D. Ability to facilitate far more precise applications of pesticides.

2. Trial results strongly suggest that peach and nectarine varieties dwarfed by this particular gene are more precocious and more productive (for their size) than standard varieties.
3. Commercial acceptability of these drawf varieties hinges on the development of varieties with higher fruit quality than presently available in existing varieties.
4. Full exploitation of the potential of genetic dwarfs will probably depend on some modifications of the cultural methods appropriate for trees of standard size.

Dwarf tree breeding

Fortunately, dwarfing of tree fruit breeding stocks of the University of California will induce a several-fold increase in the effectiveness of its variety improvement programs because the cost of evaluating individual dwarf seedlings is only a small fraction of the cost of evaluating large-sized standard tree fruit seedlings. That means more seedlings can be evaluated without increasing costs, and the more seedlings evaluated the greater the odds are for breeding improved varieties.

Because of the potential advantages of dwarf tree fruit varieties, we initiated in 1975 a breeding program designed to improve fruit quality of dwarf freestone and clingstone peaches and nectarines. The best available genetically-dwarfed peaches and nectarines were crossed with standard breeding stocks maintained by the University of California at Davis and at Parlier. Inasmuch as the dwarfing gene involved is recessive, the F_1 progeny are all heterozygous (*Dw/dw*) for the dwarfing gene and therefore of standard size. Intercrosses between F_1 seedlings having superior fruit quality were made this past year and one-fourth of the resulting progeny are F_2 genetic dwarfs (as genetic theory predicts). These dwarfs should have significantly improved fruit quality. Evaluation of improved genetically dwarfed F_2 selections should begin in 1981.

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Mature dwarf trees are only about 6 feet tall, less than half the height of the standard variety shown next to Staff Research Associate Jim Doyle. Dwarf trees require little pruning.

The inves
research:

Criticism of the land grant college system's research and extension programs began in 1972 with Jim Hightower's book, *Hard Tomatoes, Hard Times,* and has extended to the recent lawsuit by the California Rural Legal Assistance to arrest farm mechanization research at the University of California. Numerous studies have estimated the returns to society from public monies spent for agricultural research and extension, but these studies have generally been couched in academic jargon intended only for academicians to read. Our purpose here is to explain clearly and simply the essence of these studies.

In one of the first attempts to estimate returns to research expenditures (in 1958), Agricultural Economist Zvi Griliches used the development of hybrid corn as a case study. He added up private and public research costs between 1910 and 1955 and concluded that for every dollar spent on hybrid corn research, society can expect back about seven dollars each year in perpetuity.

Subsequently, agricultural economics researchers used Griliches' model as a prototype or developed their own methodology to estimate the returns from agricultural research and extension in the U.S. and elsewhere. Serious criticisms have been launched against these studies, many with valid points, but the fact remains that the

tment in agricultural A success story

Carole Frank Nuckton

Americans enjoy variety, quality, and abundance of food and fiber, thanks to 'seed money' investments.

studies—using different methodologies, different commodities, and different time periods, and undertaken in different areas of the world—universally acclaim tremendous benefits to society from its investment.

How does society capture the returns? Generally, farmers have not joined the ranks of the wealthy. Consumers are perhaps unaware of the benefits they are enjoying. Changes in the structure of American agriculture, partially as a result of research achievements, have meant painful adjustments, at least in the short run. One of the most painful adjustments: the displacement of farm laborers by mechanization. Nevertheless, in examining the economics of technological change, brought about in part by public agricultural research, consumers generally benefit the most.

Basic types of research

Two basic types of research lead to two different kinds of change: (1) yield-increasing crop and animal-improvement research and (2) mechanization research. Frequently, the two are complementary.

First, let us consider yield-increasing research, such as in hybrid corn. The first farmers to adopt the new variety reap "abnormal" profits, for they harvest a greater-than-normal quantity and sell it at the prevailing market price. As more farmers grow the new variety, however, the supply of corn is greatly increased. Given that demand for most farm products is inelastic—that is, when the quantity increases by 1 percent the market price drops more than 1 percent—producers soon return to a "normal" profit, selling more for less and consumers enjoy getting more and paying less.

It was shown by two researchers, for example, that the urban poor benefit most from yield-increasing rice research in Colombia, for they spend the largest portion of their budgets on rice and pay less in taxes supporting the research. The argument can be extended to low-income persons of any country, for they must spend a higher percentage of their incomes on food, and in any country with a progressive income tax system, they pay little or no taxes. Thus, they benefit more from research and pay less to support it.

Although the intention of a farmer who adopts a mechanical device—say, a new harvester—differs from that of a grower planting a new variety, the same economic forces ultimately determine the distribution of society's benefits. A farmer risks capital to invest in a new machine because he believes it will lower his per-unit costs of production. To make the best use of the investment, he will devote more acreage to the crop for which the machine was designed and may rent or purchase additional land to spread the high initial cost. Many farmers behaving similarly will produce a greater quantity of the crop. At this point all of the market forces previously explained come into play, and consumers will gain again, getting more and paying less.

Some of the gains accruing will, of course, be offset by a reduction in the quantity of the product that would have been produced had the change not occurred. Nevertheless, there is generally a net gain from the shift.

Rates of return from 14 to 77 percent annually (see table 1) are far higher than the average return to capital investment in the economy as a whole. With technological change, however, occur adjustment costs. The expansion that accompanies investment in a new machine results in larger farm operations—and fewer farms. The nonadopting farmer whose per-unit costs have not been lowered may be faced with a market price that no longer covers his costs. He is forced to get out or catch up.

Yield-increasing research can have a similar impact on increasing farm size and reducing farm numbers. Tremendous productivity increases and resulting price effects have also taken their toll among U.S. farm operators; to maintain an acceptable family income level from farming at the reduced price that productivity increases entail, more acreage must be added. Furthermore, yield increases subsequently call for mechanization to handle the increased quantities.

According to the U.S. Department of Agriculture, 58 percent of farmland transfers in 1977 were for purposes of expansion; 68 percent for the same reason occurred in 1976. This process has been going on for several decades. Much concern has been expressed about the growing concentration within the food and fiber industry as fewer farms account for a greater share of our agricultural product. (According to the Census of Agriculture, under 7 percent of America's farms produced 54 percent of total commodity sales in 1974.) Sociologists worry about the deterioration of the quality of life in rural communities when they are no longer surrounded by many small farming units. Some call for subsidies to smaller family farms to preserve some of these important noneconomic factors.

Technological change resulting in part from public investment in agricultural research is a mixed blessing. Gradual attrition in agriculture has been one of the necessary adjustments. Although the process has been costly, it has conferred significant net benefits on society

Statistical analyses

To test the hypothesis that a nation's economic welfare is inversely related to the percentage of population in agriculture, we did two statistical analyses. In the first, the relationship between the 1970 per capita gross domestic product and the percentage of the population in agriculture in 1970 was plotted for 111 nations. The United States had the highest per-capita product ($4,789) and the second lowest percentage in agriculture (4 percent). Mali, a small African nation, had the lowest per-capita product ($54) and nearly the highest percentage in agriculture (91 percent). The graph revealed a strong nonlinear relationship between the two variables. Regressing the percent of the population in agriculture on the natural logarithm of per-capita gross domestic product resulted in a correlation coefficient of -.92. This strong nonlinear result means not only that a high per-capita product is associated with a low percentage in agriculture and vice versa, but that as the percentage in agriculture declines, the per-capita product increases at a faster rate (exponentially).

The second statistical analysis was for the United States only from 1939-1977. Although no direct causal connection can be proved from the analysis, there is an extremely high negative linear correlation between the percentage of the population in agriculture, which has declined steadily over time, and per capita, disposable, personal income, which has increased steadily over time. Income figures were computed in "real" terms; inflationary effects were removed. The correlation coefficient of -.88 indicates that a high percentage in agriculture is associated with low per-capita income and a low percentage (3.6 percent in 1977) with a high per-capita, personal, disposable income ($4,290 in "real" dollars, 1977).

Both analyses lend strong empirical support to our hypothesis that attrition from agriculture has been of economic benefit to society. The long-term impact has been twofold: hundreds of Americans each year are freed from growing our raw food and fiber to produce other goods and services, while those remaining in agriculture produce more food and fiber than ever before. American agriculture has "come of age." Managing a large, efficient farm is no longer very different from managing a large, family business in the nonagricultural sector.

Costs of progress

Progress, however, has its costs, the most conspicuous being the displacement of hired farm laborers by mechanization. Only a few studies have subtracted these displacement costs before calculating the returns to society. Under varying assumptions about alternative employment opportunities for the displaced, Schmitz and Seckler in their 1970 study of the impact of the tomato harvester included compensation for wages lost. Their estimate that the return was "still above 15 percent" is probably conservative when one considers the expansion of the tomato processing industry in California made possible by the harvester.

Although new jobs in canneries, transportation, farm machinery factories and sales, and even pizza parlors do not generally draw from the displaced farm worker population, the overall gain to society is apparent. Furthermore, on the eve of the harvester's adoption, processors were in serious conversation with growers in Mexico and Guatemala. Sales from processing tomatoes, valued at $426 million in 1977, would have been lost to California growers.

Following the Schmitz-Seckler approach, Martin and Johnson included 100 percent of the displaced persons' wages for one year in their formula for computing the returns to tobacco harvester research. They concluded: "It is clear that no reasonable definition of adjustment costs will reduce the estimated benefits from agricultural research enough to suggest that outlays be redirected."

It is essential that displacement and transition costs be recognized in evaluating the impact on society of any new development. The weight of these costs will differ from commodity to commodity: the number of workers involved will, of course, differ, whether they are seasonal or fulltime, whether the job provides supplemental family income or is the family's sole source of livelihood, etc.

Analogous to price supports and other government programs designed to assist farm operators are programs for displaced farm workers, such as unemployment compensation, retraining and education, job referral services, and welfare. It is not our purpose here to discuss the relative merits of remedies, except to say that those facilitating adjustment are preferable to those that are only compensatory. With compensatory policies the underlying assumption is that the displaced will remain unemployed at least for a time. Society in general and the displaced persons in particular fare better with policies that seek to shorten that unemployment period and speed adjustment.

Public investment in agricultural research has paid off handsomely, even when including adjustment costs. Benefits have far outweighed the costs, economically speaking. Social costs resulting at least in part from agricultural research, however, need to be recognized and dealt with. The solution to social problems is not to curtail

TABLE 1. Estimated Returns To Agricultural Research Investment.

Authors	Farm Product	Country	Internal Rate of Return* %
Masakatsu Akino and Yujiro Hayami	Rice	Japan	73-75
Harry W. Ayer and G. Edward Schuh	Cotton seed	Brazil	77
Maury Bredahl and Willis Peterson	Cash grain	U.S.	36
	Poultry	U.S	37
	Dairy	U.S.	43
	Livestock	U.S.	46
Zvi Griliches	Hybrid corn	U.S.	35-40
Yao-Chi Lu and Philip L. Cline	Aggregate agricultural product	U.S.	26.5
Marshall A. Martin and Joseph Havlicek, Jr.	Cotton (harvester)	U.S.	†
Philip L. Martin and Stanley S. Johnson	Tobacco (harvester)	U.S.	28
Willis L. Peterson	Poultry	U.S.	14
Willis L. Peterson	Aggregate agricultural product	U.S.	19
Andrew Schmitz and David Seckler	Tomato (harvester)	U.S.	15+

*A 19 percent internal rate of return means that on the average each dollar invested in agricultural research (and extension) returns 19 percent annually from the date of investment. Willis L. Peterson, "The Returns to Investment in Agricultural Research in the United States," in Walter L. Fishel (ed.), *Resource Allocations in Agricultural Research*, Minneapolis: University of Minnesota Press, 1971, p. 149.

†The internal rate of return was not computed, but for 1952-1969, the gain in consumers' surplus in constant (1947-1949) dollars was about $350 million—$230 million to U.S. consumers, $120 million to consumers outside the U.S.

agricultural research in general nor mechanization research in particular, for society would surely be the loser. Rather, additional research needs to be undertaken—research that is directed at social problem-solving.

Change has been integral to agricultural development, and research has been an important part of the process. Today in America, one commercial farm operator provides the raw food and fiber for 125 Americans and many in other countries as well. The others in the nation's vast food and fiber system are in farm input manufacturing industries, food processing plants, transportation, textile mills, clothing manufacture, wholesale and retail trade, and restaurants. Still others are freed from any direct connection with the food and fiber system. Consumers in America enjoy variety, quality, and abundance of reasonably-priced food and fiber products unrivaled anywhere else in the world and at a level never before attained. Much of this success is thanks to what can literally be called "seed money"—the public's investment in agricultural research.

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Spider mite damage to soybean plots at the West Side Field Station at Five Points.

The search is on to find a way to reduce chemical control of two major soybean pests.

Testing soybeans for resistance to spider mites

Elmer C. Carlson □ Benjamin H. Beard □ Ronald Tarailo □ Robert L. Witt

Spider mites [*Tetranychus urticae* (Koch) and *T. pacificus* (McGregor)] have been the most important pests on soybeans grown in California in at least five of the last seven years. While it may be possible to control these pests with chemicals or even with integrated pest management, host-plant resistance would be more satisfactory. As early as 1966, potential for this was found at the West Side Field Station when a few cultivars were found to have lower mite infestation and damage levels.

Testing procedures have been developed to find spider mite-resistant soybean germplasm as a first step in developing resistant cultivars for commercial production in California. Field and greenhouse tests are useful and necessary to determine resistant lines. Since testing began in 1967 we have found that B-106, B-107, L62-561, L67-3388, and P.I.86,452 are resistant lines compared with Wells, Chippewa 64, or Portage, which are used as susceptible checks.

How damage starts

Damage to soybeans begins when a small number of mites feed, causing a white-stippled type of injury to appear on the upper surface of the leaflet. Increasing numbers of mites cause leaflets to turn yellowish and then brown and to drop prematurely. Defoliation reduces seed yield significantly, particularly if it occurs early in the growing season.

Yield loss is difficult to correlate with actual mite counts because the relationship varies from one leaflet to another and mite numbers vary from one to another area of the same leaflet. Experiments have indicated, however, that five or more mites in a 12.7 mm circle on a leaflet (about 100 mites per leaflet) will lead to leaf yellowing and some yield loss. At counts above 25 per circle (1,000 or more mites per leaflet),