and an untreated control are from a 2010–11 trial near Watsonville, CA.

We compare the field-level net returns for three options for managing the buffer zones: fallowing, planting strawberries without any pre-plant treatment, or planting strawberries using steam for pre-plant soil disinfestation. Results are reported in Table 5.

Treating the buffer with steam prior to planting strawberries results in higher net revenues for the field than not treating the field—approximately $1,000 or around 10% of net revenue. Planting strawberries results in field-level net revenues that are higher than fallowing. The benefit from steam over untreated and/or fallow in the buffer zone for any given field is greater as the buffer zone increases.

Conclusion

The increasing number and complexity of use regulations and associated label restrictions regarding pre-plant soil fumigation increases the challenges associated with managing pest and disease pressure in an economically viable way. Effective buffer zone management is one such challenge. Pre-plant soil disinfestation using steam is one method that can enhance field-level returns for California strawberry production when buffer zone requirements prohibit fumigating some portion of a field.

The use of steam for pre-plant soil disinfestation extends beyond strawberry production. Organic producers can incorporate it into their pest management programs. Much of California's flower production occurs on small fields close to urban areas, even more than in the case for strawberries, so steam can be a part of that industry's response to increased regulation as well. Similarly, there is interest in using steam for golf course renovation.

More broadly, the development of new technology takes years. The regulatory environment is changing much more rapidly. The economically viable uses of steam will almost certainly increase as the technology continues to be improved and regulations become more stringent.

Suggested Citation:

Xu, Y., S.A. Fennimore, R.E. Goodhue, K.M. Klonsky, and T. Miller. 2014. "Buffer Zone Regulations and Alternatives to Pre-plant Soil Fumigation: Using Steam in California Strawberry Production." *ARE Update* 17(3):9-11. University of California Giannini Foundation of Agricultural Economics.

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For additional information, the authors recommend:

Fennimore, S., T. Miller, R. Goodhue, N. Dorn, J. Broome, J. Muramoto, C. Shennan and F. Martin. "Evaluation of an Automatic Steam Applicator in Strawberry: 2012-13 Results." Presented at the 2013 Methyl Bromide Alternatives Conference, November 2013. http://mbao.org/2013/Proceedings/11FennimoreS.pdf.

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Agricultural and Resource Economics
UPDATE
GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS • UNIVERSITY OF CALIFORNIA

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One Shields Avenue
Davis CA 95616
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http://giannini.ucop.edu

ARE Update is published six times per year by the Giannini Foundation of Agricultural Economics, University of California.

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