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**Resource Quality and Agricultural Productivity:
Evidence from Sub-Saharan Africa and Implications for Ethiopia¹**

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Introduction

Over the next several decades, trends in population, income, and urbanization are projected to raise world demand for cereals, roots, and tubers by about 40%, and for meat by about 60% (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant, 1999). Population and demand for agricultural products are projected to grow nearly twice as fast in sub-Saharan Africa, at 2-3% per year, as they are in the world as a whole (FAO, 2000). Given land constraints in some areas and environmental concerns about agricultural land expansion in others, most of the increased production necessary to meet this demand will have to come from increased productivity on land already in agricultural production. Increasing agricultural productivity is especially critical in sub-Saharan Africa, where food security has been a persistent concern.

Although economists have long recognized the importance of accounting for differences in the quality of land and other resources when studying productivity, these

¹ This paper is drawn from previous studies reported in Wiebe et al. (2000) and Wiebe and Tegene (2000). The views expressed here are those of the authors, and may not be attributed to the Economic Research Service or the U.S. Department of Agriculture.

efforts have been limited by data constraints, particularly in terms of information on soils. No studies to date have explicitly incorporated indicators of the quality of soils. However, recent advances in data and analytical methods allow improved understanding of the ways in which agricultural productivity and food security are affected by differences in the quality of resources. Distinguishing the relative impacts of input quantity and quality is important in determining appropriate policy measures to improve agricultural productivity and food security. Moreover, studies that focus on sub-Saharan Africa are scarce in the empirical literature of agricultural studies (Frisvold and Ingram, 1995). In this paper we take advantage of new spatial data on soils and climate and new high-resolution data on land cover to develop improved measures of land quality for 37 sub-Saharan African countries¹. These land quality measures, along with conventional inputs, infrastructure, quality indicators for labor and institutions, and infrastructure, are used in a production function to examine their impacts on agricultural output per worker.

The issues of agricultural productivity and food security are especially relevant for Ethiopia where food shortage has become a recurring phenomenon. Poverty and institutional turbulence have combined to generate increasing vulnerability to famine in Ethiopia in recent decades (Webb, von Braun, and Yohannes, 1992). Given the dependence of the majority of the population on agriculture, researchers and policymakers are keenly interested in improved understanding of the factors, including those relating to natural resources, that support maintenance and sustainable growth in agricultural productivity.

Keyzer and Sonneveld (1999) note that 95% of Ethiopia's cultivated area is located in highland areas characterized by relatively fertile soils, abundant rainfall, and moderate temperatures. However, water-induced erosion of topsoil is identified as a key form of land degradation in the highland areas, while wind-induced erosion plays a greater role in the drier and lower-elevation southeastern portion of the country. Wide diversity in inherent land quality, as well as in types and degrees of land degradation, make analysis of resource quality and agricultural productivity critical to address concerns about food security in Ethiopia.

Productivity Issues

Sustained growth in agricultural productivity is critical to improvements in food security for two reasons. First, growth in agricultural productivity translates into increased food supplies and lower food prices for consumers. And second, growth in agricultural productivity means higher incomes, and thus improved ability to purchase food and other basic necessities, for many food-insecure people who earn their livelihoods through agricultural production (whether they produce food or not). In 1990, for example, 62% of sub-Saharan Africa's labor force was employed in the agricultural sector; the corresponding figure for Ethiopia was 86% (World Bank, 2001).

Agricultural productivity depends, in return, on a variety of factors. Recent studies (e.g. Craig, Pardey, and Roseboom 1997 and Frisvold and Ingram 1995) indicate that most differences in agricultural productivity, whether across households or countries or over time, can be attributed to differences in the quantity of conventional inputs used in

agricultural production, such as land, labor, fertilizer, and machinery. But agricultural productivity also depends critically on the quality of inputs used, including the quality of natural resources such as land. As simple as this statement seems, the influence of resource quality on agricultural productivity has received insufficient attention in the past because appropriate data have been scarce. Recent developments in data and analytical methods help to understand better the intricate relationship between agricultural productivity natural resources. These developments are illustrated in the following three maps.

Map 1 illustrates differences in land quality in the Horn of Africa region. This measure of land quality is based on assessment by USDA's Natural Resource Conservation Service of the suitability of soils and climate for agricultural production, based on soil characteristics and long-term average temperature and precipitation (Eswaran et al., 1997). Areas of relatively suitable land are evident in southern Sudan and in the highlands of Ethiopia, with quality diminishing sharply towards the east and north.

Map 2 illustrates regional differences in average annual rainfall over the period 1961-96, based on analysis by the Climatic Research Unit of the University of East Anglia. Here too the advantages of the Ethiopian highlands are clear relative to the surrounding areas.

Poor soils and climate do not make agricultural production impossible, but they do mean that costs of production are likely to be higher, and/or that yields and net returns are likely to be lower than they would be under more favorable conditions—in other words,

that agricultural productivity is likely to be lower. Using high-resolution satellite data from the U.S. Geological Survey, map 3 illustrates where crop production actually dominates the landscape, based in part on land quality and rainfall patterns, along with other physical and economic characteristics. Reflecting the underlying distribution of suitable soil and climate characteristics as well as the influence of irrigation, cropland is concentrated in the Ethiopian highlands and in the irrigated regions of east-central Sudan.

These inherent soil and climatic differences are used to construct land quality indicators used in the econometric analysis. Combining maps 1 and 3, we can estimate the share of each country's cropland that is of high quality. For sub-Saharan Africa as a whole, this share is about 6 percent. (This compares with a median of 16 percent in Asia 19 percent in the Middle East and North Africa, 27 percent in Latin America, 29 percent in the high-income countries (as defined by the World Bank), over 50 percent in Eastern Europe, and 20 percent for the world as a whole.) Combining maps 2 and 3, we can estimate annual rainfall on cropland in each country. Table 1 summarizes agricultural land and water characteristics for selected countries in the Horn of Africa region.

Table1. Cropland characteristics in Eriteria, Ethiopia,

	Arable land	Permanent cropland	Irrigated land	Rainfall on cropland	High-quality cropland
Country	1,000 hectares, 1997			Millimeters, 1996	Percent
Ethiopia	9,900	680	190	1,149	15
Sudan	16,700	200	1,950	483	22
Somalia	1,043	23	200	NA	<1
Eriteria	391	2	22	NA	<1

Sources: FAO, USDA/NRCS, US Geological Survey, and the Climatic Research Unit of the University of East Anglia

Data and Methods

We began with data developed by Eswaran et al. (1997), who combined FAO's Digital Soil Map of the World and associated soil characteristics (e.g. slope, depth, and salinity) with spatially referenced long-run average temperature and precipitation data to establish nine land quality classes in terms of their suitability for agricultural production (map 1). Wiebe et al. (2000) then overlaid these land quality classes with political boundaries and global land-cover data generated from satellite imagery with a resolution of one kilometer (USGS/UNL/JRC, 1999). They focused on cropland identified according to the International Geosphere-Biosphere Programme land cover classification scheme (map 3). The result is a dummy variable based on the share of each country's cropland that is found in the three best quality classes. Countries where this share exceeds the median value for their region are identified as having good soils and climate; those with less than the median are identified as having poor soils and climate.

This static measure, based on cross-country differences in inherent soil and climate characteristics, supplements existing time-variant quality indicators such as the

percentage of agricultural land that is cropped (or irrigated) and long-term average or annual rainfall. To better capture this last effect, we also developed a high-resolution measure of annual rainfall by aggregating and overlaying monthly precipitation data on a 0.5-degree grid (map 2; Climatic Research Unit 1998) with national boundaries and cropland as described above. The result is a country-specific time-variant measure of rainfall on cropland.

The dependent variable in our analysis is output per agricultural worker. Output is the value of total agricultural production, measured as the sum of price-weighted quantities of all agricultural commodities, expressed in international dollars, after deductions for feed and seed. Agricultural land refers to the sum of arable land, permanent cropland, and permanent pasture. Other variables include country-level indicators of agricultural labor (the total economically active population in agriculture), tractors (total number used in agriculture), livestock, and fertilizer, as well as measures of the quality of labor, the institutional environment, and infrastructure. The data are combined in an econometric analysis of 37 sub-Saharan African countries over the period 1961-1997, using a two-way fixed-effects specification of a Cobb-Douglas production function. Additional details are provided in Wiebe et al. (2000).

Results

Not surprisingly, econometric analysis reveals that after taking into account other factors such as input levels, differences in the quality of cropland soils and climate are significantly related to differences in agricultural productivity (table 2, column 1).

Taking the inverse log of the coefficient on “Good soils and climate” indicates that within sub-Saharan Africa, agricultural output per worker is 28 percent higher, on average, in countries with high land quality than it is in countries with poor land quality. These findings confirm our expectations and provide for the first time an empirical estimate of the significant impact that differences in the inherent physical quality of soils and climate have on agricultural productivity. Perhaps more important, however, are the insights they provide into the impact on agricultural productivity of more conventional inputs, such as quantities of land, labor, fertilizer, and machinery.

To capture these impacts, we included in our econometric analysis country-level measures of conventional agricultural inputs like agricultural land, labor, tractors, livestock, and fertilizer (FAO, 1999). We also included factors such as annual rainfall on cropland, the percentage of each country’s agricultural land that is classified as arable land or permanent cropland, the percentage of arable land or permanent cropland land that is not irrigated, life expectancy and illiteracy rates (as measures of labor quality), an indicator of the occurrence of armed conflict (as a measure of institutional stability), and road density and cumulative agricultural research and development expenditures (as measures of infrastructure). (Data on agricultural research and development expenditures were available only for 1961 through 1985, but revealed a significant and positive association with agricultural productivity over that time period.)

To further explore the role of land quality in relation to that of other factors, countries were classified according to the share of their cropland that is highly suitable for agricultural production. Countries where this share exceeds the median value for sub-

Saharan Africa were identified as having good soils and climate; those with less than the median were identified as having poor soils and climate. Each group of countries was then analyzed separately to compare the impacts of individual factors on agricultural productivity by region and land-quality class.

Results are presented in table 2, columns 2 and 3. In sub-Saharan African countries with good soils and climate, 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 African countries with poor soils and climate, productivity responds even more strongly to fertilizer application, irrigation, and political instability, but is not sensitive to increases in labor or improvements in tractors, labor quality, or infrastructure. Whereas Frisvold and Ingram (1995) found labor to be the principal source of growth in land productivity for sub-Saharan Africa as a whole over the period 1973-1985, our result suggests that subsequent population growth has brought sub-Saharan African agriculture close to the effective land frontier, at least in countries characterized by poor land and low levels of fertilizer and irrigation.

Livestock coefficients are significant and positive in each case, while those on tractors are significant only for countries with good land. Fertilizer is positively associated with output per worker regardless of the quality of soils and climate, although elasticities are larger in countries with poor land.

Annual rainfall is significant for countries with good land, but not for countries with poor land. Coefficients on the share of agricultural land that is arable or permanently cropped are higher in countries with poor land, although significant and positive in both groups of countries. Land productivity is sensitive to the share of cropland that is not irrigated in both cases, with the magnitude of the impact being higher in countries with poor land.

Results for other resource quality indicators are mixed. Neither life expectancy nor adult illiteracy are significant in countries with poor land. Coefficients on both indicators are significant with the expected signs in countries with good land. Armed conflict is significant and negatively associated with output per worker in each case, and more strongly so in countries with poor land. Road density is positively associated with output per worker in countries that have good land, but not in those that do not.

Coefficients on country dummies are significant for most countries in both groups (omitting Zimbabwe from countries with good land and Tanzania from countries with poor land). Coefficients on time dummies (omitting 1995) are not significant for any year for either group of countries. This suggests that unmeasured cross-sectional differences remain important in explaining productivity differences in sub-Saharan Africa, but that changes in productivity over time have been largely accounted for by changes in conventional inputs and other included variables.

Overall, the results suggest a land quality-related hierarchy of constraints limiting agricultural productivity in sub-Saharan Africa. In countries poorly endowed with soils and climate, basic inputs such as fertilizer, water (in the form of irrigation), and

institutional stability are more important than they are in countries that are relatively well endowed. The evidence suggests that only when these constraints have been overcome do factors such as labor quality, road density, and mechanization become significantly associated with improvements in agricultural productivity -- as they are in countries with better soils and climate.

Analysis of inherent land quality thus improves our understanding of the impacts on agricultural productivity of factors over which policy makers exercise at least some influence. The policy implications of these findings will be discussed further below. Analysis of differences in land quality across countries and regions also provides an initial indication of the potential impact on agricultural productivity of changes in land quality -- i.e. land degradation -- over time. Data on land degradation rates and impacts remain even more scarce than data on land quality, but most studies to date find that productivity losses due to processes such as soil erosion, nutrient depletion, and salinization are small (on the order of 0.1 - 0.2 percent per year) in relation to historic gains in productivity (on the order of 2 percent per year) due to improvements in technology and input use (den Biggelaar et al. forthcoming, Crosson 1997, Byerlee, Heisey, and Pingali 1999, Pinstруп-Andersen, Pandya-Lorch, and Rosegrant 1999). Nevertheless, in some areas characterized by poor or fragile soils and inappropriate agricultural management practices, productivity losses could be significantly higher (Scherr 1999, Lal 1998). It is cause for concern, for example, that such conditions are found in parts of sub-Saharan Africa, where productivity levels are already low and the need for growth is correspondingly high. Analysis by Keyzer and Sonneveld (1999)

suggests that in Ethiopia, the northern provinces of Welo, Gondar, and Tigray are potentially the most vulnerable to agricultural productivity losses due to land degradation.

Implications for food security and policy

As noted earlier, agricultural productivity is important for food security both through its impact on food supplies and prices, and through its impact on the incomes and purchasing power of those whose livelihoods depend on agricultural production. Through its effect on agricultural productivity, land quality is thus related directly to both food availability and food access. Land quality is, on average, lower in low-income food-deficit countries than it is in high-income countries, and agricultural productivity is more sensitive to differences in land quality. This has important implications for policy makers concerned with improving food security, both through protection and/or improvement of land quality itself and through recognition of the distinct roles played by more conventional agricultural inputs in areas that differ in land quality.

In sub-Saharan African countries with relatively poor soils and climate, for example, the policy-sensitive variable most strongly associated with agricultural productivity is irrigation, followed by armed conflict and fertilizer use. Among the policy measures most important for increased agricultural productivity in those countries are thus investments in the efficient delivery and use of water and fertilizer, combined with efforts to improve institutional stability through the cessation of armed conflict. In sub-Saharan African countries with good soils and climate, these factors remain important, but agricultural productivity becomes relatively more sensitive to

improvements in labor quality and infrastructure. Policy makers in those countries may thus find it appropriate to focus additional resources on investment in education, health, extension services, and transportation.

In general, results and implications are consistent with the expectation that the greatest improvements in agricultural productivity will be realized from relaxing the constraints that bind most tightly, and that the most tightly-binding constraints will vary from region to region according to differences in resource endowments and other factors. Neither is it surprising that the quality of soils and climate should play a key role in defining these differences. Yet it is only recently, with improvements in spatial data and methods, that it has become possible to characterize these differences with increased precision at the multi-country scale. Analysis to date supports the conclusion that policy makers in low-income, food deficit countries face a hierarchy of priorities that depends critically on the quality of soils and climate, but holds broadly across regions. Continued research will be needed to further refine our understanding of the links between resource quality, agricultural productivity, and food security.

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Table 2 – Regression results for sub-Saharan Africa

Variable	All Countries (1)	Countries with good soils and climate (2)	Countries with poor soils and climate (3)
Intercept	-3.03*** (-3.24)	-7.97*** (-4.97)	16.36*** (5.16)
<i>Conventional inputs</i>			
Land	-0.08*** (-10.43)	0.20* (1.68)	-0.67*** (-4.63)
Labor	0.53*** (29.35)	0.19*** (2.76)	-0.12 (-1.18)
Livestock	0.19*** (15.19)	0.35*** (12.30)	0.28*** (8.20)
Tractors	0.03*** (2.73)	0.02** (2.03)	-0.01 (-0.33)
Fertilizer	-0.01** (-2.20)	+0.00** (2.31)	0.01*** (3.29)
<i>Land quality</i>			
Annual rainfall	0.13*** (5.87)	0.18*** (4.29)	0.06 (1.33)
Percent arable or permanently cropped	0.17*** (9.44)	0.16*** (4.26)	0.74*** (5.90)
Percent not irrigated	-0.94*** (-6.95)	-0.65*** (-3.46)	-3.44*** (-5.53)
Good soils and climate	0.25*** (9.85)	--	--
<i>Labor quality</i>			
Life expectancy	0.98*** (7.82)	1.00*** (7.57)	-0.09 (-0.41)
Illiteracy	0.20*** (5.21)	-0.35*** (-6.66)	0.09 (1.17)
<i>Institutional quality</i>			
Armed conflict	-0.08** (-2.73)	-0.05*** (-2.82)	-0.18*** (-6.56)
<i>Infrastructure</i>			
Road density	0.07*** (7.63)	0.04*** (3.26)	+0.00 (0.67)
R ²	0.93	0.99	0.99
Countries	37	19	18
Years	1961-95	1961-94	1961-95

Note: figures in parentheses are t-statistics; *** indicates significance at the 1% level, ** indicates significance at the 5% level, and * indicates significance at the 10% level. All models include year dummies; the second and third models also include country dummies.

Notes

¹ The 37 sub-Saharan countries in the sample are Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African republic, Chad, Congo, Cote D'Ivoire, Ethiopia, Gabon, Gambia, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, and Zimbabwe.