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PERSPECTIVE

Food and fuel for all: realistic or foolish?

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Abstract

In 2005, few would have predicted the current revolution in global agriculture that is being driven by a sudden rise in the price of petroleum and a rapid expansion of global biofuel production from grain, sugar, and oilseed crops. The result has been a convergence of valuation between petroleum and agricultural commodities such that food prices are likely to rise substantially. While countries with adequate resources to support an expansion of biofuel crop production will benefit from this convergence, developing countries and regions that consistently experience food shortages or rely on food imports will face greater food insecurity. To avoid an excessive rise in food prices and increased numbers of undernourished will require a rapid response to improve global targeting of research and development funds to assure an acceleration in food production capacity while protecting natural resources and environmental quality.

Keywords: biofuels, corn-ethanol, crop yields, food security, sustainability

Introduction

In 2005, few would have predicted the current revolution in global agriculture. For more than 50 years, the real price of major food crop commodities such as maize, wheat, rice, and sugar have steadily decreased due to continuous improvements in agricultural production and trade.[1] But in the past year there has been an abrupt rise in commodity prices despite abundant supplies. For example, in each of the past three years (2004–2006) the US maize crops were the largest in history, yet maize prices rose abruptly from \$78 t^{-1} in December 2005 to \$142 t^{-1} in December 2006. Anticipation of a marked rise in maize demand from the rapidly expanding ethanol biofuel industry is the reason for this fundamental change in valuation. Hence, prices for crops that can be used for both food and fuel are now determined by their value as a feedstock for biofuel rather than their value as human food or livestock feed.[2]

Driving forces

The steep rise in petroleum price is the primary reason for the increase in food crop prices. Petroleum prices have risen because of political instability in major oil-exporting regions and rapid demand growth in China, India, and other developing countries. A price range of \$53–63 per barrel is predicted through 2010.[3] At prices above \$50 per barrel it is profitable to produce

Figure 1. A maize grain-ethanol biorefinery in Hastings, Nebraska, which uses about 0.6 million tons of grain annually to produce 250 million liters of ethanol.

ethanol from maize grain without subsidies.[2] Current trends of crop yield growth, greater fertilizer efficiency, and improvements in biofuel plant design and use of co-products promise to further increase profit margins from biofuel production. In response, there is rapid expansion of biofuel production capacity from food crops in the USA, Brazil, Europe, and several Southeast Asian countries. Food crops used for biofuel production include: grains (maize, sorghum, wheat), sugar crops (sugarcane, sweet sorghum, sugar beet), starch crops (cassava), and oilseed crops (soybean, oil palm, rapeseed). In the USA, for example, ethanol production from maize grain (hereafter called maize-ethanol) was 15 billion liters in 2005, requiring 36 MMt of grain, or about 13% of the total maize crop.[4] Although the 2005 Energy Policy Act mandates annual production of 28 billion liters of ethanol by 2012, current rates of expansion suggest a substantial overshoot of this target as maize-ethanol biorefineries are sprouting up throughout the Corn Belt (Figure 1). One recent estimate predicts USA ethanol production will reach 37 billion liters by 2010, which would require about 30% of the projected USA maize crop assuming a 10% increase in maize area and trend-line increases in crop yields.[5] Indonesia and Malaysia are planning to devote 40% of their current palm oil output for production of biodiesel.[6] Together these two countries account for 88% of global palm oil exports,[7] which means reduced supplies of this relatively low-cost vegetable oil on global markets unless there is a large expansion of area cropped to oil palm.

Other factors supporting expansion of biofuel production include the contributions to economic development, especially in rural areas, and environmental benefits. Growth of the US maize-ethanol industry from 2005–2012 is expected to increase GDP by $200 billion from direct and indirect economic effects.[4] Because higher grain prices contribute to greater farm income, there is potential to reduce crop subsidies in developed countries, which would foster improved trade relations with developing countries that view reduced subsidies as a precondition for liberalized trade agreements.[8] Finally, substitution of biofuels for gasoline is generally thought to further the environmental goal of decreasing greenhouse gas (GHG) emissions. Although estimates of GHG emission reductions vary, the most comprehensive studies to date estimate a net reduction of 13–35% for maize-ethanol.[9,10] Moreover, there is tremendous potential to increase this reduction through adoption of more environmentally sound crop and soil management practices and improved design of ethanol plants.[2]

Some criticize policies to promote biofuel production from food crops because only a relatively small portion of global motor fuel requirements can be replaced without causing an unacceptable rise in food prices.[11, 12] However, even 10% petroleum replacement of today's motor fuel usage would represent an important component of a broader strategy that includes development of other renewable energy sources, such as wind and solar energy, and aggressive conservation measures to improve vehicle fuel efficiency. For example, annual US production of 60 billion liters of maize-ethanol, as deemed possible by the National Corn Growers Association,[13] would represent replacement of

8% of current gasoline use, and considerably more if energy efficient vehicles were promoted to reduce gasoline consumption (these calculations account for the lower energy content of ethanol, which is about 70% that of gasoline). Furthermore, a number of developing countries (Brazil, Indonesia, Malaysia, and several African countries) will be able to substitute a much greater portion of their petroleum use because of relatively small motor fuel consumption levels and substantial potential to increase production of biofuel crops.

Given these trends, total food crop supply will ultimately determine the maximum biofuel production capacity that can be achieved without causing food shortages and high food prices, which would lead to increased poverty and hunger. While a transition to ethanol production from cellulosic biomass crops not used for food is a promising option to reduce the intensity of food versus fuel competition, we believe profitable technologies for large-scale biomass production, harvesting, transport, storage, and conversion to ethanol, which are prerequisites for rapid expansion of cellulosic ethanol production capacity, are at least 7–10 years off . In the meantime, global biofuel production capacity from food crops will build out rapidly. Hence, a key issue is whether crop productivity can grow fast enough to meet global demand for food, feed, and fuel during this buildout phase.

Food supply and hunger

Developing countries with adequate arable land, water resources, and infrastructure to support an expanded biofuel industry may realize substantial economic benefits from the biofuel revolution. The sugarcane-ethanol industry accounts for 4.2 million jobs in Brazil,[14] while the palm oil-biodiesel industry in Indonesia is expected to create 2.5 million jobs over the next three years.[15] Such employment opportunities represent a strong foundation for economic development although appropriate policies are also needed to foster equitable distribution of these benefits. In contrast, there are more than 850 million undernourished people in the world with greatest numbers in India (212 million), Sub-Saharan Africa (206), South and Southeast Asia (152), and China (150).[16] Reducing these numbers by half is a critical component of the United Nations Millennium Development Goals. Although it is widely recognized that most food insecurity is caused by poverty and associated public policy failures,[17] rather than actual food shortages, widespread use of food crops for biofuels is likely to result in higher food prices, which increases the risk of hunger for the world's poor. Over the longer term, however, higher crop value may motivate policy-makers in developing countries to make greater investments in the agricultural research, education, and rural infrastructure required for improved agricultural productivity—reversing a decades-long trend of disinvestment. Renewed investment is especially important for enhancing economic development in countries where a majority of the population depends on agriculture for their livelihood.

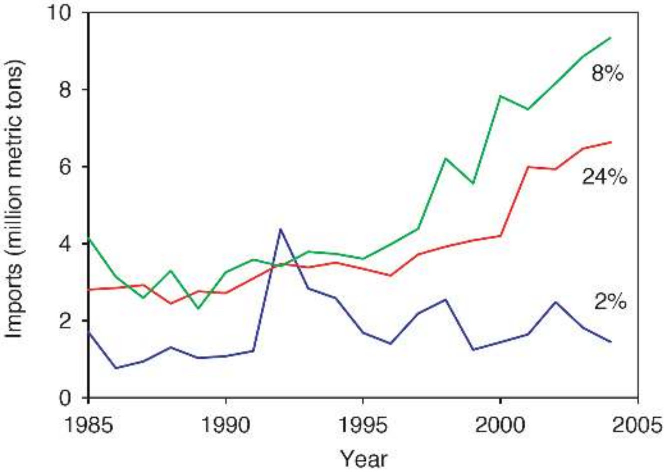

Figure 2. Sub-Saharan Africa grain imports: Maize (blue), rice (red), and wheat (green). Percentages represent the proportion of total world exports that were imported to Sub-Saharan Africa in 2004 (FAOSTAT 2006).

Regions that experience acute food shortages, or are net food importers on a regular basis, are likely to face greater food insecurity challenges in the short term before higher grain prices can stimulate a renewed emphasis on agricultural development. Sub-Saharan Africa is particularly vulnerable since it is heavily dependent on grain imports (Figure 2) and has seen an increase in the number of undernourished people in recent years.[16] Although maize imports are small relative to imports of rice and wheat, higher prices for biofuel crops will indirectly raise prices of all major food crops because farmers will shift area from lower-yielding food crops like rice and wheat, to higher-yielding and more profitable biofuel crops such as maize and sugarcane. Therefore, net grain importing countries and regions will be in a race against time to improve agricultural productivity as food prices rise and there is less surplus for export and humanitarian aid.

Crop production capacity for biofuels and food – the case of US maize

Policy-makers in the USA do not anticipate difficulties in meeting maize requirements for both food and fuel. Agriculture Secretary Mike Johanns recently stated that "A top seed company announced it is developing an experimental drought-tolerant maize seed that may boost yields in dry areas by an astounding 40 percent, not in the next lifetime but in the next few years."[18] At the same conference, Dr Robert T. Fraley, Chief Technology Officer of Monsanto, echoed this optimism with regard to progress towards developing drought resistant maize. In addition, Fraley predicted average US maize yields will double within a generation. Given current average US maize yields of about 9.2 metric tons ha^{-1}, this would require a 2.3% exponential rate of annual yield increase over the next 30 years to reach average yields above 18 metric tons ha^{-1}. Such optimism is certainly good news to maize consumers who worry about adequate grain supply for food and livestock feed because the USA is the largest maize producer in the world accounting for about 40% of global production and 60% of global exports.[7] It is also good news for environmental groups that have supported expansion of biofuel production because such rapid rates of yield gain will reduce the need to expand maize production onto fragile land in the Conservation Reserve Program. But are these optimistic predictions reasonable, and what would it take to achieve them?

The 40-year time trend for USA maize yields is markedly linear, not exponential, and has proceeded at a steady annual rate of 112 kg ha^{-1} (Figure 3). This rate of increase represents only a 1.2% relative rate of gain when compared to the 2005 trend-line yield of 9.2 metric tons ha^{-1}. It also is notable that the other major cereals follow linear rates of gain.[19] And, because yield gains are increasing in a linear fashion, the relative rate of gain decreases over time as average yields rise. Hence, Fraley's prediction of a 2.3% exponential rate of increase would require an abrupt jump in the rate of yield gain and a steady acceleration of yield growth over time.

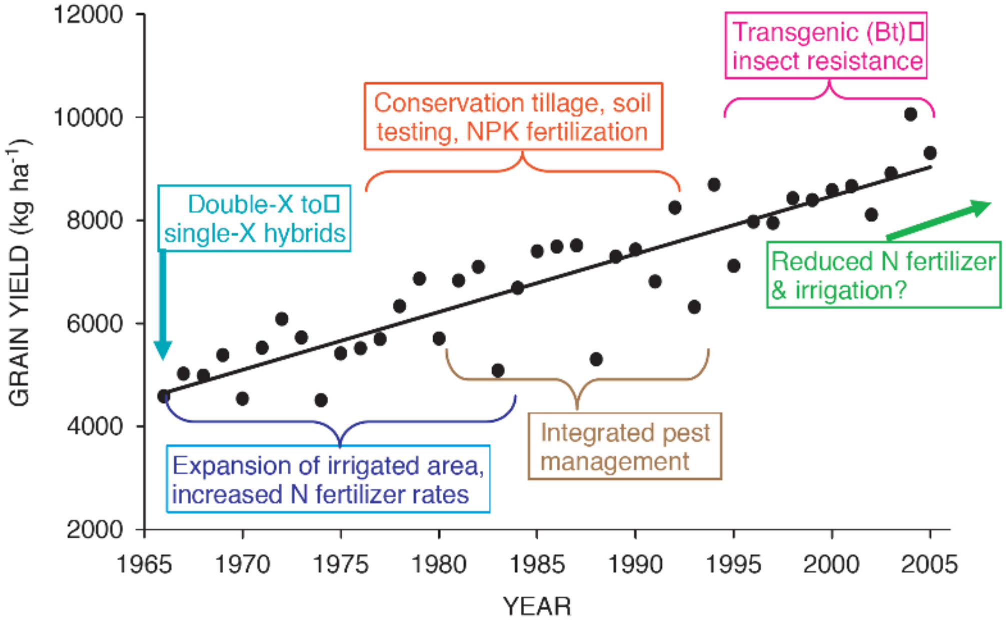

Figure 3. US maize yield trends from 1966–2005, and the technological innovations that contributed to this yield advance. Rate of gain is 112 kg ha^{-1} yr^{-1} ($R^2 = 0.80$). Modified from CAST, 2006.[2]

In fact, US maize yield trends since the mid-1960s have been supported by a powerful train of research and technology development (Figure 3). New breeding methods, expansion of irrigated area, soil testing and balanced fertilization, conservation tillage, and integrated pest management were the driving forces of innovation in the first 30 years of this time series. Insect resistant "*Bt*" maize, which is a transgenic crop variety produced by genetic engineering (commonly called a GMO), was introduced in the mid-1990s. However, despite investment of hundreds of millions of dollars in genomics and crop genetic engineering by both the public and private sectors since then, there has been little additional impact of biotechnology since *Bt* maize other than incorporation of herbicide resistance through the "Roundup Ready" trait, which also was discovered before the advent of genomics. Others have questioned whether genetic engineering has the potential for substantial improvements in yield potential or drought resistance based on the premise that evolution has already optimized such traits and conventional breeding can access them in existing crop germplasm.[20]

Apart from the record, some still argue that acceleration in yield gain is underway because of the power of genomics and genetic engineering to create crop varieties with substantially greater yield potential and drought resistance.[13] Although large seed companies like Monsanto make similar claims in their annual reports, there is no scientific evidence published in peer reviewed journals to substantiate these assertions. Hence, it is not possible for scientists at large to challenge these claims. Equally disturbing is the fact that these optimistic projections have a strong influence on setting the research priorities of the US Department of Agriculture and the US Department of Energy. While these agencies make substantial investment in genomics and chemical engineering to improve conversion of cellulosic biomass to ethanol, there is little research funding to accelerate the rate of gain in crop yields using an ecological systems-based approach to ensure protection of environmental quality. In spite of the optimism of policy-makers and seed industry executives, it is more likely that crop yields will remain on their current linear trajectory over the next 10 years without additional research to identify factors limiting crop yields and development of innovative crop and soil management practices to overcome them. The fact that average US maize yields are only 60% of the contest-winning yields indicate the limitation is not genetic because contest winners in the rain-fed category use the same maize hybrids as average farmers and yet contest-winning yields are rising two times faster than average rain-fed farm yields.[19]

The preferred scenario

The critical challenge is not only to produce enough food to meet increased demand from population increase and expansion of biofuel production, but to do so in an environmentally sound manner. Achieving these dual objectives in a relatively short time period will require a substantial increase in research and extension with an explicit focus on increasing the rate of gain in crop yields while protecting soil and water quality and reducing greenhouse gas emissions. It is sobering to note that agronomists have never been asked to develop innovative management systems that both accelerate yield gains and protect natural resources. In the absence of such investment, global demand is likely to exceed supply for crops that can be used for both food and biofuel. The resulting high grain prices may motivate farmers to achieve larger yields by using greater amounts of nitrogen fertilizer with current, relatively inefficient technologies,[21] and a reversion to conventional tillage from conservation tillage systems without regard for environmental consequences. While such gains may give a short-term spike in yields, they would not represent a new yield trajectory because they require practices that are not sustainable over the long term due to degradation of soil and water quality. The same is true for expansion of crop area onto marginal soils not suited for continuous crop production.

Ten years from now the rapid expansion of biofuel production may look foolish, or worse—unethical, if it leads to environmental degradation, high food prices, and increases the number of undernourished people. While we are optimistic that this scenario can be avoided, it would require both an increase and redirection of the global research, development, and extension portfolio because the magnitude of the scientific challenge has been grossly underestimated and critical research areas are currently neglected.[22] Without the luxury of food surpluses, it will become increasingly important to make the right bets on research and development priorities in developed and developing countries alike.

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