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Resource Quality, Agricultural Productivity, and Food Security

Stacey Rosen and Keith Wiebe
USDA Economic Research Service
Washington, DC

American Agricultural Economics Association
Selected Paper, Chicago, August 2001

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Introduction

Global food production has grown faster than the world's population over the past forty years. Yet many poor countries and millions of poor people continue to suffer from food insecurity and hunger. USDA's Economic Research Service (ERS) estimates that a third of the population of 67 developing countries—roughly 900 million people—currently suffer from insufficient food intake. Also, the amount of food needed to secure nutritionally adequate diets for these people was estimated at more than 17 million tons in 2000 and is projected to grow by 70 percent over the next decade. Sub-Saharan Africa, the most vulnerable region, is projected to account for almost 80 percent of this 'nutritional gap' in 2010.

For many developing countries, growth in agricultural productivity is critical to improvements in food security for two reasons. First, growth in agricultural productivity translates into larger food supplies and lower food prices for all consumers. This is particularly true in many of the poorest countries, which depend heavily on domestic food production for a large part of their food because financial constraints limit imports. In Sub-Saharan Africa, for example, domestic production accounts for 90 percent of food availability on average. Second, growth in agricultural productivity means higher incomes, and thus improved ability to purchase food, for the large share of low-income countries' populations that depend on agriculture for their livelihoods.

Agricultural productivity depends in turn on the quantity and quality of resources used in agricultural production. Data on resource quality have historically been scarce, but recent improvements have allowed a more complete understanding of how land quality in particular affects productivity and food security. In this paper, we examine the factors underlying observed disparities in agricultural productivity across countries, including land quality, and review patterns in input use over time. We then incorporate results from these analyses in ERS's food security assessment model to project trends in food security across regions and explore the sensitivity of these projections to changes in input use. Two specific scenarios are modeled: a reduction in the rate of agricultural expansion and an adjustment in the response of yields to fertilizer applications based on differences in land quality.

Factors underlying agricultural productivity

Most studies indicate that observed differences in agricultural productivity can be attributed largely to differences in the quantity of conventional inputs used in agricultural production, such as land, labor, fertilizer, and machinery. Frisvold and Ingram (1995), for example, found that

conventional inputs—especially labor—accounted for two thirds of growth in the productivity of agricultural land in Sub-Saharan Africa in the 1970s and 1980s.

While input quantities are certainly important, agricultural productivity also depends significantly on the *quality* of inputs used, including the quality of natural resources such as land. Distinguishing the relative impacts of input quantity and quality is not easy, but it is essential in determining appropriate policy measures to improve agricultural productivity and food security. Land quality is of particular importance because it not only affects yields directly (e.g. via differences in soil depth, fertility, and water-holding capacity), but it also affects how yields respond to other inputs, such as fertilizer. Recognition of differences in land quality is thus critical to the explanation of observed productivity differences and the identification of appropriate policy responses.

Using information on soils, climate, and land cover, researchers at ERS recently examined the quality of cropland by country and region (Wiebe et al. 2000). They found that while the average quality of *all* land is generally lowest in the Middle East and North Africa, the average quality of *cropland* is lowest in Sub-Saharan Africa. Among 38 Sub-Saharan African countries studied, only about six percent of cropland, on average, was classified as highly suitable for agriculture. By contrast, high-quality land constituted an average of 16 percent of cropland in Asia, 19 percent in the Middle East and North Africa, 27 percent in Latin America, and 29 percent in the high-income countries (as defined by the World Bank 1999).

Land quality and agricultural productivity

Land quality differences help explain agricultural productivity differences across countries and regions. Land quality can also vary over time, improving or deteriorating as a result of environmental conditions and farm management practices. As population has grown in many developing countries, agricultural land has come under increasing pressure. Farmers have expanded onto marginal lands and intensified production on lands already cultivated. In some cases poverty, insecure land tenure, inappropriate agricultural policies, and other factors have resulted in inappropriate management practices. In many areas, nutrients have been depleted from soils and yields have stagnated, especially where fertilizer use is low and nutrient loss is high. In Sub-Saharan Africa, for example, fertilizer application rates average around 10 kilograms per hectare per year, compared with 99 kilograms in Latin America, 117 kilograms in North Africa, and 135 kilograms in Asia (FAO 2001). According to IFPRI, soils in most African countries lose more than 30 kilograms of nitrogen, phosphorus, and potassium (NPK) per hectare per year, and losses exceed 60 kilograms per year in much of Western and Eastern Africa (Henao and Baanante 1999). Nutrient losses on a similar scale have recently been identified in many parts of Latin America as well (Wood, Sebastian, and Scherr 2000).

To explore the link between land quality and the productivity of agricultural land, Wiebe and Tegene (2000) recently combined information on soil and climate quality with data on land, labor, fertilizer, and other inputs in an econometric analysis of 110 countries over the period 1961-1997. They found that differences in agricultural land productivity are significantly related to differences in the quality of agricultural land. Within Sub-Saharan Africa, the productivity of agricultural land is 28 percent higher, on average, in countries with relatively high land quality

than it is in countries with poor land quality. The productivity differential attributable to high land quality is 34 percent in Asia, and 22 percent in high-income countries.

As expected, land quality also affects the impact of other inputs on agricultural productivity. In Sub-Saharan African countries with good soils and climate, for example, agricultural land productivity rises significantly with increases in quantities of labor, livestock, tractors, fertilizer, and annual rainfall. Productivity also improves with irrigation, labor quality (in the form of longer life expectancy and higher literacy rates), and transportation infrastructure, and falls significantly with the occurrence of armed conflict. In Sub-Saharan countries with poor soils and climate, the results are mixed. Productivity responds even more strongly to fertilizer, irrigation, and political instability than it does in the countries with good soils and climate, but is not sensitive to improvements in tractors, labor quality, or infrastructure.

The results indicate that in countries poorly endowed with soils and climate, basic inputs such as fertilizer, water (or irrigation), and institutional stability are more important than they are in countries that are relatively well endowed in terms of natural resources. Most farmers in resource-poor areas are subsistence producers with limited participation in commercial markets. This suggests that until these basic resource constraints are removed, improvements in labor quality, transportation, and mechanization may have only a limited impact on agricultural productivity. Improvements in policy and reductions in armed conflict are essential in both sets of countries.

These findings suggest an important role for land quality and agricultural productivity in refining our understanding of food security. This role is explored after a brief overview of ERS's food security assessment research.

Food security assessment

ERS's food security assessment (FSA) model is a partial-equilibrium simulation model used to project food availability in 67 developing countries in five regions (North Africa, Sub-Saharan Africa, Asia, Latin America, and the New Independent States (NIS) of the former Soviet Union) (Shapouri 2000). Each country model includes three commodity groups: grains, root crops, and other crops. The production side of the grain and root crops consists of yields (a function of input use) and area responses. Commercial imports are assumed to be a function of domestic prices, world commodity prices, and foreign exchange availability.

Food security is assessed by measuring the size of and trends in several alternative food gaps. The *status quo gap* is estimated as the amount of food needed to support 1997-99 levels of per capita consumption for each country, while the *nutritional gap* is the gap between available food and food needed to support a target per capita nutritional standard. However, the aggregate food availability projections do not account for food security problems due to food distribution difficulties within a country, so we also project food consumption by different income groups based on income distribution data for each country. The concept of an income-consumption relationship is used to allocate the projected level of food availability among different income groups. The estimated *distribution gap* measures the amount of food needed to raise the food

consumption of each income quintile to the nutritional standard. Finally, based on the projected population, we project the number of people who cannot meet their nutritional requirements.

The baseline results of the food security assessment project that nutritional and status quo food gaps will grow over the next decade. However, the number of people who will be unable to meet nutritional requirements will decline. These results suggest that nutritional problems among the food insecure population will intensify more than the food deficits will spread. In other words, the hunger problem will become more severe in the vulnerable countries and/or among the lower income groups.

Linking land quality, agricultural productivity, and food security

Over the past four decades, growth in agricultural production at a global scale has come predominantly from increases in yields, and this pattern is projected to continue in the future (FAO 2000). In many low-income countries, however—particularly in Sub-Saharan Africa—yields have stagnated in recent years and most increases in agricultural output have stemmed from area expansion (table 1) (FAO 2001). While additional land was available to be brought into food production, in most countries it was marginal land with lower productivity, more uncertain rainfall, and potentially greater vulnerability to degradation, implying lower and more variable crop yields. Moreover, area growth cannot be sustained indefinitely, since continued conversion of range and forestland to cropland involves increasingly high economic and environmental costs. In Asia, nearly 80 percent of potentially arable land is already cultivated.

Table 1: Growth in factors of production, 1980-99

| Region | Area | Yield |
|---------------------|------------------|-------|
| | -----%/year----- | |
| North Africa | 0.5 | 3.0 |
| Sub-Saharan Africa* | 2.2 | 0.4 |
| Asia | 0.1 | 2.4 |
| Latin America | 0.7 | 0.4 |

*these figures are exclusive of Nigeria; because of the size of the Nigerian numbers, their trends heavily skew the results of the region.

These trends imply that for most food-insecure countries, particularly those in Sub-Saharan Africa and Asia, land constraints will play an increasingly important role in determining food security in the future. To explore the possible impacts of land constraints on food security, we compared the FSA baseline results with two alternative scenarios: (1) reduced growth in area planted, to reflect rising costs of land conversion as well as cropland lost to land degradation; and (2) variation in region-specific yield response to fertilizer use, adjusted for regional differences in land quality.

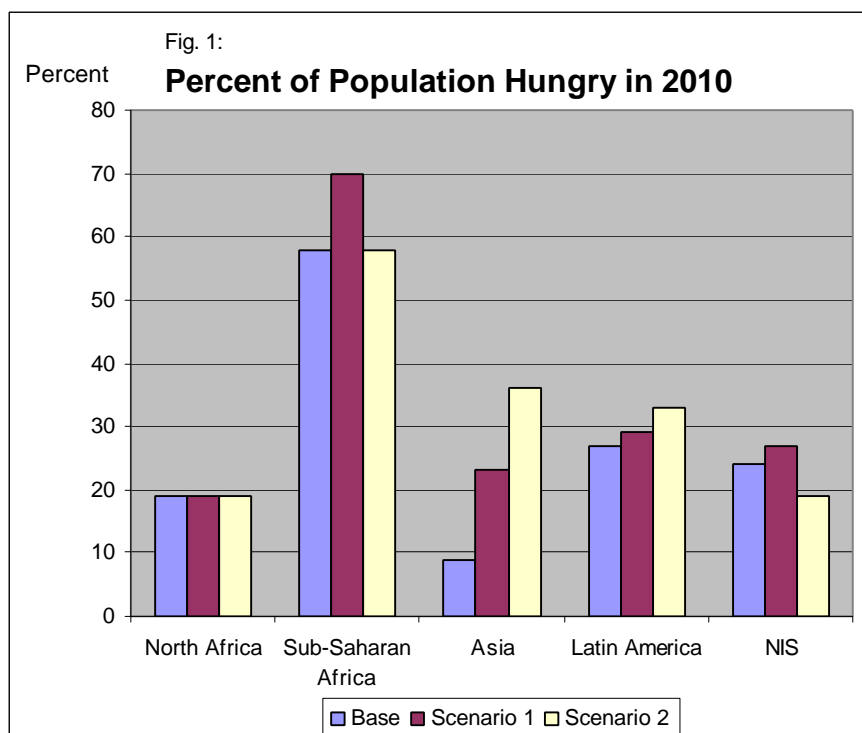
Scenario 1: Reduced area growth

Agricultural land in Asia, Africa, and Latin America has expanded by about 6 million hectares per year over the past four decades (FAO 2001). Data on land degradation at a global scale are scarce, but recent estimates suggest that some 5-6 million hectares of agricultural land worldwide are lost each year as a result of soil erosion, salinization, and other processes (Scherr 1999). If half of that degradation occurs in developing regions, effective area growth in those regions would be about half the rate apparent in simple historic trends. Accordingly, in our first scenario, area expansion is assumed to be half the rate used in the base model for North Africa, Sub-Saharan Africa, Latin America, and NIS. In Asia, where average annual area growth has fallen to negligible levels in recent years, area is assumed to remain constant (table 2).

Table 2: Growth in factors of production, 2000-10

| Region | ---Baseline--- | | ---Scenario 1--- | | ---Scenario 2--- | |
|--------------------|------------------|-------|------------------|-------|------------------|-------|
| | Area | Yield | Area | Yield | Area | Yield |
| | -----%/year----- | | -----%/year----- | | -----%/year----- | |
| North Africa | 1.65 | 0.27 | 0.81 | 0.66 | 2.59 | 0.76 |
| Sub-Saharan Africa | 1.18 | 1.29 | 0.59 | 1.18 | 1.20 | 1.32 |
| Asia | 0.09 | 1.58 | 0.00 | 1.39 | 0.02 | 1.08 |
| Latin America | 0.63 | 1.08 | 0.35 | 1.04 | 0.41 | 0.76 |
| NIS | 0.73 | 1.02 | 0.36 | 0.88 | 1.37 | 2.30 |

Under the baseline assumptions, the number of people whose consumption falls short of the nutritional target in 2010 is projected to be roughly 700 million—or 22 percent of the total population—for the 67 countries. Under the reduced area growth scenario, this number rises dramatically to 1.1 billion—or a third of the population of the 67 countries (fig. 1). In this scenario, production growth falls to 1.5 percent per year, compared with 1.8 percent in the baseline projections.



For Sub-Saharan Africa, production under the baseline run was projected to rise at a rate of 2.2 percent per year; under the reduced area growth scenario this growth rate is projected to slow to 1.8 percent. As a result, the nutritional gap in 2010 jumps 34 percent above that of the baseline scenario. In addition, the number of people with inadequate diets in 2010 jumps 15 percent relative to the base scenario, and consumption is projected to exceed the nutritional standard only in the highest income group.

In Asia, the results varied widely by country. While this scenario did not generate much change in production growth rates for the region as a whole, for certain countries like Afghanistan, Indonesia, North Korea, and Pakistan, the reduction in area growth did have an impact. In these countries, area growth was projected to be a significant contributor to production performance in the baseline run. As a result of the changes in these countries, the region's per capita consumption growth through 2010 was cut by more than half—from 0.5 percent per year to 0.2 percent under this scenario. Consequently, consumption is projected to fall short of the nutritional standard for 23 percent of the population by 2010. In the baseline scenario, this number was only 9 percent. Reduced area growth also resulted in large increases in food gaps in Latin America, despite that region's high import capacity—and therefore lower relative dependence on domestic production.

Scenario 2: Land quality-adjusted fertilizer response

To capture findings that land quality influences the response of yields to inputs such as fertilizer, we modified the FSA model to incorporate region-specific fertilizer response coefficients. These coefficients were derived from the multi-country productivity analysis described earlier,

modified to match the FSA model's specification of yields as a function of labor, fertilizer, and technology. To account for differences in soils and climate, labor and fertilizer levels were first estimated as functions of land quality, labor quality, conflict, and transportation infrastructure.

The baseline model assumed a uniform fertilizer response of 0.2 for all regions, based on estimates from earlier studies. By contrast, estimated resource quality-adjusted fertilizer response coefficients are 0.04 for Asia, 0.55 for North Africa and NIS, 0.13 for Latin America, and 0.24 for Sub-Saharan Africa. These coefficients imply that a one-percent increase in fertilizer use, holding everything else constant, will result in a 0.24-percent increase in the productivity of agricultural land in Sub-Saharan Africa, for example, but only a 0.04-percent increase in Asia. These results are intuitively consistent with the fertilizer application rates noted earlier, with low initial application rates indicating relatively large marginal responses in Sub-Saharan Africa, and the converse in Asia.

When applied to the FSA model, the negligible estimated fertilizer response for Asia results in a precipitous decline in the region's production growth rate relative to the baseline projections. This change, in turn, generates a 47-percent increase in the region's 2010 status quo food gap relative to the baseline run. Moreover, as a result of the reduced growth in production, consumption levels are projected to fall relative to those in the baseline projections; consumption in 2010 is projected to fall below the nutritional target for 36 percent of the region's population (compared with 9 percent in the baseline projection). For Latin America the results under this scenario do not change significantly relative to the base scenario because the change in the fertilizer response coefficient was small and because this region is highly dependent on imports (the region's import dependency averaged roughly 45 percent in the late 1990's, compared with 5 percent in Asia and 10 percent in Sub-Saharan Africa).

In the two cases where the fertilizer response rose, the resulting changes were also modest. Production growth did rise in North Africa and NIS, but because the countries in these regions are more import dependent than those in Asia, this change did not have as strong an impact on overall consumption levels, food gaps, and numbers of hungry people. Sub-Saharan Africa is much more dependent on domestic production, as noted earlier, but the estimated resource quality-adjusted fertilizer response—at 0.24—was only slightly higher than the level assumed in the baseline projections. As a result, projected food security outcomes for the region did not change significantly from those in the baseline.

Policy lessons

More work needs to be done to test the sensitivity of these results to alternative land quality indicators, functional forms, and econometric specifications. Nevertheless, these preliminary findings suggest the importance of recognizing the links between land quality, agricultural productivity, and food security. In particular, increased attention needs to be addressed to changes in resource quality over time. Adjusting projections of growth in agricultural land area to reflect land degradation sharply reduces production growth and increases the magnitude of food gaps. Adjusting projections of growth in yields to reflect differences in fertilizer response (due to a combination of land quality, current fertilizer application levels, and other factors) has

marked food security implications in some regions but not in others. In general, the two scenarios indicate the need for further work in these hitherto distinct areas of research.

They also suggest several areas that deserve priority in seeking to reduce or avert projected food gaps. First, they indicate the importance of removing macro policy distortions and infrastructure constraints that make essential inputs, such as fertilizer and water, prohibitively expensive for many small-scale farmers in developing countries (even in the absence of these distortions and constraints, basic climate and geographic conditions will make water availability costly in less favorable areas). Several studies document that the timely physical availability of fertilizers to farmers, in appropriately-sized packages, remains the main constraint to increasing fertilizer use in Sub-Saharan Africa. An adequate fertilizer supply at the farm level remains essential for maintaining reasonable fertilizer costs even when domestic prices are tied to world prices without subsidies. Improved marketing systems, particularly through increased private marketing and better infrastructure, will reduce farm-gate prices of fertilizers, regardless of their origin.

Second, research on farm management practices that protect and improve the quality of the land resources on which agriculture depends, and extension efforts to share these practices with farmers needs to be encouraged. To maximize the benefit of fertilizers, application must be combined with soil conservation, recycling of crop residues, livestock management, and the use of organic fertilizers. If fertilizer supplies are going to continue to be unreliable or prohibitively costly, then viable substitutes for commercial fertilizers need to be adopted that would achieve the same goal of increasing yields. Besides the established practice of using livestock manure, legume rotations are being experimented with in some parts of the region as well as the planting of leguminous trees interspersed with crops. Using new plants as a green manure source is also being explored as an alternative to traditional practices. However, these practices require sacrificing area in food crops and applying additional labor.

Finally, improvements in land quality and productivity are not likely to be sustained in the absence of property rights that protects farmers' incentives to invest in their land. Individual private ownership is not a necessary condition; research increasingly shows that such incentives can be protected under a variety of tenure systems, including share leasing in the United States and customary tenure systems in Sub-Saharan Africa. Rather, what is critical is what is too often lacking in many developing countries: a sound and stable institutional structure. In many cases, this may constitute the most fundamental challenge to efforts to improve land quality, agricultural productivity, and food security (Soule, Tegene, Wiebe, 2000; Bruce, Migot-Adholla, 1994).

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