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Changes in Wheat Varieties and Yields in the United States, 1919–1984

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> The word "productivity" pushes a historian toward economics, but the phrase "productivity growth" pushes an economist toward history.
>
> *William N. Parker, 1971*[1]

Wheat has long been one of the keystones of U.S. agriculture. Increases in production have traditionally been associated with technological innovation—particularly, in the popular mind, with mechanical technologies such as threshers and combines. But there are other and less well-known forms of technologies, particularly those developed through biological science, which are of much greater importance in increasing productivity in terms of yields per acre of land.

The relative importance of these major forms of technologies has varied over time. In general, mechanical technologies were of major impor-

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1. William N. Parker, "Productivity Growth in American Grain Farming: An Analysis of Its 19th Century Sources," in R. W. Fogel and S. L. Engerman, eds., *The Reinterpretation of American Economic History* (New York: Harper and Row, 1971), 176.

tance well before biological technologies. A study of overall productivity in U.S. agriculture has suggested that the years from the Civil War to WW II may be characterized as the period of, successively, horse and mechanical power; the period from WW II to the present is characterized as the period of science power. Overall productivity increased only gradually through the first period and did not begin to increase substantially until about 1940 and the onset of the period of science power.[2]

The same pattern has been followed in wheat yields.[3] Yields increased very little from 1866 through the end of the century. This situation moved Sir William Crookes, in his presidential address to the British Association for the Advancement of Science in 1898, to state that: "It is almost certain that within a generation the ever-increasing population of the United States will consume all the wheat grown within its borders, and will be driven to import, and . . . will scramble for a lion's share of the wheat crop of the world."[4] This did not happen, but the reason was that area continued to expand for the next 35 years. Yields remained about level and did not begin to increase significantly until the early 1940s.

What is the relationship of technology to these yield trends? The problem for the period up to 1940 is to sort out the effects of technology from the effects of other variables such as the change in the natural resource base. The mechanized technology that increased productivity per person, for example, also helped make it possible to extend cultivation into more arid and less well-endowed areas where yields per acre were lower.[5] Weather and disease (rust) were also of significance at various points during this period. The effect of some yield-increasing technologies may have been masked.

Yet a profound change in yields began in the 1940s. The reason for the change was the same as for agriculture as a whole: the contribution of biological science. At the forefront of this change was a shift in the approach taken by some plant breeders which resulted in significant modifications in the genetic characteristics of the wheat plant. The improvements were expressed in new varieties with higher yield potentials. This

2. Yao-chi Lu, Philip Cline, and Leroy Quance, *Prospects for Productivity Growth in U.S. Agriculture* (Washington, D.C.: U.S.D.A., Agricultural Economics Report 435, September 1979), 9–10. (The authors have drawn on the work of Wayne Rasmussen on this point.)

3. Yield data for wheat, as well as several other crops, from 1866 to 1972 are summarized graphically in C. B. Luttrell and R. A. Gilbert, "Crop Yields: Random, Cyclical, or Bunchy?" *American Journal of Agricultural Economics* 58 (August 1976) 3:526–27.

4. Sir William Crookes, *The Wheat Problem* (New York: G. P. Putnam's Sons, 1900), 17, 18.

5. A vivid personal account of the effect of increased tractorization in wheat production on soil conservation is provided in Lawrence Svobida, *Farming the Dust Bowl; A First-Hand Account from Kansas* (Lawrence: University Press of Kansas, 1986), 33–255; also see the very useful Foreword by R. Douglas Hurt, 7–32, especially 8–9.

story is, oddly, relatively little known in the United States. The nation has heard much of the green revolution in developing nations, but virtually nothing of a similar change right under its own feet.[6]

This relative silence is partly due to the unobtrusive nature of the higher-yielding varieties. They did not look much different—with one vital exception which will be noted—from their predecessors. Their use has expanded gradually. And it is difficult to determine their exact impact at the farm level.

Biological scientists have, for some time, measured the effect of genetic improvement on crop yield under experimental conditions—particularly in federal-state regional performance nurseries. These trials provide an excellent opportunity to measure the impact of varietal change. But they are usually conducted at the regional level, the results are generally highly detailed and unpublished, and they are not necessarily indicative of results at the farm level. They also do not reveal much about the particular plant characteristics that result in higher yield.[7]

While agricultural economists and historians have long been interested in technological change, they seldom look very closely at varieties unless a dramatic shift, such as hybrid corn is involved. The technology variable is often measured by fertilizer use (where known) or a time variable. In the case of wheat in the United States only a few studies have included a variety variable, and then they generally have drawn on yield trials.[8] One significant exception is provided by Johnson and Gustafson who intro-

6 The major dimensions of this process are outlined in Dana G. Dalrymple, "The Adoption of High-Yielding Grain Varieties in Developing Nations," *Agricultural History* 53 (October 1979) 4:704–26. The contribution of similar varieties in Australia have recently been analyzed in John P. Brennan, *Impact of Wheat Varieties from CIMMYT on Australian Wheat Production* (Haymarket: New South Wales Department of Agriculture, Agricultural Economics Bulletin 5, September 1986), 1–56.

7. A number of these studies are briefly summarized in A. M. Feyerherm, G. M. Paulsen, and J. L. Sebaugh, "Contribution of Genetic Improvement to Recent Wheat Yield Increases in the USA," *Agronomy Journal* 76 (November–December 1984) 6:985–90. Two recent wheat studies of interest are: C. J. Peterson, V. A. Johnson, J. W. Schmidt, and R. F. Munn, "Contribution of Genetic Improvement to Increases in Wheat Yields and Variance of Productivity in the Great Plains," in J. R. Anderson and P. B. R. Hazell, eds., *Variability in Grain Yields and Its Implications for Agricultural Research and Policy* (Baltimore: Johns Hopkins University Press [for International Food Policy Research Institute], in press); and John W. Schmidt, "Genetic Contributions to Yield Gains in Wheat," in *Genetic Contributions to Yield Gains of Five Major Crop Plants* (Madison, WI: American Society of Agronomy, Special Publication 7, 1984), 89–101.

8. See J. J. Bond and D. E. Umberger, *Technical and Economic Causes of Productivity Changes in U. S. Wheat Production, 1949–76*, (Washington: U.S.D.A., Technical Bulletin 1598, 1979), 1–102; E. O. Heady and Ludwig Auer, "Imputation of Production to Technologies," *Journal of Farm Economics* 66 (May 1966) 2:309–322; and Frank Orazem and M. A. Jamison, "Importance of New Varieties in Kansas Wheat Production," in *Evaluation of Agricultural Research* (St. Paul: University of Minnesota, Agricultural Experiment Station, Miscellaneous Publication 8, April 1981), 116–20.

duced a "newness of variety" variable.[9] In 1975, in a study of yields in the midwest, Perrin and Heady stated that "There have been no dramatic, indentifiable innovations in wheat varieties . . . This introduces a problem in identifying a variable to represent this factor."[10]

In reality, one characteristic of the new varieties—which was at the heart of their higher-yielding capacity—was readily visibly apparent: shorter height. The reduced height enabled the plants to respond to improved fertilization and other cultural practices without lodging or falling over before harvest. And it provided an excellent "marker" for measurement. While this characteristic was well-known to wheat breeders, it evidently escaped the notice of others who might have profitably drawn on it. The same characteristic is found in high-yielding rice varieties and may increasingly be a factor in some other crops. Utilization of the height characteristic, however, requires some knowledge of wheat varieties and the varietal improvement process.

Historically, the varietal improvement process in wheat has gone through three stages:

- Introduction of varieties from foreign countries;
- Isolation of pure-line selections from introduced varieties; and
- Creation of new varieties by crossing (hybridization), followed by selection.

The first stage began when the first settlers came to the United States and was soon followed by the second. The third stage started in the late 1800s, took hold in the 1920s, and became a major force after 1940.

New and improved varieties are constantly needed, in part to replace older varieties which have fallen prey to diseases (particularly rust). In this sense, as Johnson and Gustafson observed in 1962, much of the research constitutes a maintenance operation.[11] But other significant forms of plant improvement are also carried out.

9. D. Gale Johnson and Robert L. Gustafson, *Grain Yields and the American Food Supply: An Analysis of Yield Changes and Possibilities* (Chicago: University of Chicago Press, 1962), 69–70, 80, 85, 90, 120, 139. This concept, and a variant, was used in a study in Australia: see John P. Brennan, "Measuring the Contribution of New Varieties to Increasing Wheat Yields," *Review of Marketing and Statistics* 52 (December 1984): 175–95.

10. Richard K. Perrin and Earl O. Heady, *Relative Contributions of Major Technological Factors and Moisture Stress to Increased Grain Yields in the Midwest, 1930–71* (Ames: Iowa State University, Center for Agricultural and Rural Development, CARD Report 55, March 1975), 30.

11. Johnson and Gustafson, *Grain Yields*, 120. It was recently reported that over 70 percent of the expenditures on wheat research in the state of Washington are needed to maintain yields (Manfred W. Heim and Leroy Blakeslee, "Biological Adaptation and Research Impacts on Wheat Yields in Washington" (Pullman: Washington State University, Department of Agricultural Economics, unpublished, August 1986), 10–11).

Table 1. Number of Wheat Varieties Reported Planted and Ranking of the Top Five Varieties in Terms of Area Planted, 1919 to 1984[a]

Survey Year	Number of Varieties	Rank 1	2	3	4	5
1919	146	Turkey	Marquis	Fultz	Mediterra-nean	Fulcaster
1924	152	Turkey	Marquis	Kanred	Fulcaster	Fultz
1929	190	Turkey	Marquis	Blackhull	Kanred	Fultz
1934	213	Turkey	Marquis	Blackhull	Ceres	Kanred
1939	208	Turkey	Blackhull	Thatcher	Ceres	Tenmarq
1944	216	Tenmarq	Turkey	Blackhull	Thatcher	Rival
1949	199	Pawnee	Comanche	Triumph	Mida	Thorne
1954	203	Pawnee	Wichita	Triumph	Lee	Comanche
1959	212	Triumph	Wichita	Selkirk	Pawnee	Cheyenne
1964	223	Wichita	Triumph	Improved Triumph	Monon	Bison
1969	263	Scout	Improved Triumph	Monon	Wichita	Triumph
1974	315	Scout	Arthur	Waldron	Centurk	Era
1979	370	Centurk	TAM W-101	Scout	Olaf	Eagle
1984	429	Newton	TAM 105	Vona	Tam W-101	Marshall

[a]Individual varieties: excludes "families" (except for Turkey).

The combined effect of plant improvement efforts has been the release and adoption of a large number of new wheat varieties in the United States. Fortunately, data are available on the use of varieties on an area planted basis every five years from 1919 to 1984 (see Appendix), so that we can trace patterns of adoption. The number of varieties reported in use are listed in the first column of Table 1. The totals grew through 1934, levelled out until 1964, and then increased very sharply.

While there are many varieties, they varied considerably in importance. The five leading varieties as reported in each survey year are also summarized in Table 1. The degree of concentration is shown graphically in Figure 1. Clearly, prior to 1944 the area was heavily dominated by a few varieties. Their relative importance, however, has dropped sharply over time and by 1984 the five leading varieties occupied a smaller proportion of the area than the leading variety did in 1919 or 1924.[12]

12. While the degree of varietal concentration has decreased, it cannot be said that there has been a corresponding increase in genetic diversity because of varietal interrelationships. The decline in concentration from 1964 to 1984 noted here, for example, would not have been as great if varietal "families" rather than individual varieties had been considered (see Table 2). Also, some of the older varieties such as Turkey were in reality quite heterogeneous. Still, a detailed recent study of red winter wheat varieties, which utilized the same varietal surveys,

The pattern has also changed among leading varieties. From 1919 through 1944, the composition was rather static. Turkey was the leading variety in five of the six survey years, and was followed by Marquis in four of the years. A few other varieties largely completed the picture: Blackhull, Thatcher, Tenmarq, Kanred, Fultz, and Fulcaster. From 1949 to 1984, the variety picture was much more mixed and dynamic. No variety occupied the number one position for more than two survey years. None of the leading varieties from the first period held this position in the second period.

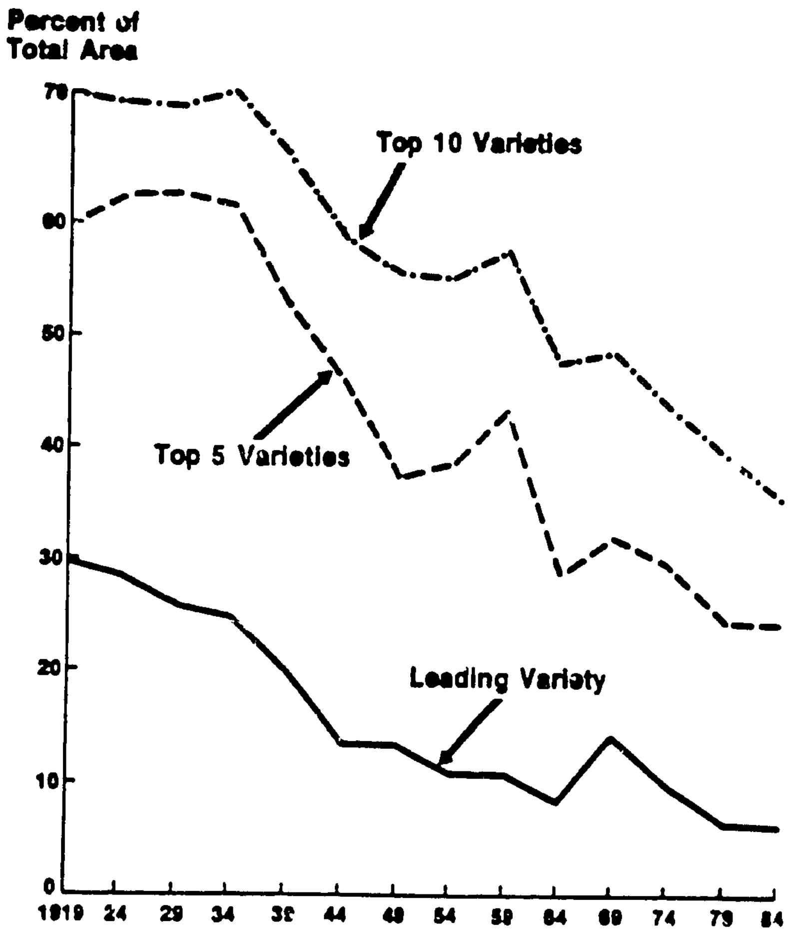
The foregoing data may be summarized in terms of the area of the leading varieties in the 14 reporting periods (Table 2). As might be expected, the older varieties which dominated the variety scene up to 1944 also dominate in this tabulation. But several of the varieties from the more dynamic period from 1949 to 1984 also appear: Triumph ("family"),

Table 2. Wheat Varieties Planted on Total of More than 7 million Acres During 14 Survey Years, 1919–1984

Rank	*Variety*	*Peak Survey Years*[a]	*Total Area*
			(acres)
1	Turkey	1919–1954	93,517,500
2	Marquis	1919–1944	47,598,500
3	Triumph[b]	1949–1979	38,589,100
4	Blackhull[c]	1924–1949	33,052,700
5	Scout[d]	1969–1984	25,582,400
6	Wichita	1949–1974	24,326,200
7	Pawnee	1949–1964	24,074,800
8	Thatcher	1939–1954	18,258,600
9	Tenmarq	1939–1949	16,413,100
10	Kanred	1924–1944	13,776,400
11	Cheyenne	1944–1974	13,128,900
12	Fultz	1919–1944	13,006,900
13	Ceres	1934–1949	12,360,600
14	Arthur[e]	1974–1984	11,764,700
15	Comanche	1949–1959	11,636,600
16	Fulcaster	1919–1939	9,696,200
17	Centurk	1974–1984	8,732,700
18	TAM W-101	1979–1984	7,421,900

[a]Survey years in which area was over 1 million acres.
[b]Includes Triumph "family": Super Triumph (1,447,200), Newest Improved Triumph (753,100), Improved Triumph (8,334,700), and Triumph 64 (Rust Resistant Triumph) (2,602,700).
[c]Includes Early Blackhull (3,787,000).
[d]Includes Scout 66 (6,510,700).
[e]Includes Arthur 71 (4,837,600).

Figure 1. Proportion of Wheat Area Planted to Leading Varieties, United States, 1919 to 1984



Scout ("family"), Wichita, Pawnee, Arthur ("family"), Comanche, Centurk, and TAM W101. Do these latter varieties have any particular quality that would characterize them? The answer is yes, either short or semi-dwarf height.

Virtually all of the varieties raised through 1940 were tall. Until that time most U. S. breeders believed that only tall wheats had the potential for

suggested that they are entering a new era of increasing diversity [T. S. Cox, J. P. Murphy and D. M. Rodgers, "Changes in Genetic Diversity in the Red Winter Wheat Regions of the United States," *Proceedings of the National Academy of Sciences* 83 (August 1986) 15:5583–586].

high yield.[13] Just why this was the case is uncertain, but it may have reflected the extensive nature of wheat production. Only a relatively small area was fertilized or irrigated (even by 1959 the respective proportions had only reached 42.1 and 3.6 percent respectively).[14]

Yet the potential for higher yield levels was not unknown. In 1874 the U. S. Commissioner of Agriculture reported on high-yielding, semidwarf wheat in Japan.[15] Shorter height enabled the plants to respond to heavier fertilization without lodging.

The first major short variety used in the United States was Federation. It was introduced from Australia in 1914, released in 1920, and became widely grown in the Pacific Northwest by 1929. It was not, however, particularly high-yielding. The second short variety, Alicel, was developed in Oregon and released in 1932; it had greater yield potential.

With the release of Elgin, a selection from Alicel, in 1942, high yield potential became a reality. A subsequent report in 1953 stated:

> Previous to the creation of Elgin, it was often believed that short stiff-strawed varieties could be obtained only with some sacrifice in yield. Elgin proves conclusively that this is not true in the Pacific Northwest and for this area, at least, has done much to determine the objectives of varietal improvement for the future. Hereafter, no variety for the Pacific Northwest can be expected to be endorsed enthusiastically by farmers unless it has short stiff straw similar to or better than that of Elgin.[16]

Other varieties considered short at the time included Ramona (1935), Idaed (1938), Lehmi (1939), Triumph (1940), Pawnee (1942), and Wichita (1944). As noted in Table 1, the latter three were among the top five varieties from 1949 to 1964. In addition to resistance to lodging, these short varieties and those that followed had, to varying degree, other desirable plant characteristics such as earlier maturity.[17]

The overall area planted to short varieties and the names of the varieties

13. L. W. Briggle and O. A. Vogel, "Breeding Short-Stature, Disease-Resistant Wheats in the United States," *Euphytica* 17 (December 1968, Supplement 1): 108.

14. Dana G. Dalrymple, *Development and Spread of Semi-Dwarf Varieties of Wheat and Rice in the United States* (Washington: U.S.D.A., Agricultural Economic Report 455, June 1980), 86–89.

15. Horace Capron, "Agriculture in Japan," *Report of the Commissioner of Agriculture for the Year 1873* (Washington GPO, 1874), 369.

16. S. C. Salmon, O. R. Mathews and R. W. Leukel, "A Half Century of Wheat Improvement in the United States," in *Advances in Agronomy* (New York: Academic Press, 1953) V, 90, 92.

17. Short height is a relative measure: standards vary over time and by region. No one measure can be given in terms of inches or centimeters that covers all cases. Extremely short height is not desirable because it is generally associated with other undesirable genetic characteristics.

Table 3. Estimated Area Planted to Short Varieties of Wheat, 1924-1984

Survey Year	*Area of Short Varieties (acres)*	*Proportion of Total Area (percent)*	*Short Varieties Added to Category*
1924	34,000	0.1	Federation
1929	791,300	1.3	--
1934	803,100	1.3	Ramona
1939	831,700	1.3	Alicel/Elgin, Idaed
1944	1,253,400	1.9	Pawnee, Triumph
1949	21,922,000	25.8	Wichita
1954	23,027,300	37.2	Brevor, Chinook, Lee, Ponca
1959	21,849,900	37.8	Burt, Columbia, Druchamp, Lakota, Tascosa, Wells
1964	25,810,000	46.9	Gage, Lancer, Monon, Omaha, Ottawa, Warrior
1969[a]	21,842,300	40.2	Arthur, Chris, Manitou, Parker, Waldron
1974[a]	31,502,300	44.3	Abe, Baca, Centurk, Eagle, Leeds, Rolette, Ward
1979[a]	25,759,200	36.0	Butte, Larned
1984[a]	10,780,100	13.6	Manning, Rose

[a]Includes principal, but perhaps not all, new releases and may be underestimated. Varieties classified as short in earlier periods were considered of medium height during this period.

included in this category are summarized in Table 3. From 1924 to 1964, the table includes varieties listed as short in USDA wheat classification reports issued in 1954 and 1963.[18] From 1969 to 1984, it includes the above varieties plus principal new releases of medium or short height identified by wheat specialists (the height standards became more strict over time); this list may be incomplete and hence the total is probably slightly underestimated. Neither grouping includes some varieties of slightly greater height which arguably might have been included (Thatcher, Knox, Dual, Vermillion, and, most significantly, Scout).

The area planted to short varieties grew rather modestly through 1944, when it represented less than 2 percent of the total area. By 1949, however, it rose very sharply and represented nearly 26 percent of the total wheat area. It dropped in 1959, but by 1964 had increased again and represented nearly 47 percent of the total area. Thereafter the area (which as noted above is incompletely reported) varied and eventually declined sharply by 1984. Leading short varieties in terms of area planted were, in

18. B. B. Bayles and J. Allen Clark, *Classification of Wheat Varieties Grown in the United States in 1949* (Washington: U.S.D.A., Technical Bulletin 1083, March 1954), 1-133; L. W. Briggle and L. P. Reitz, *Classification of Triticum Species and of Wheat Varieties Grown in the United States* (Washington: U.S.D.A., Technical Bulletin 1278, May 1963), 1-135.

Table 4. Estimated Area Planted to Semidwarf Varieties of Wheat, 1964–1984

Survey Year	*Area of Semidwarfs (acres)*	*Proportion of Total Area (percent)*	*Principal Semidwarf Varieties Added to Category*[a]
1964	1,609,000	2.9	Gaines
1969	3,806,000	7.0	Blueboy, Era[b], Nugaines, Sturdy
1974	15,756,400	22.1	TAM W-101
1979	22,367,400	31.3	Coker 747, Daws, Hart, Len, McNair 1003, Newana, Newton, Olaf, Pioneer S-76, Stevens, Vona, Wings
1984	46,491,400	58.7	Brule, Caldwell, Coker 762, Coker 797, Coker 916, Frankenmuth, Hawk, Marshall, Oslo, Pike, Pioneer 2550, Pro Brand 812, TAM 105

[a]Varieties listed planted on more than 400,000 acres in any one of the years noted
[b]Only planted on 300 acres in 1969; not officially released until 1970.

decreasing order: Triumph, Wichita, Pawnee, Arthur, Centurk, Lee, Waldron, Eagle, Monon, Federation, Wells, and Warrior.

The reason for the decline in area of short varieties was not any lack of interest in height. Quite the contrary: the short varieties were in part replaced by even shorter and more productive varieties—semidwarfs. The history of semidwarf wheats in the United States has been reported elsewhere and will not be recounted in detail here.[19] Suffice it to say that breeding work on semidwarfs was instituted at a number of U. S. institutions during the 1950s. The first semidwarf varity, Gaines, was released in 1961 and was followed by Nugaines in 1965. Both were developed in Washington State and found their widest use in the Pacific Northwest (the first area, as we have noted, to make wide use of short varieties). The number of releases was relatively small through 1968, and thereafter began to increase rapidly. By 1979, the total number of semidwarf varieties released reached at least 151; by 1984 it reached at least 223.[20]

The estimated area planted to semidwarfs from 1964 to 1984, based on the varieties identified above and area data reported in the wheat variety surveys, is reported in Table. 4.[21] The area rose gradually in 1970, and then sharply in subsequent years. By 1984, the semidwarfs occupied nearly 59

19. Briggle and Vogel, "Breeding Short Stature . . . Wheats . . . ," 107–30; Dalrymple, "Development . . . of Semi-Dwarf Varieties . . . ," 30–39; Dana G. Dalrymple, *Development and Spread of High-Yielding Wheat Varieties in Developing Countries* (Washington: Agency for International Development, 1986), 95–97 (appendix).

20. Dalrymple, "Development. . . . of Semi-Dwarf Varieties . . . ," 55–56, "Development . . . of High-Yielding Wheat . . . ," 96. The classification of a few of these varieties as semidwarfs is a matter of judgement and is open to question.

21. Note that column 4 of Table 4 includes only the leading varieties. Many of the semidwarf releases, as is true of other varieties, are planted on small or insignificant areas.

percent of the total wheat area. The leading semidwarf varieties for the period in terms of area planted were, in decreasing order: TAM W-101, Newton, TAM 105, Era, Nugaines, Vona, Olaf, Gaines, Sturdy, Stephens, Marshall, and Len.

The growth in total area of short and semidwarf varieties is represented graphically in Figure 2. The data through 1959 represent short varieties; beginning in 1964 semidwarfs played an increasing role. Following the initial surge in adoption from 1944 to 1949, the total continued to increase on an irregular basis, with substantial increments in 1964 and 1974. In 1984, the overall percentage did not increase greatly, but the semidwarf proportion grew sharply (to 81.7 percent of the short and semidwarf total).

Data on concurrent changes in wheat yields in the United States from 1900 to 1985 are also provided in Figure 2. As noted in the introduction, yields began to increase about 1940. The figure reveals that the process took place in two steps: an increase to a slightly higher plateau in 1941 which held until about 1955, and then a period of more substantial and sustained growth which continued until 1985.

Annual yield levels show substantial variation, as would be expected, due to the influence of weather, diseases and other factors. Drought and rust had a particularly pronounced effect from 1933 to 1938.[22] Rust was a problem again from 1949 to 1956, when rust resistant varieties were introduced.[23] Following study of the period from 1900 to 1956, Johnson and Gustafson concluded that most of the decade-to-decade variation in yields prior to 1940 could be attributed to weather, but that non-weather influences apparently caused an increase in yields in the 1940–1949 and 1950–1956 periods.[24]

The data provided in Figure 2 have suggested that the expansion in use of short and semidwarf varieties and the growth in yield levels generally coincided.[25] The two appear, moreover, to have been highly correlated. And indeed simple correlation analysis reveals an r^2 value of 0.82 for the eight survey years from 1949 to 1984.[26]

The high correlation should be immediately qualified. While the short

22. The drought (the dust bowl) was at its peak from 1933 to 1936 and rust epidemics occurred in 1935, 1937, and 1938.

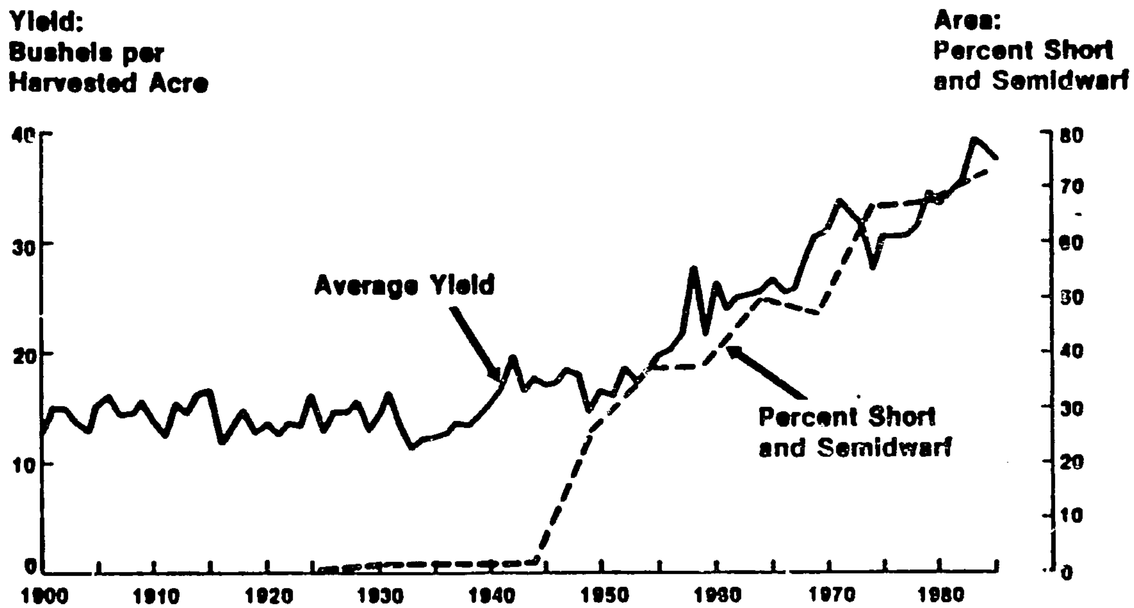
23. Luttrell and Gilbert, "Crop Yields," 529.

24. Johnson and Gustafson, *Grain Yields*, 33–35, 137.

25. An exception is provided by the period from 1944 to 1949; while there was a sharp increase in the use of short varieties, overall yields did not increase. The potential impact of the varieties may have been muted by other factors such as limited fertilization.

26. Johnson and Gustafson (*Grain Yields*, 78, 80) obtained a similar result for their "newness of variety" figure for a earlier period in the western region. The coefficient reported here was raised, to as high as 0.86, when the data were manipulated in various ways (such as using a three-year moving average of yields and calculating the varietal proportions for intervening years).

Figure 2. Wheat: Average Yields and Proportion of Area Planted to Short and Semidwarf Varieties, United States, 1900 to 1985



and semidwarf varieties have the potential for higher yields, this potential is not due to shortness alone; other improved genetic qualities such as early maturity and disease resistance are also involved. Realization of the genetic potential is usually associated with a higher level of inputs, particularly fertilizer. The varieties also benefit from improved water supplies (irrigation) and other cultural practices.

Additional factors which influenced wheat yields during the 1949 to 1976 period were changes in: (1) the proportion grown on summer fallow, (2) the share of wheat grown on land with a relatively low soil productivity base, (3) wheat market classes, (4) pesticide use, and (5) cultural practices.[27] Land diversion programs begun in 1983, which relate to item (2) above, could also influence subsequent yield levels.[28]

Of the agronomic variables, fertilizer is generally the most important.[29] Higher yields are, however, a joint product of the two: in general the shorter varieties will not yield much more unless they receive more fertilizer, but higher fertilization in the absence of the shorter varieties may not be worthwhile. This interaction presents a significant analytical problem in isolating and quantifying the contribution of each factor.

Hence, just how much of the increase in yields reported here should reasonably be attributed to the improved varieties is uncertain. Studies by biological scientists, usually based on performance nurseries, have suggested that about half of the yield increase has come from genetic improvement and half from other factors.[30]

While one might wish to see the contributions of varieties and the other factors of production more precisely measured at the farm level, there is

27. Bond and Umberger, *Technical and Economic Causes*, 1–2, 17–66.

28. Mark S. Ash and William Lin, "Wheat Yield Response: Policy Implications and Projections," *Wheat Situation and Outlook Report* (Washington: U.S.D.A., Economic Research Service Report WS-275), May 1986, 10–16.

29. The simple correlation (r^2) between yield and the proportion of wheat area fertilized from 1954 to 1974 as reported in the census was 0.60. Survey data gathered for 17 states by USDA from 1964 to 1985 indicate increases in the proportion of wheat area (a) receiving any fertilizer, (b) receiving nitrogen, and in (c) the amount of nitrogen applied per acre; by 1984, the respective proportions were 76 percent, 76 percent, and 62 percent (Dalrymple, "Development . . . of Semi-Dwarf Varieties . . . ," 87; Paul Andrilenas, "Fertilizer," in *Agricultural Resources: Inputs Outlook and Situation Report* [Washington: U.S.D.A., Economic Research Service. Report AR-1], February 1986, 11). The data for item (a), including census data for 1954 and 1959, which are not strictly comparable, are summarized graphically in L. T. Evans, "Opportunities for Increasing the Yield Potential of Wheat," in *The Future Development of Maize and Wheat in the Third World* (Mexico City: International Center for Maize and Wheat Improvement, 1987), 83; the pattern is very similar to that reported here for the short and semidwarf varieties.

30. These studies are summarized in: L. T. Evans, "Physiological Aspects of Varietal Improvement," in J. P. Gustafson, ed., *Gene Manipulation in Plant Improvement* (New York: Plenum, 1984), 129; Dalrymple, "Development of . . . Semi-Dwarf Varieties. . . . ," 110–111; Schmidt, "Genetic Contributions," 90, 100; and Peterson et al., "Contribution of Genetic Improvement" (in press).

some question about how valid and useful any such calculations might be. As Evans has recently noted, "it is not really meaningful to divide the credit for yield increases between breeders and agronomists as if their contributions were independent of one another."[31] Suffice it to say that varietal improvement is a key factor in the process.

The improved varieties did not appear by chance. They were the result of introductions from other countries and/or research in the United States. Wheat is not native to the United States. All our varieties are introductions or, as is now generally the case, descended from introductions. Foreign varieties have played a major role in the varietal and yield changes described in this report.

Foreign introductions were widely planted during the first part of the century. Reitz has calculated the proportion of the wheat area directly planted to introductions in the 12 reporting periods from 1919 to 1974. The overall average was 27.2 percent and dropped in importance from 55.6 percent for 1919–1934, to 29.9 percent for 1939–1944, and to 7.4 percent from 1949 to 1974.[32] The most important introductions were Turkey and Marquis.

Beyond direct use, introductions (1) provided a source of selections, and (2) were used as parents in cross breeding. Prominent selections, for example, were: Blackhull from Turkey; and Kanred and Cheyenne from Crimea (a strain of Turkey). Marquis was a parent of Ceres, Thatcher, and Tenmarq (Tenmarq in turn was a parent of Comanche and Pawnee). Triumph is descended from crosses involving Blackhull, Kanred, and Florence (from Australia).[33]

There is an additional dimension in the case of the semidwarfs. All those utilized so far contain one or two dwarfing genes. With a few exceptions these can all be traced back to one Japanese variety, Daruma, which may have in turn come from Korea. Norin 10 is the best known descendent

31. Evans, "Opportunities for Increasing Yield Potential," 81.

32. Louis P. Reitz, "60 Years of Wheat Cultivar History in the United States," *Annual Wheat Newsletter* 25 (June 1979): 12–17. The proportions varied rather widely by market class and region. For a recent analysis of mid-western varieties, see Joanne Geigel and Wallace E. Huffman, "Improvement of Wheat Varieties in the U.S., 1919–1979" (Ames: Iowa State University, Department of Economics, Staff Paper Series 156, April 1986), 1–44.

33. Background on these and other varieties is provided in Bayles and Clark, *Classification of Wheat Varieties*, 1–33, Briggle and Reitz, *Classification of Triticum Species*, 1–135; J. Allen Clark, "Improvement in Wheat," *Yearbook of Agriculture, 1936* (Washington: U.S.D.A., 1936), 207–302; Jan L. Flora, "History of Wheat Research at the Kansas Agricultural Experiment Station," in Lawrence Busch and William B. Lacy, eds., *The Agricultural Scientific Enterprise* (Boulder: Westview Press, 1986), 186–205; J. W. Morrison, "Marquis Wheat—a Triumph of Scientific Endeavor," *Agricultural History* 34 (October 1960) 4:182–88, and K. S. Quisenberry and L. P. Reitz, "Turkey Wheat: The Cornerstone of an Empire," *Agricultural History* 48 (January 1974) 1:98–114. Information on more recent releases is provided in *Crop Science* (bimonthly).

of Daruma, but there were others, such as Seu Seun 27 and Suweon 92. Norin 10 was received in the United States in 1946 and was crossed with Brevor in Washington State in 1948. The cross was used as a parent (1) in other U. S. breeding programs, and (2) in breeding work by Dr. Norman Borlaug in Mexico at what is now the International Maize and Wheat Improvement Center (CIMMYT). A number of varieties and breeding lines developed by CIMMYT in turn have been introduced in the United States and either grown directly or used as parents. About 36 percent of the semidwarf area in the U. S. in 1984 (or 21 percent of the total wheat area) was composed of varieties with some CIMMYT-Mexican ancestry.[34]

The yield effects of the foreign contributions have been variable. The early introductions appeared to have little direct effect on overall wheat yield levels—but did provide other desirable qualities which helped make possible an expansion of production into less favored areas (Turkey is a case in point). More recent introductions and the shorter offspring of earlier varieties had a considerably more substantial influence on yield levels. And the effect of the semidwarf introductions on U. S. yields has been even more pronounced.

The other key dimension in wheat improvement in the United States has been the involvement of both the public and private sectors. In the beginning wheat improvement was largely carried out by private individuals. Starting about 1890, much of the crossing work was taken up by federal and state research institutions, often as collaborative efforts. In 1979, the wheat variety survey indicated that 75.4 percent of the varieties and 89.8 percent of the area was planted to varieties developed in the public sector; the rest was composed of privately developed varieties. In 1984, the proportion of the much larger number of varieties developed by the public sector dropped to 66.2 percent and their proportion of area dropped to 81.5 percent; again the remainder was composed of private varieties.[35]

Clearly the contribution of the private sector increased significantly from 1979 to 1984. This is reflected in the growth in the number of private sector varieties in use on over 500,000 acres: from four in 1979 to 10 in 1984. The expansion may have been in part due to the influence of the

34. Dalrymple, "Development of. . . . Semi-Dwarf Varieties . . . ," 30–39; "Development . . . of High-Yielding Wheat . . . ," 95–97.

35. L. W. Briggle, S. L. Strauss, D. E. Hamilton, and G. W. Howse, *Distribution of the Varieties and Classes of Wheat in the United States in 1979* (Washington: U.S.D.A., Statistical Bulletin 676, February 1982), 14; V. L. Siegenthaler, J. E. Stepanich, and L. W. Briggle, *Distribution of the Varieties and Classes of Wheat in the United States, 1984* (Washington: U.S.D.A., Statistical Bulletin 739, January 1986), 8.

Plant Variety Protection Act of 1970.[36] Many of the private sector varieties draw on germplasm developed in the public sector; the public sector is increasingly using varieties released by the private sector as parents. The private sector has released all of the hybrid varieties in use; as of 1984 their total area was negligible but will probably increase in the future.[37]

The recent emphasis on biotechnology has influenced the institutional nature of varietal development. A study of plant breeding and biotechnology revealed that many state experiment stations have created biotechnology programs in part by reducing conventional plant breeding programs. A similar process appears to be taking place in the Agricultural Research Service. And whereas nearly every state could afford a conventional plant breeding program, this is not true of plant biotechnology which is much more costly. All of this may lead to a greater role for the private sector in wheat breeding programs, at least for the major wheat growing areas.[38]

In summary, wheat production in the United States has undergone a virtual "green revolution." Just as in the better-known case in the developing nations, the development and adoption of short and semidwarf varieties, and improved production practices, has led to significantly increased yields. But the process in the United States has been more gradual and has gone on for a longer period. It has also been difficult to measure. Hence the process has largely been unnoticed. Accomplishments to date have been heavily dependent on (1) genetic characteristics found, or improvements made in other nations and in international agricultural research centers, and (2) a balance between research in the public and private sectors. If this productive balance is maintained, and the potential of biotechnology is realized, the past could indeed be prologue.

36. Of the 127 certificates issued for wheat varieties from 1971 to 1983, 91 were from the private sector and 36 were from the public sector (Robert E. Evenson, "Intellectual Property Rights and Agribusiness Research and Development: Implications for the Public Agricultural Research System," *American Journal of Agricultural Economics* 65 (December 1983) 5:971).

37. The public sector was initially fairly heavily involved in research with hybrid varieties but over time almost completely dropped out. Most, but not all, of the recent hybrids are semidwarfs. For further recent details on the development of hybrids see Mary K. Knudson and Vernon Ruttan, "The Research and Development on a Biological Innovation: Commercial Hybrid Wheat," *Food Research Institute Studies* 21 (1980) 1:45–68. More general information on the private sector is provided in R. L. Kalton and Phyllis Richardson, "Private Sector Plant Breeding Programs: A Major Thrust in U.S. Agriculture," *Diversity* 5 (1983): 16–17.

38. Michael Hansen, Lawrence Busch, Jeffrey Burkhardt, W. B. Lacy, and L. R. Lacy, "Plant Breeding and Biotechnology," *Bioscience* 36 (January 1986) 1:29–39; Donald N. Duvick, "North American Grain Production: Biotechnology Research and the Private Sector," in C. Ford Runge, ed., *The Future of the North American Granary: Politics, Economics, and Resource Constraints in North American Agriculture* (Ames: Iowa State University Press, 1986), 191–94.

Appendix

1. Sources of wheat variety data:
   Periodic issues of *Distribution of the Varieties and Classes of Wheat in the United States,* U. S. Department of Agriculture.
   1919 and 1929. Department Bulletin No. 1498, May 1929.
   1929. Circular No. 283, November 1933.
   1934. Circular No. 424, April 1937.
   1939. Circular No. 634, August 1942.
   1944. Circular No. 761, January 1948.
   1949. Circular No. 861, March 1951.
   1954. Agriculture Handbook No. 8, January 1957.
   1959. Statistical Bulletin No. 272 (issued by Agricultural Research Service), November 1960.
   1964. Statistical Bulletin No. 369 (ARS), July 1966.
   1969. Statistical Bulletin No. 475 (ARS), May 1972.
   1974. Statistical Bulletin No. 604 (ARS), June 1978.
   1979. Statistical Bulletin No. 676 (ARS), February 1982.
   1984. Statistical Bulletin No. 739 (issued by Statistical Reporting Service), January 1986.

2. Sources of wheat yield data: Crop Reporting Board, U.S.D.A.:
   - *Wheat: Area, Yield, Production by States, 1866–1943,* Agricultural Research Service, Statistical Bulletin No. 158, February 1955.
   - *Acreage, Yield, and Production of Principal Field Crops, Revised Estimates, 1944–49,* Bureau of Agricultural Economics, Statistical Bulletin No. 108, March 1952.
   - Various issues of *Field Crops by States, Acreage, Yield, Production:* Statistical Reporting Service, Statistical Bulletin (SB) No. 185, June 1956; SB No. 290, June 1961; and SB No. 384, December 1966 (1949–1964).
   - *Wheat, Outlook and Situation Yearbook,* Economic Research Service, WS-274, February 1986 (1961–1985).