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Part Three

Employment and Productivity

Chapter 5

Changes in Technology

EXCEPT for Part Four, in which we summarize our findings, the remainder of this volume is devoted to a consideration of trends in agricultural productivity. In this discussion we shall be concerned primarily with the comparison of changes in output and changes in employment. But the productivity from one period to another of any industrial segment, in terms of the ratio of output to input of labor, is largely a function of the technological methods in vogue, and trends in this productivity ratio can be understood and interpreted only in the light of the technological state of the industry. In order to provide a background for later discussion, the present chapter will review the development of agricultural technology. It should be regarded, therefore, as an introduction to the statistical treatment of employment and productivity in Chapters 6 and 7.

To agricultural technique as we now know it a great variety of innovations have contributed. Some of these were developed exclusively for the farmer: for example, the combine. Others—gasoline power, for instance—were originally introduced with small thought of their agricultural applications, but were nevertheless adopted eagerly by the farmer once their usefulness in agriculture was established. The discussion of all these various innovations will be grouped under two general topics: changes in farm machinery and equipment and changes in plants and animals.

FARM MACHINERY IN 1899[1]

Much of the machinery commonly regarded as basic to the technique of modern farming had already been invented, and had received considerable development, prior to 1899. The steel plow, many different kinds of cultivating, mowing, harvesting and threshing machinery—all these had decades of experimentation behind them, and had been accepted as standard equipment in one form or another on the larger farms, particularly in the West. By the turn of the century the use of "improved machinery" was widespread; it was commonly considered indispensable to the production even of the much smaller agricultural output of those days,[2] and was looked upon as a vital factor in the development of the West.[3] By "improved machinery" the writers of forty years ago meant apparatus that had already undergone a lengthy process of adaptation since its introduction: gang plows and other four-horse machinery, for example, rather than two- or three-horse machinery;[4] the self-binder rather than the early reapers of the middle nineteenth century; the eight-foot as against the simpler four-foot-cut mowing machinery.[5]

The history of agricultural machinery, as distinguished from hand implements, goes back at least a hundred years,

[1] For an excellent illustrated historical account of agricultural implements prior to 1899, see Leo Rogin, *The Introduction of Farm Machinery in its Relation to the Productivity of Labor in the Agriculture of the United States during the Nineteenth Century* (University of California, 1931); a briefer sketch, with special reference to the harvester and to the priority of its invention, will be found in M. F. Miller, "The Evolution of Reaping Machines," *The Making of America*, ed. R. M. La Follette (Morris, Chicago, 1905), Vol. V. As an original source for the history of agricultural machinery the farmers' journals of the period are of first importance; in the rather summary treatment accorded the subject here we have drawn heavily upon the reprinted material to be found in *The Prairie Farmer*, Jan. 11, 1941.

[2] *Report of the Industrial Commission*, Vol. X (Washington, 1901), pp. 115, 135, 895.

[3] *Ibid.*, p. 96.

[4] W. M. Hays and E. C. Parker, *The Cost of Producing Farm Products*, Bulletin 97 (Minnesota Agricultural Experiment Station, 1906), p. 39.

[5] *Report of the Industrial Commission*, Vol. X, p. 267.

and most of the machines of today appeared in elementary form at a surprisingly early date. In reviewing the technological changes that have occurred during the first four decades of this century—the period selected for the present study—we shall be concerned mainly with the further development and improvement of existing basic types of equipment, and with the introduction of certain new types for special purposes. Above all we shall deal with the application to agriculture of an entirely new source of motive power whose potentialities still went unrecognized in 1899—the gasoline engine. Field implements, which we shall discuss at the outset, fall roughly into three categories according to their use: for tillage, for cultivation, for harvesting. In each category they had made striking progress in the period preceding 1899.

Plowing and Seeding Equipment

The principal instrument of tillage, at once the most ancient and the most universally used agricultural implement, is of course the plow. The typical plow in the eighteenth century was made of wood, faced more or less with metal. Besides being heavy and cumbersome, and needing constant repair, it had the great disadvantage that the shape of a successful instrument could not be freely or accurately reproduced. The standardization of the best model available at any period for any purpose was greatly facilitated by the introduction (by Jethro Wood in 1814–17) of the cast-iron plow, which was also stronger and more manageable than the wooden type. The cast-iron plow found ready acceptance in the East, but would not scour well in the heavier soils of the Mississippi Valley which were then being developed.[6] The next important step came in 1833 or shortly thereafter, when John Lane of Chicago devised the first steel plow from an old saw; he was followed closely by the more famous John Deere, who appar-

[6] Rogin, *op. cit.*, Part I.

ently used the same material.[7] Although considerable variations in shape were to be found, the new models still took the form of the traditionally pointed instrument known as the moldboard plow, which derived its name from the use of a board placed behind the share to mold the furrow. Not until the 1860's, however, was it mounted on wheels, so that the plowman might ride where the terrain was suitable.[8] Riding implements of this type were originally known as *sulky* plows; but this term is now applied to riding plows possessing only one *bottom* or share, which turn a single furrow, in contrast to *gang* plows with two or more bottoms, and which cover correspondingly increased territory.[9] Sulky plows (in this sense) still predominate on the Atlantic coast and in the cotton states; gang plows, which have become steadily more popular, were invented quite early, but made demands upon the source of draft power which could be satisfactorily met only through the development of the tractor.[10] Nevertheless, in 1909 the two-bottom moldboard plow drawn by four or more horses had become standard equipment in the grain areas of the Middle West, and must already have been fairly common in those regions in 1899. At the turn of the century, however, the modern disk plow had not yet evolved from the harrow.

For seeding, drills drawn by horses had long been in use, but the more elaborate implements which open a furrow and plant and fertilize at the same time (especially for corn) had

[7] *Ibid.* See also L. W. Ellis and E. A. Rumely, *Power and the Plow* (Doubleday, 1911), pp. 151-52; J. B. Davidson, *Agricultural Engineering* (Webb, St. Paul, 1918), p. 181. At that period saws imported from Europe provided the easiest available source of high grade steel plate. See also R. L. Ardrey, *American Agricultural Implements* (published by the author, Chicago, 1894), pp. 14-17.

[8] H. P. Smith, *Farm Machinery and Equipment* (McGraw-Hill, 1937), p. 67.

[9] Rogin, *op. cit.*, pp. 36-37.

[10] For some statistics relating to the distribution of moldboard plows by size and region at different dates since 1909, see E. G. McKibben, J. A. Hopkins and R. A. Griffin, *Field Implements* (National Research Project, Philadelphia, 1939), Table 8.

not yet been developed. During the 1850's a corn planter combining the first two of these operations was introduced; drawn by two horses, it had become common by the turn of the century.[11] The two-horse cultivator, dating from about 1861,[12] was still standard equipment in 1914, at least for cultivating corn.[13] Here again real progress had to wait upon the development of mechanical traction, and especially upon the introduction of the all-purpose gasoline tractor of the 1920's which is especially designed to avoid damage to the growing crop.

Harvesting Equipment

By far the most sensational developments of the nineteenth century were in harvesting. The efforts of the early inventors in this sphere, and especially of Hussey and McCormick, were directed toward a lightening of the burden imposed upon the labor supply through the harvesting of small grains by the methods then in vogue. Cyrus McCormick patented his reaper in 1834 [14] and brought it into commercial production during the 1840's, but in its earlier forms the machine was little more than a device for mechanical mowing: [15] the gathering of the grain had still to be performed on the ground

[11] Ardrey, *op. cit.*, pp. 30-31.

[12] Davidson, *op. cit.*, p. 181.

[13] L. K. Macy, L. E. Arnold and E. G. McKibben, *Corn* (National Research Project, Philadelphia, 1938), p. 33.

[14] There were undoubtedly reapers in existence before this date, but none appear to have been practical. The popular interest in the subject may be judged by a quotation from Ardrey (*op. cit.*, p. 42): "In 1814 a theatrical genius by the name of Dobbs invented a reaper, which he advertised by introducing it upon the stage, the latter being planted with wheat and cut by the machine during the course of a play adapted to it." This extraordinary scene apparently occurred somewhere in Britain, where most of the earliest reapers were constructed. The period of incubation of the reaper appears to have been exceptionally long, as inventions go, and in fact lasted almost half a century. The first British patent dates from 1799 and the first American from 1803; the McCormick reaper was first produced in quantity in 1846 when about a hundred were sold (*ibid.*, pp. 41-46).

[15] Rogin, *op. cit.*, pp. 73 *et seq.*

with rakes. The demand for these early machines and the invention of further labor-saving machinery received a sharp impetus from the labor shortage resulting first from the Mexican War and then from the California gold rush; the same stimulus was to operate again even more powerfully during the Civil War.[16] The first harvester, which developed from the reaper and carried men to bind the sheaves, appeared in the early 1850's; and mechanical binding, initially with wire and later with twine, was introduced during the 1870's.[17] Apparently threshing by machinery, of course with the use of animal power, was fairly common as early as the 1830's; but such threshing was carried on as a process entirely independent of harvesting until the combine (harvester-thresher) made its spectacular appearance in California about 1880.[18]

It is always easier to set a date for the invention of a given implement than to say just when its adoption became general. With the exception of the combine, whose introduction was very gradual, most of these machines appear to have made a considerable impression upon actual farming practice within a decade or so of their appearance. In particular, shortage of labor and high grain prices led to rapid mechanization during the Civil War; at its close, according to Rogin, horse-drawn machinery of one kind or another was in almost universal use for harvesting small grains.[19] On the other hand

[16] *The Prairie Farmer,* Jan. 11, 1941, pp. 40-41.

[17] Rogin, *op. cit.,* pp. 107, 110 *et seq.*

[18] *Ibid.,* p. 164; also pp. 119 *et seq.* Experiments with combines had already been made, especially in Michigan, about 1840, but these early attempts seem to have been unsuccessful; see R. B. Elwood, L. E. Arnold, D. C. Schmutz and E. G. McKibben, *Wheat and Oats* (National Research Project, Philadelphia, 1939), pp. 27-28; also *The Prairie Farmer,* Jan. 11, 1941, p. 40.

[19] *Op. cit.,* p. 91. Also, "more harvesting machines were produced in the few years of the Civil War than had been turned out during the entire period which elapsed from the time Hussey sold his first machine in 1833 to the outbreak of the struggle" (p. 93). The effect of the Civil War in furthering the introduction of the reaper seems to have been very similar to the effect of the first World War in stimulating the use of the combine.

it seems probable that public acceptance lagged somewhat as equipment became more complicated; frequently it was necessary to dispatch a mechanic with each machine in order to show the purchaser how to use it—perhaps also to make adjustments which later would become standardized at the factory.[20] This seems to have been true at least of the combine, and perhaps also of the steam tractor for plowing. It has been estimated, for example, that even as late as 1920 less than 5 percent of the nation's wheat crop was harvested by combine; [21] on the other hand we may reasonably suppose that substantially the entire crop was threshed mechanically in that year, whatever the situation may have been in this regard in 1899. It seems fair to conclude that by the turn of the century the use, if not of the combine, at least of the horse-drawn self-binder in conjunction with threshing by steam had become almost standard practice, even in the rice fields of the South where mechanization has always been notoriously slow.[22] Regional variations in practice of course existed. In the Wheat Belt a substantial acreage was probably still cut by header, a machine which clips the stalks below the heads. And it has been estimated that in California two thirds of the wheat acreage was harvested by combine in 1900, although the use of combines elsewhere cannot have been appreciable at that early date.[23] Besides those already discussed, other types of equipment common in 1899, if by no means universally adopted, were the corn harvester, the corn husker and the cotton planter.[24]

All of these machines were at first operated by animal power: for example the combine of the 1880's was commonly drawn by a team of 20 to 24 horses.[25] Such large demands for

20 *Report of the Industrial Commission,* Vol. X, p. xii.

21 U. S. Department of Agriculture, *Technology on the Farm* (Washington, 1940), p. 14.

22 *Report of the Industrial Commission,* Vol. X, p. 772.

23 Rogin, *op. cit.,* p. 124.

24 *Report of the Industrial Commission,* Vol. X, pp. 157, 816.

25 Rogin, *op. cit.,* p. 147.

motive power naturally led to a call upon the steam engine, which had been introduced into agriculture, primarily for threshing, shortly after the Civil War.[26] By 1899 steam was common as a source of stationary power for threshing; it was also in use, particularly in the West, for plowing as well as for the operation of the combines of that day.[27] Indeed steam power was applied to plowing experimentally in Pennsylvania as early as 1858, but the differential was not invented until about 1870, and even by 1890 steam traction (as distinct from stationary power for threshing) was used only under rather exceptional conditions.[28] By 1894, however, steam plowing, according to Ardrey, was "in general use on large farms in the west." [29] The early tractors seem to have been mechanically much less reliable than were the stationary engines of the same period.[30] Even when mechanical difficulties were overcome, however, there could be no doubt that steam engines were expensive, clumsy, and too heavy for use with draft machinery where the ground was soft or very uneven. It must have become clear that a fresh source of power was needed: yet it was not by any means obvious, at the turn of the century, that it was the new-fangled gasoline motor which would furnish this driving force. Even as late as 1901, an author wrote an eloquent description of the future of electricity as a source of power for farmers while making no mention

[26] The steam engine which Horace Greeley noticed on a farm at Watertown, N. Y., in 1850 (Ardrey, *American Agricultural Implements*, p. 114) must indeed have been a curiosity.

[27] Rogin, *op. cit.*, pp. 44, 147-53.

[28] Ellis and Rumely, *Power and the Plow*, pp. 41-43.

[29] *Op. cit.*, p. 20.

[30] *Ibid.*, p. 239. In 1860 the rather hesitant behavior of Mr. Waters' steam plow in Grundy County, Illinois, was described triumphantly as follows: "Ran for 23 minutes; stopped six minutes for wood; ran 13 minutes; stopped 8 minutes for water; ran for 1 minute. Plowed 2.63 acres in 72 minutes, using only six of a gang of 13 plows. Burned 1½ cords of wood. Was managed by a hand and team to supply fuel and water, a fireman, two men to manage the plows, and Mr. Waters." See *The Prairie Farmer*, Jan. 11, 1941, pp. 30-31.

whatever of the internal combustion engine.[31] Although electricity has been widely applied during the last forty years as a source of stationary power on farms, particularly for pumping, it remained for the gasoline tractor to revolutionize the business of hauling draft machinery for plowing, cultivating and harvesting alike.[32]

FARM MACHINERY SINCE 1899: THE TRACTOR

The introduction of the gasoline tractor is a development confined wholly to the period following 1899, and perhaps not yet entirely completed. The transition from steam to gasoline as a source of draft power, and the displacement of animal energy by the gasoline motor in regions in which steam had never been adopted, were matters of rather gradual change. Dates are not easy to establish. Certainly bigger and better self-propelled steam-powered combines were still being built in California as late as 1905.[33] It is possible that the internal combustion engine was not applied seriously to the combine until about 1910; its successful use in this connection in Argentina appears to have played a part in its introduction in this country. Beyond a doubt, however, the war of 1914–18 was the immediate occasion for the widespread adoption of the gasoline tractor for harvesting grain: for high grain prices accompanied by a shortage of labor led to extensive mechanization in the Great Plains wheat area. While this war-

[31] See E. P. Powell, "Farming in the Twentieth Century," *The Making of America,* Vol. V.

[32] Among the few who perhaps foresaw the new development was J. D. Lewis, writing in 1902: "It seems safe to predict, in view of the development of the automobile, that within the next decade this feature of modern invention will have found an additional application as a motive force in connection with agricultural implements of tillage, planting and harvesting. An automobile lawn mower is already meeting with considerable favor where the conditions warrant its use" ("Agricultural Implements," *Twelfth Census, Manufactures,* Vol. X, Part IV, p. 364). However, "automobile" may perhaps have been intended to cover other forms of traction besides the gasoline motor.

[33] Elwood, Arnold, Schmutz and McKibben, *Wheat and Oats,* pp. 28-29.

time mechanization meant the establishment of gasoline as a recognized form of draft power, displacing steam on the larger farms and gaining adoption in many places where steam traction had never been considered worth while, the older form of power continued for many years as the standard means of threshing where harvesting was performed by the binder and the combine was not in use.

So far as concerns the development of gasoline traction for the operation of draft machinery, the period since 1899 falls roughly into two parts, broken by the year 1924 which saw the introduction of the all-purpose tractor. The earlier tractors, both steam and gasoline, could be used for plowing, harvesting, and as a stationary source of power for threshing, but they could not be used for cultivating row crops. Naturally, therefore, they made most rapid progress on farms growing wheat and other small grains which do not require cultivation. Many notable inventions of an earlier period—the gang plow, the self-binder and the combine—had first made headway in the wheat-producing regions of Montana, the Dakotas, Nebraska, Kansas, and of course California, a state which was once a much more important source of wheat than it is today. It was in these states also that the gasoline tractor was first tried out on a large scale, and for very similar reasons—the presence of large areas devoted to a single crop, broken by few irregularities of terrain.

Probably the gasoline tractor appeared, and began to be substituted for steam power, before the market for the steam tractor was saturated. It is a safe assumption that the number of steam tractors in use would have continued to increase, and their sphere of usefulness have continued slowly to expand, even if the gasoline tractor had been stillborn. But the application of power, and especially of draft power, to agriculture would inevitably have been much slower in such a case. For the gasoline motor in its full development turned out to be much cheaper than the steam engine; it was less trouble to operate; and it could be applied to terrain and crops to which steam power was entirely unsuited. If the history of mechanical power in agriculture is not synonymous with the history of the gasoline engine, it has tended to become so as the years have passed.

It is recorded that efforts were made to apply the internal combustion engine to the solution of the problem of draft power on farms as early as 1889.[34] Certainly gasoline tractors were not entirely unknown in agriculture at the opening of our period, even if they had as yet made little or no impression upon the agricultural writers of that day. The real impact of gasoline as a source of power appears to date from the Winnipeg Exposition of 1908. On that occasion gasoline and steam tractors were pitted against each other for the first time in a series of plowing contests. It does not seem that gasoline carried off the honors in any unmistakable fashion at this meeting; probably it was still too undependable. For example Davidson and Chase, writing in the same year, do not appear to have felt that the day of gasoline traction had yet arrived. After an extended discussion of gasoline as a source of stationary power, they write of the gas tractor in the following cursory terms:

> The gasoline engine is as portable as the steam engine. As to furnishing its own traction, there are several gasoline traction engines on the market, and there is no reason why with the addition of clutches and variable-speed devices the gasoline engine cannot be made as reliable an engine as the steam traction engine. In proof of the fact that it may be made to furnish its own tractive power it is only necessary to refer to the automobile, which is made to work under great variance of speed.[35]

[34] E. G. McKibben and R. A. Griffin, *Tractors, Trucks, and Automobiles* (National Research Project, Philadelphia, 1938), p. 3.

[35] J. B. Davidson and L. W. Chase, *Farm Machinery and Farm Motors* (Zudd, New York, 1908), p. 433.

TABLE 29

TRACTORS, TRUCKS AND AUTOMOBILES: ESTIMATED NUMBER ON FARMS, 1910–42[a]

Thousands

Year	*Tractors*[b]	*Trucks*[c]	*Automobiles*[c]
1910	1	0	50
1911	4	2	100
1912	8	5	175
1913	14	10	258
1914	17	15	343
1915	25	25	472
1916	37	40	687
1917	51	60	966
1918	85	89	1,502
1919	158	111	1,760
1920	246	139	2,146
1921	343	207	2,382
1922	373	263	2,425
1923	428	316	2,618
1924	496	363	3,004
1925	549	459	3,283
1926	621	559	3,605
1927	693	662	3,820
1928	782	753	3,820
1929	827	840	3,970
1930	920	900	4,135
1931	997	920	4,077
1932	1,022	910	3,798
1933	1,019	865	3,399
1934	1,016	875	3,399
1935	1,048	890	3,642
1936	1,125	900	3,826
1937	1,230	910	4,073
1938	1,370	925	4,161
1939	1,447	925	4,101
1940	1.545	935	4,185
1941	1,665		
1942	1,800		

[a] As of January 1 of each year.

[b] Bureau of Agricultural Economics release by A. P. Brodell and R. A. Pike, "Farm Tractors: Type, Size, Age, and Life" (1942). Data for 1941 and 1942 preliminary.

[c] U. S. Department of Agriculture, *Income Parity for Agriculture* (Washington, 1940), Pt. II. Sec. 3. Data for 1939 and 1940 subject to revision.

Nevertheless it was beginning to appear that the farmer must consider in the future the possible advantages of gasoline over steam in deciding what form of power equipment to buy. Three years later, in 1911, two observers summarized their impressions of the situation at that time as follows:

> Steam engines in use for plowing undoubtedly outnumber gas tractors, even in North America, where the latter have been increasing most rapidly in numbers. But the internal combustion, or gas, tractor is coming rapidly into favor, and possibly this year, for the first time, its sale will surpass that of the steam tractor in the plowing field. The majority of the gas tractors built are now used for plowing, whereas many small steam tractors are built simply for threshing in the Central and Eastern states. The use of the electric motor for plowing is as yet confined to a few isolated localities in Europe, notably in Germany and Italy.[36]

The gasoline tractor, clearly, was coming into its own, but the concluding sentence illustrates once again the superior ability of electricity to fire the imagination of those who wrote about the problems of the farmer. The first gasoline tractors had wheel drive, were large and heavy, and looked not unlike their steam prototypes. Caterpillar treads were fitted only for special purposes, and rubber tires were still quite unknown.

When the wartime boom in grain production set in, coinciding as it did with an acute labor shortage, perhaps the most usual arrangement consisted of a gasoline tractor for plowing and a steam engine for threshing—unless indeed the farm were large and modern enough to own a combine. As the combine, whose adoption was stimulated by the wartime need to economize labor, became an increasingly commonplace piece of equipment on the Great Plains, the importance of stationary power for threshing gradually diminished.

[36] Ellis and Rumely, *Power and the Plow*, p. 14.

Meanwhile the advantage of possessing a cheap and convenient form of draft power, both for plowing and for harvesting, received more and more emphasis. The ousting of the steam engine, now proven definitely inferior for draft purposes, continued steadily.

The gasoline tractor itself was being continually improved. Ellis and Rumely, writing in 1911, do not mention any tractors lighter than two and a half tons in weight, and some of the early models apparently weighed as much as fifteen tons, which is about what a steam engine would weigh.[37] Toward 1912 the gearbox was introduced, and by 1914 crankshaft revolutions had been stepped up to 1,000 a minute from about 200 on the original models. The magneto and float-feed carburetor followed shortly thereafter, adding further to the efficiency and adaptability of gasoline.[38] Of course the tractor benefited greatly, both in design and in production, from the concurrent development of the automobile: by 1917 Ford was building tractors on the assembly line.[39] In 1918 a low-cost wheel tractor weighing only one and a half tons, but capable nonetheless of pulling a two-bottom plow, was introduced and well on the way to popularity.[40]

The problem of applying gasoline power to the cultivation of row crops had, however, still to be solved. To meet this need, a tractor which steered from the rear had been designed and manufactured on a small scale at quite an early date, but it could not perform other tasks adequately and failed to gain acceptance.[41] In 1921 it was still possible to consider that the future of the tractor lay primarily in seedbed preparation. Thus three Illinois writers of that period classified farm work as follows:

[37] *Ibid.*, p. 106.
[38] *Yearbook of Agriculture, 1932,* pp. 437-38.
[39] *The Prairie Farmer,* Jan. 11, 1941, p. 31.
[40] McKibben and Griffin, *Tractors, Trucks, and Automobiles,* pp. 6-7.
[41] Ellis and Rumely, *Power and the Plow,* p. 105.

> *Tractor operations*—Plowing, disking, harrowing; road work.
>
> *Operations of doubtful suitability for the tractor*—Drilling small grains; cutting with binder; loading hay; hauling gravel, feed and fertilizer.
>
> *Operations not suitable for the tractor*—Planting, cultivating and husking corn; mowing hay; miscellaneous hauling.[42]

But in fact the tractor was already used extensively for drilling and harvesting small grains, and to some extent for mowing; the cultivation of row crops was to follow.

A true "all-purpose" tractor at last appeared in 1924. Besides being equipped for every task it could already accomplish, the tractor was now given sufficient clearance and facility of control to permit its use for row cultivation as well: in particular, the driving wheels were made to slide on their axle so that the width of the track could be adjusted according to the requirements of individual row crops. The new tractor continued to offer a power takeoff, first brought out in 1922, and a belt pulley for stationary work.[43] Once these various functions had been successfully combined, the all-purpose tractor gained rapid popularity for tasks that previous types had been unable to handle; it now invaded farming areas, especially in the East, which had been unacquainted with the advantages of mechanical power. Nearly half of all tractors at present in use, and nearly three quarters of current sales of new tractors, are of the all-purpose type.[44]

A more recent development is the mounting of tractors on rubber, a trend that has become important only during the last ten years with the manufacture of specially designed, highly serrated, low pressure pneumatic tires. The first tires for farm tractors were sold in 1932. Fourteen percent of trac-

[42] W. F. Handschin, J. B. Andrews and E. Rauchenstein, *The Horse and the Tractor,* Bulletin 231 (Illinois Agricultural Experiment Station, 1921), p. 203.

[43] *Yearbook of Agriculture, 1932,* pp. 438-39.

[44] McKibben and Griffin, *Tractors, Trucks, and Automobiles,* p. 9.

tors manufactured in 1935 had rubber tires; the proportion rose to 83 percent in 1939 and to over 90 in 1940. Tests have shown considerable fuel economy for tire-equipped tractors because the machine offers less resistance in travel; while the reduced strain to which the machine is subject has cut down the need for repairs. In addition rubber tires have the advantage that they make operation more comfortable and less fatiguing, and enable the tractor to travel at relatively high speed on an ordinary highway. With the attachment of a trailer it can be used to some extent for actual highway transportation. Rubber tires have also made possible the very small tractors and combines which have recently been placed on the market.[45]

There were about 1,800,000 tractors of all types in the United States in 1942, almost double the number reported for 1930 (Table 29). Of these about one third were in the Corn Belt, and nearly one tenth in the state of Illinois.[46] It is interesting to inquire how far the market for new machines—as distinct from replacements—should now be considered saturated. In spite of the continued development of cheap low-power machines, the market for tractors among very small farms is probably rather limited. If we confine our attention to farms of more than 100 acres, the number of tractors per farm in 1939 ranged from .78 in the North Central states to as little as .39 in the South Central and .33 in the South Atlantic states.[47] The advent of cheap and efficient mechanical power has affected the different phases of cropping in very varying degree. According to a survey made in 1939 [48] tractor power was used for breaking land on about 55 percent of the nation's crop acreage (not including acreage under hay);

[45] *Technology on the Farm*, pp. 101-03; also *The Prairie Farmer*, Jan. 11, 1941, pp 38-39.

[46] *The Prairie Farmer*, p. 32.

[47] *Technology on the Farm*, pp. 9-10.

[48] See a release by A. P. Brodell entitled "Machine and Hand Methods in Crop Production" (U. S. Department of Agriculture, 1940).

while 57 percent of the disking and 43 percent of the harrowing was performed by tractor. Manure was spread mechanically on 58 percent of all land so treated, but this may not

TABLE 30

PERCENTAGE DISTRIBUTION OF TRACTORS SOLD FOR DOMESTIC USE IN THE UNITED STATES, BY TYPE[a]

Year	*Standard Wheel*	*General Purpose*	*Track Laying*	*Garden*
1925	92.5	.9	3.8	2.8
1930	45.5	38.5	11.4	4.6
1935	18.4	68.3	10.2	3.1
1940	4.1	85.5	6.7	3.7

Source: A. P. Brodell and R. A. Pike, *Farm Tractors: Type, Size, Age, and Life* (U. S. Department of Agriculture, 1942).

[a] Includes sales to users other than farmers. According to the compilers of the table, only some 5 percent of standard wheel and general purpose tractors are bought by nonfarmers, while of the track-laying tractors not more than one third are bought by farmers.

always have involved the use of a tractor. Of the acreage of small grains, as much as 71 percent was tractor-broken; on this acreage 70 percent of the disking, 57 percent of the harrowing, 48 percent of the drilling, and 69 percent of the harvesting was performed by tractor. Cotton growing is much less highly mechanized. Tractor plowing was found on 30 percent of the cotton acreage, mostly in the newer cotton areas from Texas to California. It is in these areas also that other phases of cultivation are handled by tractor, for in the older eastern sections of the Cotton Belt tractors remain relatively scarce. These figures suggest that even on the Great Plains there is still scope for further mechanization; and a considerable increase in the use of mechanical power seems likely in the South, even in the absence of a satisfactory cotton picker. Of course the rate at which mechanical power is introduced in any area depends upon feed and other costs of maintaining work animals as well as the price of tractors and their fuel. It has been predicted that a further half million tractors will be in use by 1950.[49] The substantial proportion of horse-drawn cultivators, binders and mowers still in use suggests that this estimate may not be wide of the mark.[50]

FARM MACHINERY SINCE 1899: FIELD IMPLEMENTS

The strongest influence upon the development of field implements in recent decades has naturally been the extensive adoption of mechanical draft power. Because of the use of greater power and higher speeds, tillage implements, for example, have been redesigned, the disk has displaced the moldboard plow in many regions, and numerous implements are now attached to the tractor itself instead of being drawn through some kind of hitch. Among other advantages the latter practice allows a closer approach to fences, and adoption of a power lift for raising and lowering the implement in use. It may also economize labor, for instance in mowing, for if the mechanism is mounted on the tractor one man is sufficient, whereas if the mower is hauled through a hitch two men are required.[51] The coming of the tractor has had other effects also. The considerable investment involved in mechanical power has naturally suggested that the fullest use should be made of it. For example, a much wider range of cultivating equipment has been developed than was formerly available. Virtually all crops may be seeded or planted mechanically if appropriate attachments are used; fertilizer is often distributed simultaneously with planting. Nor have the special requirements of truck farming been forgotten.

[49] *Technology on the Farm,* p. 12.
[50] McKibben, Hopkins and Griffin, *Field Implements, passim.*
[51] F. N. G. Kranich, *Farm Equipment for Mechanical Power* (Macmillan, 1923), Ch. V.

Plowing and Seeding Equipment

The moldboard plow has become heavier, in order to cope with the increased speed of mechanical plowing: it has also been altered somewhat in shape, since the line of haul of a tractor is horizontal, and there is no tendency to pull the share out of the furrow as with the horse-drawn implement. Besides this, higher speeds require a tougher share. Most notable perhaps has been the popularity of the vertical disk plow for large scale cultivation on the Great Plains.

The disk plow was originally developed as a means of improving the efficiency of mechanical tillage. It made a heavier demand upon draft power than the moldboard plow; on the other hand it was less likely to be broken by an obstruction and so could be used at higher speeds. The disk plow is essentially a pulverizing instrument and has slight cutting action: it is therefore unsuitable for breaking virgin soil, or for use where much vegetable matter has to be plowed under. The disks in a gang were originally mounted separately, one in front of another, and of course each at an angle to the direction of travel. In 1924 the vertical disk plow, in which the disks were all mounted on a common axle, was introduced; this axle now became horizontal, and the disks were therefore vertical, instead of being tilted as in previous models. The disk plow was at one time thought to be ideally suited for shallow plowing in semi-arid regions,[52] and in fact gained rapid acceptance on the western plains.[53] Recently, however, experience has shown that where rainfall is uncertain its use leads to wind erosion, particularly if plant residue is absent from the soil. In the dry-farming areas, therefore, the tendency is now to replace the disk plow by implements like the field cultivator or the duckfoot cultivator. The majority

[52] Ellis and Rumely, *Power and the Plow*, pp. 178-82.
[53] McKibben, Hopkins and Griffin, *Field Implements*, pp. 29-31.

of disk plows sold in recent years have been of the vertical type, and practically all are designed for use with tractors. But sales of moldboard plows still outnumber the disk variety by more than five to one.[54] The advantages of the moldboard type are of course that it may be used on a wider variety of soils, and that it can be drawn by horse as well as by tractor.

Improvements in secondary tillage during the last forty years have been less sensational, but still important. For example the availability of mechanical draft power has encouraged the use of heavier harrows, often operated in tandem, and particularly of implements like the duckfoot field cultivator which require large amounts of power for their operation.[55]

The influence of the tractor upon the design of drills and other seeding implements has apparently been slight, for the amount of power they require for their operation is in general small. According to the survey conducted by the National Research Project, sowing is still carried out almost exclusively by animal power except in the Wheat Belt—and even here the horse is still largely used for this purpose.[56] The lister-planter for corn, which opens a furrow and seeds in a single operation, requires more power than the ordinary grain drill and is usually drawn by tractor; however, this implement has not yet been extensively adopted except in the West.[57] Indeed in 1939 six percent of the total acreage under corn was still planted by hand.[58] The cultivation of row crops with the all-purpose tractor has already been mentioned; it is likely to become increasingly important, especially in the case of crops like corn, which must be cultivated several times.

54 *Ibid.*, pp. 100-01.
55 *Ibid.*, Ch. III.
56 *Ibid.*, Table 28.
57 Macy, Arnold and McKibben, *Corn*, pp. 31-32, 54, 73, 88, 105.
58 Brodell, "Machine and Hand Methods in Crop Production."

Harvesting Equipment

Harvesting equipment falls into a number of separate categories according to whether it is designed to handle (1) small grains, (2) hay and other forage crops, (3) corn, or (4) crops presenting special problems, such as cotton or potatoes. The simplest type of apparatus still commonly in use for harvesting grain is the cradle and mower; the great advantage of this combination, besides its relatively low first cost, is that the mower can be used also for cutting forage crops. According to a recent study, however, only 4 percent of the wheat acreage and 7 percent of the acreage of oats were cut in 1938 by devices other than the binder and the combine. The acreage still cut by mower and cradle must therefore be very small, for these percentages also include acreage cut by the header, a machine which clips the stalks below the heads and delivers these to wagons for subsequent threshing. During the late nineteenth century the header was very common in the Wheat Belt where the stalks were not required for fodder, but it has now been almost entirely superseded by the combine. We are safe in assuming that acreage cut by header is today smaller even than acreage harvested by mower and cradle; the latter is concentrated mainly in the eastern and southern states.[59]

[59] See A. P. Brodell, "Increasing Use of the Combine," *The Agricultural Situation,* Aug. 1939, pp. 14-16. The detailed data upon which this article is based appear in a release by the U. S. Agricultural Marketing Service, "Acreage of Wheat, Oats and Corn for Grain, Harvested by Specified Methods, and Custom Harvest and Labor Rates, 1938" (1939).

The survey did not cover the New England states or Florida. However, it appears that in 1938 West Virginia, Georgia and Alabama harvested more than 40 percent, and South Carolina as much as 30 percent, of their wheat acreage by means other than binder or combine. The percentages in the remaining states included in the survey and reporting wheat acreage were all lower than this. In the case of oats, harvesting appears to be somewhat less highly mechanized than in that of wheat; several states reported more than half, and ten states together (all in the South and East) reported more than 30 percent of their acreage of oats as harvested by methods other than binder or combine.

The binder, which developed from the reaper soon after the middle of the nineteenth century, and the combine (harvester-thresher), which appeared in 1880,[60] have evidently both been in use for many decades. Indeed among field implements these two machines are peculiar, as we have seen, in that they were already highly developed (though not widely adopted) before the advent of the tractor, in spite of the large demands they make upon the source of draft power. Combines are now almost always drawn by tractor, but binders are still most frequently horse-drawn except in the southern Wheat Belt.[61] In 1938 combines harvested 49 percent of the wheat acreage and binders 47 percent; for oats, on the other hand, only 10 percent went to the combine and 83 percent went to the binder. Farmers consider oat straw superior to other straws, and to obtain this straw a binder must be used. Broadly speaking, binders are at present by far the commonest means of harvesting small grains except in the southern Wheat Belt, in the Southwest, and on the Pacific Coast: in these areas, which of course are noted for the large size of their farms, the combine is the more important.[62]

Since 1935 the baby combine, and since 1939 the "midget" combine, have opened up the smaller farms as a potential market for mechanized harvesting equipment. In 1939, 80

60 Twenty combines were in use in California by 1881 and 500 of them seven years later; see Brodell, "Increasing Use of the Combine."

61 McKibben, Hopkins and Griffin, *Field Implements,* Tables 37 and 40. The horse-drawn binder appears to be steadily diminishing in importance, however. Mr. H. L. Boyle of the International Harvester Company informs us that in 1941 his company sold 12,790 binders, of which 5,629 were designed for tractor use exclusively; 4,988 were of the large 8-foot type intended primarily for use with a tractor; and only 2,173 were of the smaller sizes which are commonly horse-drawn.

62 According to the Agricultural Marketing Service more wheat acreage was harvested in 1938 by combine than by binder in the following states: Nebraska, Kansas, Oklahoma, Texas, Montana, Colorado, New Mexico, Arizona, Nevada, Washington, Oregon and California. In all other states reporting wheat a larger acreage was harvested by binder than by combine. A larger acreage of oats was harvested by binder than by combine in all states except (curiously) Louisiana and Mississippi; the acreage of oats in these two states is very small, however.

percent of the combines sold were either of the baby or the midget class.[63]

For the harvesting of hay and alfalfa the mower is used. Like the grain binder, from which it may sometimes be converted, its demands upon draft power are not great, and it is still most commonly horse-drawn.[64] Some more complicated haying machines have indeed been developed, in combination with the tractor, but acreages of forage crops large enough to justify their use are rare. However, recent improvements in the pick-up baler have led to its adoption in some farming areas, particularly for harvesting alfalfa.[65]

The harvesting of corn has been less widely mechanized up to the present than has the harvesting of small grains.[66] In 1939, 43 percent of the total acreage cut, and about the same proportion of the acreage cut in the Corn Belt itself, were still harvested by hand; only in the Wheat Belt was the harvesting of corn fully mechanized.[67] Where mechanical harvesting is in operation the type of equipment depends upon whether or not the stalks as well as the ears are desired. If corn is grown for ensilage, and both are harvested—conditions common outside the Corn Belt—the binder is employed. This implement, which resembles a wheat binder, was already in use at the beginning of our period. Being largely confined to the dairy regions of the North and East, and requiring only moderate tractive effort, the corn binder is still

63 *Technology on the Farm,* p. 14. For baby combines the swath is 5 to 6 feet in width; for midgets, only 40 inches.

64 McKibben, Hopkins and Griffin, *Field Implements,* Table 47.

65 *Ibid.,* p. 92.

66 The estimated growth of combines from 4,000 in 1920 to 100,000 in 1938 is to be compared with about 10,000 corn pickers in 1920 and 70,000 in 1939; see A. P. Brodell, "Increasing Use of the Combine," and "Mechanizing the Corn Harvest," *The Agricultural Situation,* Sept. 1939, pp. 18-20.

67 Brodell, "Machine and Hand Methods in Crop Production." In Iowa only one acre in ten was cut by hand, the rest being harvested mechanically; in the other corn states (Illinois, Indiana and Ohio) the proportion was much higher. In Kansas, Nebraska and the Dakotas, by contrast, the corn acreage cut by hand was negligible.

predominantly horse-drawn.[68] On the other hand, where the corn is desired for grain and not for ensilage, the corn picker is the most efficient method of harvesting. This is a heavy and elaborate piece of machinery which gathers the ears from the standing corn, husks them, and delivers them to a waiting truck, performing much the same function as the combine in the case of wheat. It is hardly ever drawn by horses.[69] Like the combine, it was invented quite early,[70] but did not come into general use in the Corn Belt until the labor shortage of 1917–18. And just as the combine is used mainly in the Wheat Belt, so the corn picker is still found principally in the Corn Belt. For the country as a whole, only about 13 percent of that part of the corn acreage which was harvested for grain was gathered by mechanical picker in 1938.[71]

Among machines for harvesting those crops which present peculiar difficulties the potato digger is noteworthy. This ingenious implement consists of a kind of large hoe mounted before a power-driven sieve, and may have a variety of different attachments for delivering the potatoes. Requiring almost as much power to operate as the corn picker, the machine is essentially a tractor-driven implement.[72] Horse-drawn potato diggers were in existence in the 1890's, but apparently were little used.[73] In 1929 an improved two-row digger appeared on the market.[74]

[68] McKibben, Hopkins and Griffin, *Field Implements,* Table 42.

[69] *Ibid.,* Table 44.

[70] Ardrey, *American Agricultural Implements,* Ch. XII.

[71] Brodell, "Mechanizing the Corn Harvest," pp. 18-20. The highest percentages for individual states were Illinois, 43, Minnesota, 35, and Iowa, 35. Corresponding percentages for the (gross) output of corn so harvested would be somewhat higher owing to the tendency for the picker to be used on farms where the yield per acre is above average: about 20 percent of all corn used for grain was produced on the acreage mentioned in the text.

[72] Kranich, *Farm Equipment for Mechanical Power,* Ch. XIV.

[73] Ardrey, *op. cit.,* p. 146.

[74] H. E. Knowlton, R. B. Elwood and E. G. McKibben, *Potatoes* (National Research Project, Philadelphia, 1938), p. 35.

Evidently the extent of mechanization practiced at any given time has varied greatly as between farming operations, crops and regions. The earliest and most complete mechanization probably came in the seeding and harvesting of wheat, oats and other small grains in the areas which specialized in those crops. On the Great Plains wide and level areas devoted to a single crop were ideally suited to the introduction of mechanical equipment. Here harvesting was already partially mechanized even before the advent of mechanical draft power—whether steam or gasoline. Threshing was, as we have seen, one of the earliest applications of the steam engine, whereas the gasoline tractor had its first successes in seeding and harvesting the wheat fields of the West. The spread of the new implements, and of the gasoline power which normally went with them, to other crops and into other farming areas was a much slower development. It was a process which required numerous adaptations of equipment to peculiarities of task or terrain, to the needs of the fruit and the vegetable farm or of the small general farm so common in the East. Even in fields where mechanization has been most successful, the dissemination of its benefits is still far from complete. And in large measure it has passed by important areas of farming activity, such as the cultivation of cotton and tobacco.

SOME UNSOLVED HARVESTING PROBLEMS

Not all crops can be harvested mechanically at present. Several must still be picked entirely by hand, and in the case of others only a small part of the work has been mechanized. Mr. Fowler McCormick, vice-president of the International Harvester Company, summarized the situation as follows:

> At the present time, machinery is available for handling all processes in the production of hay, small grain and some row crops. On the other hand, the production of cotton, tobacco,

and vegetables can only be handled in part by machinery. It might be of interest to enumerate some of the major farm operations for which so far no satisfactory commercial machines have been developed.

A crop which badly needs mechanical assistance at present is the sugar beet crop. What is required is a machine that will pull the beet out of the ground, cut off the green top without removing a wasteful amount of the beet itself, and load the beet into a truck. Fairly successful machines can be built, but none now exists which can justify itself on a medium or small-sized farm from an investment standpoint.[75]

Existing machines for lifting and topping sugar beets perform satisfactorily only where the beets are rather uniform in size; [76] such machines were invented more than half a century ago,[77] so that advance since then seems to have been slow. Mr. McCormick continued:

Secondly, there is now a demand for a corn combine, a machine to do for corn harvesting what the combine does for wheat; that is, to pick, husk, and shell the corn in one continuous operation. The problem is not yet solved. It is not a mechanical problem, but one of the moisture content of the corn. The corn must in some way be dehydrated after shelling so that it may be safely stored in bins.[78]

It will be recalled that the corn picker described in the preceding section performs the first two of these operations, but not the third. To quote Mr. McCormick further:

Thirdly . . . there is a large demand for a sugarcane harvester. Cane presents a problem because it varies greatly in size and requires three operations by a commercially successful ma-

[75] *Investigation of Concentration of Economic Power,* Hearings, Part 30 (Temporary National Economic Committee, Washington, 1940), p. 17032.

[76] *Technology on the Farm,* p. 106.

[77] Ardrey, *American Agricultural Implements,* p. 146.

[78] Hearings, Part 30, pp. 17032-33.

> chine. The cane stalk must be cut as close as possible to the ground, the leaves must be stripped from it, and the two upper joints of the stalk, which have no sugar content, must be cut off. There is a great demand for this machine, but you might be interested to know that the problem has defied satisfactory solution so far as we are concerned for more than 35 years.
>
> Now, it is a fact that several machines have been built for these purposes, but they are very large and bulky and expensive machines, and we have never come anywhere near finding a solution to that problem mechanically and what we think is a commercial product.[79]

Some experimental sugarcane harvesters have apparently weighed as much as 20 tons.[80]

Meanwhile the harvesting of cotton still occupies 4 million pickers for a season of perhaps 40 workdays each year. Moreover, since the bolls are only one to two feet above the ground, cotton cannot be picked unless the worker stoops; harvesting is therefore exceedingly laborious. It is hardly surprising that the construction of a satisfactory mechanical cotton picker should have been a problem to puzzle the wits and fire the imagination. In fact the Patent Office is littered with abortive attempts to reach a solution. Mr. McCormick reviewed the situation as follows:

> For many years there has been a demand for a mechanical cotton picker. This was especially true during the 1920 decade when labor was fully employed and foreign migrant labor was frequently imported to pick cotton. Several machines now exist which will get the cotton off the plants in a fairly satisfactory manner provided the conditions are favorable.
>
> Our company's experimental work on cotton pickers has extended over approximately thirty years, but we are not yet really satisfied with the results and have never offered a ma-

[79] *Ibid.*, p. 17033.
[80] *Technology on the Farm*, p. 107.

> chine for sale. The necessity of leaving the cotton plant uninjured for further growth and subsequent pickings, and the great irregularities in the size of the cotton plants present difficult problems. Cotton picked with present experimental machines is usually graded down because of the presence of leaf stains and more or less trash, and the grading down means a lower price and less possibility of saving.[81]

In the semi-arid, short season, low yield, cotton areas of Texas, all the bolls, together with much of the foliage, can be stripped fairly easily with the help of a sort of large comb. Either horse or tractor power may be used, but the cotton is found to contain much trash and may require special ginning equipment. This method, by no means entirely satisfactory even in Texas, is quite unsuited to the older, more humid, cotton areas of the East, where the cotton matures over a much more extended period. Although pneumatic and electrostatic principles have been tried, the nearest approach to a successful cotton picker relies upon the rotation of a small metal spindle. These spindles engage the cotton fiber and dislodge the boll. The spindle is periodically reversed to unwind the cotton attached to it. The machines actually succeed in picking the cotton, but they also gather up a good deal of trash, as Mr. McCormick remarked; and they apparently leave some 5 percent of the crop in the field unharvested, even after three separate harvestings have taken place. This latter difficulty has suggested that mechanical picking of the major part of the crop might possibly be combined with gleaning of the remainder by hand. It appears in any case that improved ginning equipment will become necessary. These difficulties are indeed so substantial that some efforts have been made to attack the problem from the other end; that is, to adapt the cotton plant itself to the requirements of mechanical harvesting. If it were possible to breed new varieties of cotton with less foliage, bolls that open wider as they

[81] Hearings, Part 30, p. 17035.

ripen, and a shorter maturing season, the problem might be greatly simplified.[82]

CHANGES IN DAIRYING EQUIPMENT

The most important step in the mechanization of dairying was undoubtedly the introduction of the milking machine during the first decade of the present century. By 1900 numerous patents had been registered for machines using a variety of different principles,[83] and during the 1890's tests were undertaken by the experiment station at Guelph, Ontario. The first successful machine seems to have appeared in Australia in 1902,[84] and to have come on the market in this country shortly thereafter. Models using intermittent suction, which is the principle universally employed today, apparently proved their superiority at quite an early date, but the fire hazards associated with the early gasoline engines led to frequent preference for the treadmill as a source of power. For many years a prejudice existed against milking machines on the ground that they impaired the milk-producing capacity of the cow, but it has now been rather securely established that if the machine is properly used there is no ground for this notion.[85]

Besides milking machines, a number of other kinds of mechanical equipment have been more or less widely adopted on dairy farms. The declining importance of farm butter production, and the tendency for deliveries to creameries to be made in milk rather than in cream have somewhat diminished the importance of the separator as a farm implement. On the other hand a wide range of feeding equipment, auto-

[82] See R. L. Horne and E. G. McKibben, *Mechanical Cotton Picker* (National Research Project, Philadelphia, 1937).

[83] For a description of some of the early machines, see Oscar Erf, *Milking Machines,* Bulletin 140 (Kansas Agricultural Experiment Station, 1906).

[84] See G. A. Smith and H. A. Harding, *Milking Machines,* Bulletin 353 (New York State Agricultural Experiment Station, 1906), p. 329.

[85] See A. C. Dahlberg, *The Influence of Machine Milking upon Milk Production,* Bulletin 654 (New York State Agricultural Experiment Station, 1935).

matic watering equipment and litter-carrying machinery has come into use within recent years.

CHANGES IN PLANTS AND ANIMALS

Technology does not exhaust itself in the mechanics of tractors and combines or the design of improved field implements. Plant improvements, animal breeding, and the continuing wars against disease and pests are equally part of it. To the extent to which they have impinged upon bearing or producing potentialities, changes in strains of plants or animals must obviously influence agricultural productivity. They are as much part of the general picture of the output-employment relationship as are changes in working equipment.

If such innovations appear less spectacular than those introduced in the field of machinery, the reason is probably that progress in this field is slow and gradual. Moreover, the emphasis has been on maintenance rather than increase in yields, at least as far as crops are concerned. Over as long a period as 70 or 80 years available evidence reveals only isolated instances in which yields have shown any marked tendency to advance. There exists, on the other hand, a great deal of historical material which suggests that but for the timely intervention of the scientist many crops today would bring forth yields far below those actually attained.

In the case of animals, however, the weight of research has been on increasing and improving yields by breeding beasts superior in any one of a number of desired characteristics. Comparisons with past decades suffer from lack of data, but in a way the past is still with us. Even today there exist in this country dairy cows that will produce as much as 20,000 pounds of milk per year and those whose yield will measure but one tenth of this amount or less. The latter are probably as nearly representative of a past period as statistical data would be, while the dairy cow with the 20,000-pound yield points to the possibilities of purposive breeding.

Plant Breeding

Progress has taken place generally along the following lines:

(1) Introduction of new varieties.

(2) Selection of superior varieties.

(3) Crossing of existing varieties to evolve hybrids combining the desirable traits of both parents, a development which marks the transition from the art of breeding to the science of breeding.

(4) Control of pests by the institution of quarantines and eradication campaigns where the host or bearer of the pest is identified.

(5) Evolution of baits, sprays and dusts which will destroy the pest without affecting the crop.

(6) Biological control, i.e., the use of beneficial insects to suppress noxious pests.

Although up to very recently there have been few cases of substantial increase in yields,[86] we have already mentioned in passing one outstanding instance of revival through the efforts of the plant breeder after yields had dropped to a dangerously low level. We are referring, of course, to the sugarcane growing industry of Louisiana, which was saved only through the introduction of disease-resistant strains.[87] The case of spring wheat has been similar. The varieties existing 25 years ago lacked resistance to stem rust, and heavy losses were consequently suffered in years of serious infestation. Continuous introduction of new varieties and breeding of cross strains are held responsible for a segment of between 40 and 50 million bushels which could not have been produced

[86] As noted below (pp. 278-83), potatoes are one of the exceptions.

[87] See above, pp. 92-93.

by the varieties known in 1890.[88] In an analogous way, selection of new varieties at first and hybridization later have been instrumental in maintaining yields of many other crops and in protecting them from ever-changing attack by pests and diseases.

The most spectacular example of movement toward higher yields has been the case of hybrid corn, a development of most recent origin. Planted in 1939 on roughly one fourth of the country's corn acreage, hybrid corn is estimated to return a yield from 10 to 20 percent above that of open-pollinated corn.[89] In other instances, as in tobacco growing and sugar-beet cultivation, effective control for specific diseases is still developing. Another type of problem that has still to be resolved is illustrated by the declining vigor of California's lemon trees.[90] Indications are that improved varieties may be less effective than a change in the quality of the soil. Similarly, a large number of peach trees in California have aged past peak output, challenging scientists to identify and remedy the source of declining yields.[91]

Animal Breeding

Technological changes in the field of animal husbandry may be subsumed under three headings: feeding, breeding, and combating disease. Naturally, the art of feeding did not assume its present role until the exhaustion of the free range posed the question of what to feed. Since then our knowledge of animal feeding has advanced *pari passu* with our knowledge of human nutrition and so has made rapid strides, particularly in the past quarter century. Nutritional deficiencies and their consequences have become a vast field for research

88 *Technology on the Farm,* p. 138.

89 *Ibid.,* pp. 135-36.

90 *Science, Servant of Agriculture* (Agricultural Experiment Station, University of California, 1940), p. 65.

91 *Ibid.,* p. 82.

with regard to both vitamins and minerals. To cite but one example, it has been found that the hatchability of eggs is increased more than 10 percent if an otherwise well-balanced diet is supplemented by manganese.[92] Similarly, feeds rich in riboflavin have been observed to lead to increased efficiency of feed utilization by chickens.[93] The importance of feeding practices is indicated further by an estimate that if the feeding standards of only one third of the 600,000 dairy herds containing 10 or more milking cows were raised to those prevailing among the dairy herd improvement associations, total butterfat output might be expanded some 5 percent.[94] Another branch of research has concentrated not on the general influence of various feeds on the well-being of the animal, but on the type of feed that will produce certain desired qualities, such as a given consistency of fat.

Many accounts suggest that breeding retained a great deal of its haphazard character until the practice of progeny-testing was adopted. This in turn was dependent upon a rigid system of registration. As a result of years of selection, the average herds as they existed at the end of the last century were probably superior to their ancestors fifty or more years before. Yet breeding as a science did not really begin until around 1900. It is very significant, for example, that in an article published in 1899 [95] we encounter a most severe denunciation of the technique of inbreeding, itself one of the cornerstones of modern breeding when practiced wisely.[96] Linking the spread of bovine tuberculosis with that of "incestuous" breeding, the writer of 1899 observes sternly, "Nature exacts the penalty for reversion or disobedience of

[92] *Technology on the Farm,* p. 118.

[93] *Ibid.,* p. 120.

[94] *Ibid.,* p. 121.

[95] John Clay, Jr., "Work of the Breeder in Improving Live Stock," *Yearbook of the Department of Agriculture, 1899,* pp. 627-42.

[96] G. M. Rommel, *Essentials of Animal Breeding,* Farmers' Bulletin 1167 (U. S. Department of Agriculture, 1920).

her laws."[97] This homily is in sharp contrast to modern views on inbreeding.

By far the most progressive step, as indicated above, has been progeny-testing (i.e., the empirical analysis of the transmitting abilities of sires); this originated with dairy herds which provide rather prompt and continuous material for study. The first cow-testing association was organized in 1906, and by 1940 more than 700,000 cows and close to 50,000 bulls were registered. In terms of the country's total dairy cattle force this is still only a beginning. How far the increase in average milk production per cow, which between 1909 and 1940 has amounted to more than 20 percent,[98] can be linked up with the spread of progeny-testing, it is impossible to say. On the basis of records achieved by outstanding cows and sires it is clear, however, that the possibilities for improvement are great.

Progress has been much slower with beef cattle, undoubtedly because feed utilization and rate of gain—these are the qualities to be tested—are more complicated concepts, and because beef cattle are normally difficult to keep under close observation. In the case of swine the old method of selection by individual merit still prevails, even though experiments have revealed great differences in the breeding value of outwardly similar sires.[99]

Progeny-testing is widely applied to chickens, since laying ability is a quality easily observed. The knowledge that a hen of superior laying quality is not necessarily superior in transmitting this gift to her progeny has removed a great deal of the guesswork from poultry breeding.

The most recent technological advance in breeding has

[97] Clay, *op. cit.*, p. 636.

[98] R. G. Bressler, Jr. and J. A. Hopkins, *Trends in Size and Production of the Aggregate Farm Enterprise, 1909–36* (National Research Project, Philadelphia, 1938), Tables A-95 and A-96; *Agricultural Statistics, 1941,* Table 571. See also Table 50 below.

[99] *Technology on the Farm,* pp. 130-31.

been the introduction of artificial insemination. Here too the use of the new technique has been most widespread with dairy cattle, largely because of the existence of proved sires. Its advantages are many, chief among them the extension of the services of the superior bull both in place and in time, and the elimination of various obstacles to conception which exist when natural mating is practiced.

From this brief review of the outstanding changes in agricultural technology during the present century an impression may be gained of the immense variety of ways in which an advance on the technological front may be achieved. In part mechanical, in part chemical or physical, in part biological, innovation has appeared in one guise after another. Some developments, for example the mechanical cotton picker, appeared promising at the opening of the period studied here but to this day have failed to mature; others, notably hybrid corn, came suddenly upon the scene and were widely adopted within a very few years. To assess accurately the relative importance of different innovations, or even of diverse types of technological change, is an obvious impossibility. Yet all of them have influenced, in greater or less degree, the trend of agricultural productivity, and have contributed to the rise in output per unit of input, to the measurement of which we shall now turn. Estimates of agricultural employment, which are presented in Chapter 6, are followed in Chapter 7 by measures of productivity.