CAN TECHNOLOGY DELIVER ON THE YIELD CHALLENGE TO 2050?

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ABSTRACT

This paper focuses on the yield prospects of wheat, rice and maize since these cereals dominate human diet, and since continued yield growth is considered the major route to meeting future global demand for food, feed and fuel. We define for a region farm yield (FY), attainable yield (AY, as reached with the best technology and prudent economics), and potential yield (PY, yield with the best varieties and agronomy and no manageable biotic or abiotic stresses). FY progress is a function of progress in PY and in closing the gap between PY and FY (we express this gap as a percent of FY). Globally wheat and rice annual yield increases (as a percent of current yield) are falling and are now just below 1 percent, while that for maize is 1.6 percent. For rice and wheat, the growth of yields in absolute terms (kg/ha/year) are also falling in developing countries. Global demand modelling to 2050 predicts large real price sensitivity to yield growth rates, with significant price increases if current rates cannot be increased.

FY, PY and yield gaps are examined in more than 20 important "breadbasket" regions around the world. For wheat annual PY progress currently averages about 0.5 percent, and the yield gap 40 percent (range 25 to 50 percent), while for rice PY growth is also about 0.5 percent while the yield gap averages 75 percent (range 15 to 110 percent). Maize is distinctive with a current average PY growth of around 1 percent and a yield gap which ranges from around 30 percent (Iowa, some uncertainty with PY) to over 200 percent (sub-Saharan Africa). A yield gap of 25 percent or less probably implies that FY is approaching attainable yields, AY. Yield gaps tend to be larger in developing countries, and seem to be closing only slowly except in the case of maize in Iowa and major cereals in Egypt.

Prospects for yield gap closing are discussed. A multitude of constraints can reduce FY, ranging from infrastructural and institutional ones bearing upon farm gate costs and prices and farmer skills and attitudes, to diverse technical constraints. The resolution of the latter in turn depends largely on agronomic and breeding interventions (e.g., better resistance to biotic stresses), though these must be resolved in concert with the other constraints if they are to have significant impact in resource-poor farmers' fields. Yield gap closing must be a priority for maize in sub-Saharan Africa.

Prospects for PY increase are discussed. PY gain is increasingly related to greater biomass production, implying greater efficiency of utilization of solar radiation. Recent progress appears to have raised this efficiency, while the theoretical limit still appears to leave scope for further increase. In addition PY in water-limited situations (PY_w) will depend on further harvest index increase. In rice and wheat heterosis offers prospects for yield gain. We remain skeptical of the medium-term prospects of genetic modification (GM) for yield *per se*, especially PY, but recognize that existing GM crops often deliver higher yields because of gap closing benefits (such as reduced pest losses). New molecular tools for selection show promise for increasing breeding efficiency, but the marginal cost of yield gains is likely to rise. Strong private investment in breeding, as seen with maize, could play a bigger global role, accompanied by facilitating policies.

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We recognize in addition the importance of input efficiency and total factor productivity (TFP) for determining real prices, while prices of non-renewables (energy for traction and N fertilizer; phosphorus) are a relevant concern. TFP in agriculture continues to grow, and many examples confirm the general synergy amongst modern input technologies that achieve not only greater yield but also greater resource use efficiency (e.g. N, P, water, fuel, labour). There are also large gaps in input use efficiency that offer much scope for improved crop and resource management to deliver more with less. Investments in research and development, farmers' information and skills, and good policy drive this process, and will determine future success or failure.

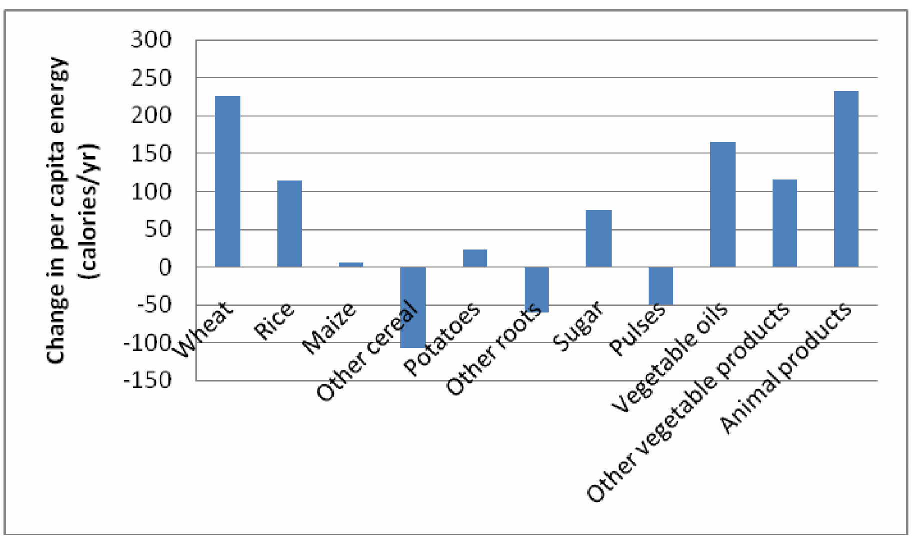
TABLE OF CONTENTS

INTRODUCTION

Projecting crop yields, especially 40 years ahead, is fraught with uncertainty. Yet three stylized facts emerge from several recent studies of world food needs. First, given land and water scarcity, climate change and rising energy prices on the supply side, and growing markets for food, feed and fuel on the demand side, global grain markets will be tighter in the future than over the past 40 years. Second, area expansion will at best be small, so future agricultural growth will be more reliant than ever on raising crop and animal yields. Third, the growth rate of cereal yields has been falling since the Green Revolution years. A major question for this paper is whether this decline means that we are reaching a technological plateau for crop yield, or whether there are still large unexploited sources of yield gains either on the shelf, or in the research pipeline.

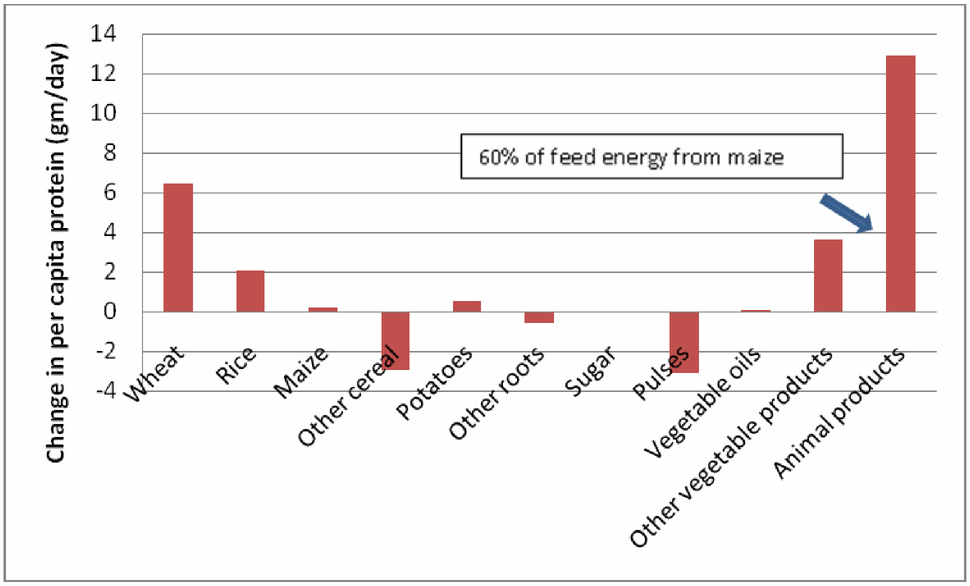
This paper addresses these questions through the analysis of cereal yields and productivity. It does so by tracing recent sources of growth and identifying future technological opportunities in terms of raising the potential yield, as well as closing gaps between existing yields and those that could be economically attainable by farmers. We focus on the big three cereals, rice, wheat and maize. Cereals account for 58 percent of annual crop area and provide about 50 percent of food calories. Rice and wheat alone accounted for about half of the increased per capita energy intake in developing countries since 1960 (Figure 1.1). Maize has been the major source of energy to support the rapid increase in consumption of animal products (Figure 1.2) accounting for over 60 percent of energy in commercial animal feeds, as well as a major feedstock for biofuels in recent years. Together these three cereals will provide about 80 percent of the increase in cereal consumption to 2050 (Rosegrant et al., 2008). However, we also recognize that diversification of food production is needed and a comprehensive review would include relevant data from roots and tubers, pulses and oilseeds. Some of these crops show declining trends, but remain critical to food security of millions, while others such as potatoes, sugarcane, soybeans, canola and oil palm are booming commercial crops serving multiple uses for food, feed and fuel.

Figure 1.1: Sources of increased per capita calorie consumption, developing countries, 1961-2003



Source: FAOSTAT

Figure 1.2: Source of increased per capita protein consumption, developing countries, 1961-2003



Source: FAOSTAT

The paper uses a bottom-up approach that reviews farm survey and experimental evidence on yields and yield gaps in the world's breadbaskets. This allows us to go beyond the estimation of yield growth by simple extrapolation of aggregate trends to explore the most likely sources of increased yields, both in terms of proximate factors, such as higher yielding varieties, input use and reducing losses from biotic and abiotic stresses, to broader policy and institutional factors that influence crop management. These include input market efficiency, risk management, and information and skills of farmers. Tentatively we pose some of the critical investments and institutional changes that will be needed to realize these changes.

Ultimately we are interested in the potential for sustainable productivity growth since it is the effects of productivity on food prices that have major welfare implications for poor people. This leads us from a discussion of yields *per se* to an assessment of input use and efficiency, and an analysis of trends in total factor productivity. In addition, sustainability is essential to ensure that productivity can be maintained in the face of depleting non-renewable resources, and that production systems do not degrade the environment.

We employ both a global and local approach to assessing crop yields. Changes in global yields are of course important for global food security. In a globalizing world, many countries will increasingly depend on trade to provision their food needs which should encourage production in the lowest cost regions, barring significant trade barriers. However, there are many situations where trade will be inadequate to assure food supplies. The "megacountries," China and India, have little choice but to produce most of their staple foods, especially rice, given relatively small, thin world markets in relation to their huge domestic markets. In Africa too, poor infrastructure, landlocked location, and lack of foreign exchange necessitate that much of the food be produced near where it is to be consumed. The high population growth in some of the more densely populated African countries places additional urgency on accelerating domestic production (e.g. projected population of Ethiopia of 185 million in 2050). The 2008 food price spike induced in part by export bans as well as rising energy costs for long-distance transport will likely lead many other countries to put a premium on local supplies.

2. DEFINING KEY CONCEPTS

There is a rich and evolving literature on various measures of yields and efficiency gaps, yet these terms are often used very loosely. This section defines the measures used in this paper and their interpretation, and relies largely on Ali and Byerlee (1991), Loomis and Connor (1992), Evans and Fischer (1999).