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CONTRIBUTORS:

• **F.W.T. PENNING DE VRIES** is Researcher for the Agricultural Research Department at Wageningen Agricultural University, in the Netherlands.

• **H. VAN KEULEN** is Researcher for the Agricultural Research Department at Wageningen Agricultural University, in the Netherlands.

• **R. RABBINGE** is Researcher for the Agricultural Research Department at Wageningen Agricultural University, in the Netherlands.

• **J.C. LUYTEN** is Researcher for the Agricultural Research Department at Wageningen Agricultural University, in the Netherlands.

• **IMRE FERTŐ** is a Hungarian economist and author of many learned papers. He specializes in privatization and transformation of post-communist agriculture in Eastern Europe.

BIOPHYSICAL LIMITS TO GLOBAL FOOD PRODUCTION

F. W. T. Penning de Vries, H. van Keulen, R. Rabbinge, and J. C. Luyten

Global food production, so far, has increased continuously because cropped area has expanded and productivity per unit area has increased. In some regions of the world, however, there is little scope for further spatial expansion of agriculture. In other areas, crop yields are stagnating. Does this imply that the world is approaching the biophysical limits of food production?

While there is an upper limit to food production, results of recent analysis indicate that global agriculture is still far from it. Because decreasing growth in global food production has been observed, policymakers should not be misled into thinking that the world is approaching that limit.

UNCERTAINTIES AND ASSUMPTIONS

Maximum world food production studies are not new. Researchers of the Agricultural Research Department at Wageningen Agricultural University in the Netherlands have added to previous analyses a discussion of alternative production and consumption technologies and more precise information about soil and water resources.

The absolute values of these production levels, computed with extensive soil, fresh water, and climate databases plus a crop growth model, may be too high or too low by 25 percent and even by 50 percent for environment-oriented agriculture. The potential benefits of biotechnological breakthroughs in biomass production and food conversion or the potential effects of global change (precipitation, sea level, soil erosion) are not considered here. Phosphorus might become a limiting natural resource when environment-oriented agriculture is practiced globally.

To permit a pure view of the biophysical limitations of food production, economic and sociological limitations are excluded from the analyses. Computations are made for situations where farmers use the best technology available, including full nutrient recycling. This may not be achieved for all regions in the time span of only two generations.

WHAT IS THE BIOPHYSICAL LIMIT?

The biophysical limit of food production is reached when all land suitable for agriculture is cropped and the potential yield on each field is attained. There is a specific upper limit to crop yield on any given piece of land, which is determined by soil type, climate, crop properties, and available irrigation water. It is attained when the farmer selects the optimal combination of crop species and management practices. This potential yield is around 10,000 kilograms of grain per hectare for a cereal crop. There may be up to three crops per year in a suitable climate. Crop varieties have been bred that allow such yield levels to be realized under many more conditions than traditional varieties could; the potential yield itself has increased only a modest degree in recent decades.

Nearly two-thirds of the earth's surface could be exploited as grazing land, half of which is also suitable for arable cropping. The earth's biophysical limit to food production is reached when all suitable cropping land is cropped and irrigated and the remaining suitable grazing land is grazed. If used very efficiently, fresh water would be available to irrigate 50–100 percent of the area where arable crops are grown. With good crop protection measures, most pre- and postharvest losses could be avoided.

There are major differences in the potential supply and demand for food in different parts of the world. Analyses were therefore carried out for 15 regions of the world.

IS IT SUSTAINABLE?

The biophysical limit of food production should be determined using sustainable agricultural practices in which the quality of soil and the nonagricultural environment either remain constant or improve, and limited natural resources (such as water and mineral fertilizer) are not overexploited. There are two views on how this sustainable agriculture might look.

In an ecotechnology-oriented approach, sustainable agriculture resembles the current system of "integrated" Western European agriculture, but one in which the emerging shortcomings are minimized. Maximum production per unit of land implies a high level of inputs resulting in a high level of outputs. A contrasting, environment-oriented approach holds that this production technology cannot be continued in the long run, because pollution and pest problems will continue to build up on farms and in the environment. Sustainable agricultural production systems should avoid use of nitrogen fertilizers and biocides (fertilizer minerals are irreplaceable) and should recycle nutrients at the local level. Under this system, maximum yields per hectare will be only one-third as high.

GLOBAL FOOD PRODUCTION IN ABSOLUTE TERMS

The upper limits of production of food and feed vary greatly from one region to another. The huge potential food-plus-feed production of South America results from its large area of suitable soil, favorable climate, and abundant water. Clearly, this includes production on soils currently covered with rain forests. The values are low for northern and southern Africa and western Asia because their fresh-water resources are limited. The global annual total production (grain plus grass) amounts to an equivalent of 72 billion metric tons of grain for ecotechnology- oriented agriculture and 30 billion metric tons for environment-oriented agricul-

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ture. This is 10–20 times the current value of 4 billion metric tons. Irrigated crops contribute about 50 percent of these totals in both cases.

Using all fresh water available to agriculture for irrigation, about 50 percent of the land suitable for cropping could be irrigated in ecotechnology-oriented agriculture and almost 100 percent in environment-oriented agriculture. Hence, major expansion of irrigation systems is physically feasible.

PRODUCTION VERSUS DEMAND

The potential demand for food will expand for two reasons: population increase and demand for more affluent diets containing more animal protein. Global population will probably continue to rise for two more generations. By the year 2040, population will have roughly doubled from today's number—reaching between 8 and 11 billion—and then it will probably stabilize. Diet changes significantly as incomes rise. At first, more food is consumed; then animal protein replaces vegetable protein. Production of animal products requires several times more biomass than vegetarian food. As a result, an affluent diet requires three times more biomass per capita (about 1,530 kilograms per year) than a healthy, largely vegetarian diet (about 476 kilograms per year). Improved food technology, summarized in vegetative biomass needed per capita, is indeed of crucial importance.

In this research nine food-demand scenarios were analyzed, ranging from minimum population growth combined with a vegetarian diet to maximum population growth combined with an affluent diet containing an ample amount of animal products. Food demand for the intermediate scenario (medium population growth with a moderate diet) is compared with the potential levels of food production in Figure 1. A region with a ratio of 1.0 or less cannot match food consumption with production.

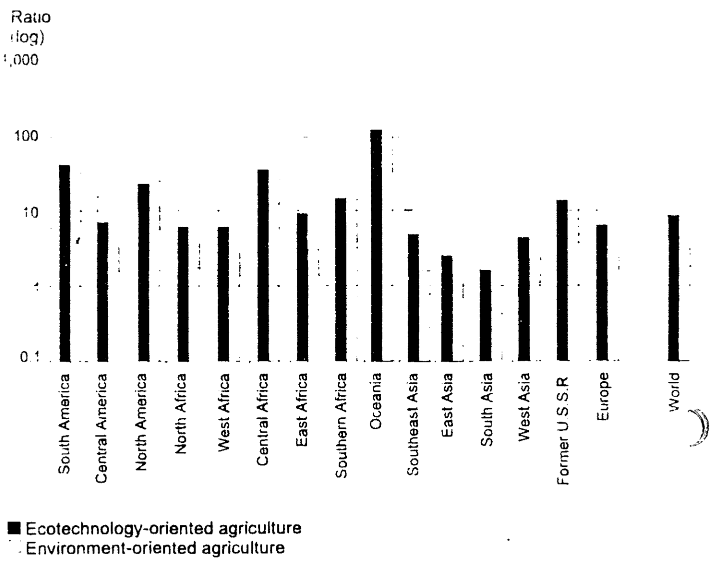
At a global level, four times more food can be produced than required using environment-oriented agriculture and nine times more using ecotechnology-oriented agriculture. When ecotechnology-oriented agriculture is practiced in the reference demand scenario, all regions can provide all of the food necessary. However, using environment-oriented agriculture, some regions in Asia cannot produce enough food to meet their needs or can produce barely enough, even with maximum utilization of natural resources.

Ratios for the extreme scenarios (maximum population with an affluent diet and minimum population with a vegetarian diet) are shown by line marks at the top of the bars in the figure. The ratio is almost twice as high for the minimum-demand scenario and half for the maximum-demand scenario.

With an environment-oriented agriculture, all regions can produce the food required even for an affluent diet, except for East, South, and Southeast Asia; the three regions with the least leeway will carry almost half of the global population. West Asia and West and North Africa come close to the lower limit. A much less expensive diet provides the only option for escape, apart from massive food imports. Europe, the former U.S.S.R., North America, Oceania, South America, and Central Africa are well-off and need only part of their suitable land to feed their populations whatever their diet. However, if trade can distribute food efficiently across the globe, all people may consume an affluent diet, but at the expense of intensive use of two-thirds of the globe for arable crops and rangeland.

In all cases, three times more land is required for environment-oriented agricultural production systems than for ecotechnology-oriented systems. Consequently, the choice of the production technique has a major effect on global land use. Depending on the diet selected, Europe can grow an adequate food supply on 30–50 percent of its suitable land, North America on 20 percent of its land, and South America and Oceania on even smaller fractions.

Figure 1—The ratio of potential food supply to demand, medium-demand scenario



Note: Lines indicate the range over which the ratio changes between the minimum- and maximum-demand scenarios.

BOOKS RECEIVED

Global Food Projections to 2020: Implications for Investment

Mark W. Rosegrant, Mercedita Agcaoili-Sombilla and Nicostrato D. Perez

International Food Policy Research Institute

In this paper, Mark W. Rosegrant, Mercedita Agcaoili-Sombilla, and Nicostrato D. Perez examine projections of global supply of and demand for food through the year 2020.

Rosegrant, Agcaoili-Sombilla, and Perez look closely at how alternative population, investment, and trade scenarios will affect food security and nutrition status, especially in the developing world. They argue that the world is at risk of maintaining its two-tiered system of food security, with rich and rapidly growing countries enjoying abundant, affordable food supplies and poor countries suffering from malnutrition and food scarcity.

National governments and international agencies can alter this situation through their investment decisions. By increasing their agricultural and social investments, for instance, they can greatly improve food security and reduce malnutrition in developing countries. This paper offers data on the results to be expected from various decisions and points the way toward a future with food security for all.

Per Pinstrup-Andersen
Director General, IFPRI