# RESOURCE EFFICIENCY IN U.S. AGRICULTURE

## INTRODUCTION

Historically, we've tended to have one of two extreme attitudes about the world food situation--feast or famine. With amazing regularity, the attitude swings from the position that U.S. agriculture has an inherent and chronic capacity for overproduction to the other extreme of viewing scarcity as a permanent characteristic of food production.

Recently, we have witnessed great turbulence in the world food and agricultural complex--severe famine in the sub-Sahara and reduced food production in other developing countries, disruptive OPEC oil pricing policies, skyrocketing prices for energy-fueling U.S. agriculture, unexpected and massive grain purchases by the U.S.S.R., a worldwide economic slowdown in many nonoil exporting countries, a swing to excess grain supplies in the United States, low farm prices and the threat of a U.S. farm "strike," and a new China perspective.

In the United States, food abundance has been based on our great natural resources, but agricultural production is becoming increasingly unnatural as greater energy, chemical fertilizers, pesticides, and irrigation water are used in increasingly concentrated and monocultured food production processes which, in some cases, are very much in opposition to natural ecosystems. As these concerns have become the focal point of public concern in agriculture, the rapid rise in agricultural productivity appears to have slowed.

These developments raise new concerns about the future capacity of American agriculture to maintain adequate food supplies in the domestic and world markets. These concerns are shared by nations around the world and at home by both farmers and consumers. Such concerns relate to our long-run capacity to produce a larger agricultural output. In increasing our output, we have several options.

First, we could increase cropland acreage. The United States currently uses about 149 million hectares for cropland compared to a 50-year high of 157 million hectares in 1949. Although there is not a very large potential for increasing output in the short run (1 to 2 years) by increasing the land input, there is a potential 77 million hectares of noncropland with high or medium potential for regular cultivation over the longer run. The second option for increasing output is through greater use of nonland capital inputs such as fertilizer, insecticides, pesticides, machinery, etc. This approach has been one of the most obvious sources of greater farm output in recent history. Finally, agricultural output can be increased through a more efficient combination and greater productivity of farm inputs. This is the potential addressed in this paper. Our objectives are to: (1) summarize historical developments in U.S. agriculture with emphasis on the technological, economic, and institutional factors which have contributed to agricultural productivity growth; (2) evaluate the possibilities for future economic and technological change that will impact on agricultural productivity; and (3) speculate about some of the difficulties and opportunities for U.S. agriculture to expand its role in an interdependent world.

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Robert D. Reinsel and C. Leroy Quance , Paris, France 1978
Economics, Statistics, and Cooperatives Service
U.S. Department of Agriculture, Washington, DC

## HISTORICAL PERSPECTIVE

The resource intensiveness of U.S. agriculture has changed quite rapidly. Only a century ago, 60 out of every 100 workers in the United States were still on farms, straining to feed and clothe a growing Nation. Farming was hard work, and a man depended mainly on his muscle. Farming practices of that time--planting corn according to the signs of the moon, for example--were handed down from one generation to the next. Indeed, for the first 300 years (up through World War I), we increased production not by raising more on each acre, but by putting new land to the plow.

In the early days, a visitor from France, Alexis de Tocqueville, observed that "Agriculture is perhaps, of all the useful arts, that which improves the most slowly among democratic nations." He could hardly have been expected to foresee the inventiveness--mechanical, political, and scientific--that was to transform the American frontier.

Agriculture, once largely a constrained biological process, has been augmented with large infusions of nonbiological stimulants. Today, farming in the United States consumes 19 million metric tons of fertilizer, 294 thousand metric tons of pesticides, 30 billion liters of fuel, and uses 4.4 million tractors. This combination of capital inputs, combined with land and labor complements, enables each of our farmers to produce enough food to feed 59 people at home and abroad. With the resources used 35 years ago, he could produce enough to feed only 11 people.

This transformation of U.S. agriculture began early in the last century with the beginning of mechanization. The mowing machine was introduced, and McCormick patented his reaper. The stationary thresher and fanning mill came along soon afterward. Although cautious about these mechanical devices at first, farmers soon began to accept them as practical necessities for profitable operation.

There was a critical need in those days for crop seeds--seeds for the new lands being brought into cultivation, and seeds to replace those brought from Europe and found unsuited to our climate and soils. The Congress took account of the needs of agriculture in 1839 with an appropriation of $1,000, partly for collecting and distributing crop seeds and distribution of free seeds--billions of packages of them--continued till the early 1920's. The beginning of the last century was also marked by a growing consciousness of the need for change in our farming practices. Agricultural journals appeared and hundreds of agricultural societies discussed farm problems of the time, disseminated general scientific information, and encouraged experimentation.

Beginning in the 1860's, the Government passed several measures which were to radically change agriculture. One of these measures, the Homestead Act, broadly and firmly established our tradition of family-owned farms by making free land available to those willing to cultivate it. This drew families by the thousands across the country and helped to settle the West. Another measure established the U.S. Department of Agriculture, with the primary job of research and education. The Department was directed to acquire useful information about agriculture and disseminate it among farm people, then making up the majority of our population. And, there was a measure granting valuable tracts of public lands to the States, thereby enabling them to establish colleges for teaching agriculture and the mechanical arts. And in 1887, Federal funds were provided to help the States set up an agricultural experiment station in connection with each college. Next, USDA and the colleges joined together in 1914 to organize an extension service to bring new ideas and technology to farmers and homemakers in all 3,000 countries across the land.

Along with the development of institutions promoting improvements in agricultural production practices, major investments were made in developing railroad systems which facilitated the transportation of inputs to farms and the marketing of farm commodities. Thus, it was possible to produce food and feed in highly productive areas that were remote from consumption centers.

Although important gains resulted from the measures Congress approved in the mid to late 1890's, agricultural productivity over the next three-quarters of a century was slow. For one thing, most farmers were skeptical and conservative. They laughed at the "book farmers"--the scientists, teachers, and advisers--who gained much of their knowledge from laboratories and test plots rather than from producers' fields, flocks, and herds. Resistance to change persisted. As recently as a generation or two ago, the lag between discovery and application often ran 20 years or more. Furthermore, improvements barely managed to offset the decline in soil productivity, and yield levels changed very little. Public concern over this condition resulted in the birth of our conservation movement early in this century. But even soaring farm prices during World War I failed to stimulate any substantial effort to produce more by increasing yields.

The period separating World War I and World War II brought changes that set the stage for our remarkable yield takeoff. Horses and mules were gradually replaced by the broad application of mechanical power in farming. And agricultural research--with backing from the Federal Government, the States, industry, and farmers--began to receive the attention it deserved. The 20 years between the two World Wars triggered major improvement in resource and input efficiency in U.S. agriculture. The technological revolution had its real beginning with the introduction and adoption of the general purpose farm tractor. The substitution which occurred was mainly a substitution of one form of capital and energy for another--fossil fuel-powered machinery replaced animal power as the dominant energy source. The 1930's also saw the advent of rural electrification with power lines extended to the majority of farmsteads by the end of the 1940's, through the efforts of rural electric cooperatives and the private utilities. In addition, major highway programs were developed and the farm truck and auto became commonplace additions to the transportation system.

During the 1930's, the farming system also benefited from the creation of Farm Production Credit Associations, initially funded by the Federal Government, but now totally farmer-owned cooperatives. These organizations, along with the Federal Land Banks and the Bank for Cooperatives, provided the necessary capital to facilitate the mechanization of U.S. agriculture. These financial institutions set the stage for the capitalization of the traditionally high risk agricultural sector with little access to capital markets. Also, during this period, the Federal/State research and extension programs were greatly expanded. Increased efforts in this area led to the development and rapid adaption by hybrid seed corn, the first major breakthrough in increasing yields, which improved the efficiency of resource use dramatically.

The beginning of the technological revolution in the 1930's developed into a radical shift in production patterns and practices during the 1940's, stimulated by higher farm prices, a ready supply of loan funds, and a reduced supply of farm labor. In addition, technology developed for the war effort, such as synthetic nitrogen for munitions and DDT for human parasite control, were made available in the late 1940's for application to farm fields as fertilizer and as pest controls. DDT and 2-4-D became the primary defense against weeds and insects, increasing both yield and quality of output.

With the reduction in dependence on natural systems provided by fertilizer, hybrid seed, and pesticides, major changes in cropping and tillage practices came about. Older crop rotation patterns were dropped in favor of continuous production of corn and grains. Increasing size of farm equipment and new technology in the form of hydraulic equipment controls extended the capabilities of individuals to work land. Farm size expansion began and specialization occurred at a rapid rate. The tractor essentially emancipated farming from its dependency upon animal power.

In 1930, we had over 19 million horses and mules on farms, and less than a million tractors. By 1959, we had 4.7 million tractors and so few farm horses and mules that we stopped counting them. A secondary impact of this mechanization often overlooked is that it freed 31 million hectares of cropland previously used to produce feed for horses and mules to be used for producing food and fiber for human consumption.

Changes in cropping patterns also increased the effective cropland base. Up to World War II, corn typically was grown in a 3-year rotation of corn-oats-clover, without fertilizer, in 1 meter rows, planted 24,700 seeds per hectare, and the Corn Belt yield was about 24 quintals per hectare. Today, corn is seldom rotated. Leading growers typically fertilize with herbicides and obtain yields of 80 to 93 quantals per hectare. And this year, the average U.S. corn yield reached a record 63 quintals per hectare. The impact on corn production is compounded--where we once planted 33 of each 100 hectares and got 318 quintals, we now plant the whole 100 and get 5,646 to 6,274 quintals.

Similar but less dramatic gains have occurred with other crops. We converted grain sorghum to hybrids in a span of 4 years, about 18 years ago. The direct impact was a 25 percent increase in yield. The U.S. average per acre wheat yield has doubled since 1930--from 9.4 to 18.8 quintals--without assistance from hybridization. This gain resulted from improved natural varieties, better and more timely tillage, more effective pest control, and heavier soil fertilization. The technical problem of wheat hybridization is now solved and hybrids are appearing in parts of the wheat region. They too promise 25 percent higher yields.

The spectacular new technologies in crop production have not occurred in livestock--except for feed conversion ratios in broilers and turkeys. By 1950, we were producing broilers commercially with a feed efficiency of about 3 kilos live weight, and it will go still lower. Nothing like that gain in feed-conversion efficiency has occurred with hogs or beef cattle. The ratio for hogs is 3.5 to 4 kilos of grain (feed concentrates) per kilo of live weight gain. But in cattle feeding, the ratio is 6 to 9 kilos of grain per kilo of live weight gain. These differences in feed-conversion ratios largely explain why chicken is priced so much lower than pork and beef in the supermarket. The substantial increases in pork and beef output have resulted from the huge increase in feed output plus a corresponding increase in animal numbers.

A U.S. farmer once produced the type, size, and quality of product he individually thought best, only to find that when he got there, the market wanted something different. Actually, farmers often had little control over the quality they produced. Today, the American farmer knows what is wanted, produces commodities according to specification--formula-fed broilers of a specified age and weight, cattle fed to an exact weight and finish, and wheat with a minimum protein level. Product specification is often part of a contract between the farmer and the buyer/processor. Today's farmer has far more control over the quality and specification of what he produces. He uses a known, specified technique and process. Much of the guesswork about quality is gone. Farm production technologies are now more standardized, more widely known, and accepted. Thus, we know the amount of fertilizer (element by element), the row spacing, and the plant population for top yields of corn, the feed ration for a meaty broiler, and how to produce fine head lettuce. Our producers do not skimp or take chances on the production mix--they simply cannot affort to.

In our modern food and agriculture complex, food processing has migrated off the farm. For example, the U.S. farmer once sold and delivered fresh raw milk to the consumers doorstep. Now milk is picked up in bulk at the farm, taken to a plant for pasteurization, homogenization, vitamin D irradiation, and bottling for delivery to food store and home. Likewise, the separation of cream from milk is now done almost entirely off the farm. Now much of the cattle feeding is done in huge specialized lots where fattening rations are carefully formulated, feed ingredients mixed and metered out to each feeding pen. Animals are fattened to the exact degree of finish desired. Broilers, eggs, and turkeys were once predominantly farm enterprises. Now these products are produced mainly in specialized facilities not necessarily associated with a "farm," where feed rations are carefully controlled. Farmers themselves now chiefly produce only the primary ingredients of food and fiber. Thus, the term "farming" does not embrace all that it did 100 or even 50 years ago.

Years ago farms were highly diversified with many individual enterprises. Feed crops were carefully balanced against livestock enterprises, and a high degree of complementarity existed between enterprises and in the use of land and labor. Today, farmers are concentrating on fewer but much larger crop or livestock enterprises. For example, we now see many one-enterprise and two-enterprise farms where formerly there were three, five, and even more enterprises. Specialization is aided, of course, by the availability of purchased production inputs and custom services, and the consequence is less need to diversify.

Farmers now purchase more production inputs and services, as they must if they are to have today's modern technology. Even 40 years ago farmers provided most of their production inputs--horsepower (and its feed), soil fertility (clover rotations), livestock feeds, crop seeds, and labor. Each farmer owned the machines to perform almost every farming operation. Today's farmer buys prodigious amounts of production inputs--fertiizer, formula feed, hybrid seeds, insecticides, herbicides, tractor fuel--and employs a myriad of custom services such as machine harvesting, fertilizing, pesticide spraying, and airplane crop dusting. Almost any production or harvesting operation can be custom-hired. This availability of off-farm produced inputs and custom services means that unit-cost efficiencies depend more on the size of the enterprise than on the farming skill of the farmer/operator. Thus, the adjustment to larger and fewer farms.

Government farm price and income policies and programs have also affected resource efficiency in U.S. agriculture. In the early 1950's, farm commodity-price support programs began to play a major role in supporting farm income and reducing risk. And, in the 1960's, acreage limitations removed land from production, slowed output growth, and limited total productivity gains because of the resources idled by the program. But this accentuated per acre yield increases because the less productive cropland was taken out of production.

During the mid-1960's, major concerns arose over the use of pesticides in agriculture and the fear of "A Silent Spring" caused major changes in pesticide use. DDT was banned in the United States and other somewhat more costly but environmentally safer insecticides were introduced. By 1970, concern over other sources of environmental hazards was having a major impact on the cost of waste disposal. And industrial firms supplying farm inputs and processing farm commodities internalized the added costs of pollution controls such that prices for agricultural inputs were further increased and downward pressure exerted on prices received by farmers.

In the early 1970's, the full impact of energy dependence surfaced with the 1973 Arab oil embargo and energy was elevated from a stable and rather inexpensive factor of production to one of the foremost concerns in agriculture. Consideration was given by some to returning to a less intensively mechanized agricultural system. Calculations on a calorie basis show that developing countries are more energy efficiency that the United States with respect to agricultural production. However, energy efficiency does not outweigh the economics of production and the demand for large quantities of food and fiber of a high quality. Thus, while energy conservation measures are being developed, and changing relative input prices are having new impacts, energy for agricultural production remains a good buy.

There are other current concerns: Millions of people once employed in agriculture have now moved to the industrial and commercial sectors of the economy and the income base for many small communities has disappeared. Rapid technological change has made capital investments or earlier generations obsolete and required a rebuilding of the capital stock. Farm production has become increasingly dependent on nonfarm produced inputs and this has lessened the resiliency of the farm sector, making it more difficult for it to accept the major shocks that create havoc with farm prices or cause scarcity of inputs. For example, rising energy prices can modify earnings and cause resouce use and production adjustments, but energy unavailability for a month could destroy an entire year's crop.

The profitability of U.S. agriculture is clearly tied to export markets and we are dependent on these markets for earnings to offset balance of trade deficiencies in other sectors of our economy. In addition, international fertilizer markets are beginning to dominate our domestic fertilizer industry. Most productive land in the United States has already been developed and we have already achieved many of the benefits from the elimination of draft animals, use of hybrid seed, and from continuous cropping. Urbanization is consuming prime agricultural land and irrigation has become very costly to continue and to expand.

And there are further energy concerns: We are currently considering alternatives to fossil fuel and possibilities for making agriculture energy independent. With the exception of direct use of solar and wind energy, most such alternatives require the production of biomass crops, which will compete with our food and feed crops for limited land resources. We have yet to sort out the most rational goals for agriculture in terms of energy production and consumption, but we know that energy concerns will impact heavily on resource use and efficiency.

With intensification of farm production, environmental concerns are increasing. The soil is tilled more continuously, larger amounts of chemicals are added, and livestock are raised in more concentrated environments. Such activities put pressure on a finely balanced ecosystem and create hazzards for the health and safety of animals and humans. And actions to correct these problems may severely impact the efficiency of resource use and the cost of achieving needed expansion in productive capability.

## THE FUTURE

After two decades of accelerated growth, the complexities of agricultural production caused an apparent slowing of productivity growth in the United States during the late 1960's and early 1970's. This phenomena alarms many people who draw the conclusion that the limit to agricultural productivity growth has, or soon will be reached. But our research indicates that agricultural productivity in the United States has not and will not reach a limit to growth over the next several decades, although the rate of growth may not be as great as in the last several decades.

For some time to come, productivity growth will result from the same developments that boosted crop yields and lowered feed/livestock conversion ratios in the past such as more and improved machinery, greater use of fertilizers, improved varieties, narrower rows and higher plant population per acre, chemical weed control, more artificial breeding, and improved livestock breeds.

Studying the historical relationships between agricultural research and extension programs, educational attainment of farmers, weather, economic phenomena, and agricultural productivity growth, and making reasonable assumptions about the determinants of productivity growth, we conclude that U.S. agricultural productivity would likely grow 1.1 to 1.3 percent per year through the year 2000 if no new unprecedented technologies come onstream. But before the limits of known technologies are reached, a new family of technologies will likely emerge.

This new epoch could include the impacts of such unprecedented technological breakthroughs as bioregulators, photosynthesis enhancement, twinning in beef cattle, and single-cell protein. Such unprecedented new technologies could boost productivity growth to 1.5 percent per year through year 2000--about the same growth rate experienced over the last 50 years. But if such technologies come onstream sooner, or their impact is greater than that expected by agricultural scientists, then productivity growth could exceed its impressive record of the past.

U.S. AGRICULTURE IN AN INTERDEPENDENT WORLD

We said at the onset that our interest in productivity growth was to increase U.S. farm output--to produce more food and fiber for a growing domestic and world population. Our recent study of U.S. agriculture production capacity included some "rough calculations" that the United States alone could currently produce 3,000 calories of food per day for each of the 4 billion men, women, and children in the world, whereas current consumption averages approximately 2,400 calories per day. But such a scenario would be unacceptable. Great sacrifices would be required, especially by Americans. These would include diversion of investment from other activities and direct consumption of cereal and vegetables without processing into meat through animals. Our standard of living would fall sharply as resources would be directed from current uses to massive irrigation programs, land clearing, fertilizer production, etc. Very troublesome issues would emerge including transportation, storage, disincentives to producers in other nations, inability of importers to provide payment, etc. This unreasonable scenario is touched upon only to emphasize that the maximum feasible production capacity of U.S. agriculture is both phenomenal and unnecessary.

In that same production capacity analysis, we concluded that considering the principle determinants of the supply and demand for farm output, including productivity growth, the U.S.'s farm sector could have an economically feasible supply capacity in 1985 of approximately double the 1967 output and much larger than the projected 1985 equilibrium output. Thus, the United States has the production capacity to assume an even larger role as the residual supplier of world food needs. This potential has been achieved not by merely putting more land, labor, and capital inputs into the hands of farmers, but through the evolution of a modern food and agricultural complex. Much of this complex is a vast agricultural infrastructure beyond the farm gate in the form of input suppliers, product processors and distributors, research and development programs, educational institutions, an efficient transportation network, communication facilities, capital and credit institutions, and Government programs in which we are continually attempting to balance the needs and benefits of both producers and consumers. And through all this, the American farmer has become increasingly dependent on world markets. The economic viability of our farm production sector depends on an increasingly greater and more stable role in supplying world food needs. But our role in world food markets should be one of supplying self-reliant rather than poor countries. We want to pursue a scenario whereby all countries can either produce or purchase their food needs without relying on massive food aid programs from surplus producers.

There are many resource base, socioeconomic, and cultural differences from one country to another. And every technology, technique, and input cannot automatically be transferred from one country to another. But there are also great similarities in agricultural production: land, labor, capital, and motivated farmers producing agricultural commodities with the support of private and governmental institutions providing an agricultural infrastructure. The United States, as well as world experience leads us to believe that all countries can make significant increases in agricultural resource efficiency. And international sharing of experience, knowledge, and technologies should increase the potential. In addition to sharing food and agricultural technologies, production and trade of both farm commodities and production inputs according to comparative advantage should further permit increases in resource efficiency from a global perspective.

If the United States is a reasonable example of the global potential, agricultural productivity growth in all countries should have a promising future in bringing about a desired world food needs-food supply balance. This potential includes advances in exploiting the potential of existing resources and conventional inputs as well as the development and adoption of new techniques and new technologies. But such important related areas as educational and extension programs and an efficient agricultural transportation, storage, processing, distribution, and financial infrastructure are equally important.