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Economic Effects of Progress in Animal Feeding

By Ronald L. Mighell and Orlin J. Scoville

Technological progress in animal production in the last 30 years has been substantial in some ways, negligible in others. On the one hand, livestock production per animal unit of breeding stock has shown gains of the same order as those in crop production per acre of land. But on the other hand, aggregate livestock production per unit of feed has shown little improvement. Progress has followed, in the main, the path of increased physical efficiency per head rather than that of increased physical efficiency in feed conversion. What are the reasons for this disparity in rates of improvement in animal production per head and per unit of feed? Is it real? If so, will it persist? Why is it that significant advances in animal breeding, nutrition, and sanitation are not reflected in available data on feed conversion? These and many other related questions need to be answered. In this paper the authors analyze several aspects of economic effects of the apparent lag in feeding efficiency.

IMPROVEMENTS IN LIVESTOCK production over the last 30 years have been noteworthy. But they do not appear to have materially affected the average level of feed conversion, at least until very recently (table 1). Several reasons may be cited for this.

Improvements that increase the number of pigs saved per sow, the number of chicks hatched per hen, or the number of calves per cow are significant in building up the scale of operations and in making better use of labor, fixed capital, and overhead, but they do not save much feed.

Mechanical incubation of eggs, for example, has vastly increased chicks hatched per hen without much direct effect on feed consumption per chicken raised. Increases in milk production per cow and in egg production per hen have been achieved through developing cows and hens with higher productive capacity and by feeding them more and better rations. But greater production has been achieved partly at the expense of higher maintenance needed with larger-sized animals, and partly by feeding farther out on the curve of diminishing physical returns. Technically improved rations have made it profitable to feed in this way.

These factors have had a tendency to reduce average output per unit of feed. The changes that have taken place are complex and differ considerably between classes of livestock. For example, as between milk and egg production different results may follow from what apparently are the same kinds of changes in feeding. A milk

cow that is fed below her economic capacity—that is, at a level less than would be marginally most profitable—may when fed farther out on the curve of diminishing returns show a *lower average* output per unit of feed. A hen fed similarly will respond with a *higher* average output per unit of feed. This apparent anomaly is explained by the fact that the maintenance portion of the ration is relatively much larger for the hen than for the cow (3).¹

Still another type of difficulty in measuring changes in feed conversion efficiency over time is represented by changes in the character of the product. This takes the simplest form when the size of the unit of measurement is subject to change. The average dozen of eggs, for example, is perhaps an ounce (about 4 percent) heavier now than 20 years ago. The average fat content of milk is less than formerly. Even more complex changes are found in meat production as average market age and quality of output change over time. A higher proportion of beef cattle is now grain fattened; and as fattening beef cattle consume on the average more grain per pound of meat produced than do other meat animals, this tends to reduce the aggregate rate of feed conversion.

Difficulties also arise in measuring changes in quality and quantity of feed consumed by livestock. The protein content of hay and pasture forage has increased appreciably in the last generation, while the protein content of corn has de-

¹ References in parentheses and italics refer to literature cited at end of paper.

TABLE 1.—*Crop production per acre, livestock production per breeding unit, and livestock production per ton of feed 1925-29 to 1950-54*¹
[1947-49=100]

Year	Crop production per acre	Livestock production per breeding unit	Livestock production per ton of feed
	Percent	Percent	Percent
1925-29-----	81	81	97
1930-34-----	73	83	100
1935-39-----	80	88	101
1940-44-----	93	95	98
1945-49-----	99	98	97
1950-54-----	101	108	104

¹ Computed from data in ARS report "Changes in Farm Production and Efficiency," (7) and other data from Production Economics Research Branch, ARS. Data do not include workstock and feed consumed by workstock. Feed data are total feed units of all feeds.

creased from about 7.0 to 6.5 percent. Thirty years ago poultry obtained a considerable part of their feed by picking up insects and waste grain around the farmstead. This feed never entered into official estimates of feed production; it made poultry appear to be more efficient converters of feed than they actually were. Allowance has been made in feed consumption studies for these secular changes but it may not be entirely accurate.

The index of livestock production per ton of feed in table 1 reflects the effects of a number of diverse and sometimes contradictory changes in livestock production processes. There are many difficulties in obtaining accurate data and in the measurement of the changes that have taken place. The short-run fluctuations in output per ton of feed within the 30-year period are probably not significant although the apparent tendency for feeding efficiency to increase in very recent years is consistent with current technological developments. Also, there appears to have been some upward trend in feed efficiency in the years prior to the period covered by table 1 (1).

Feed Efficiency Varies by Kind of Livestock

The different kinds of livestock vary widely in the physical efficiency with which they convert feed into product, as shown in table 2 and figure 1 for four kinds of meat producing animals. Other important kinds of meat animals are omitted because of the difficulty of allowing for feed consumed in producing such joint products as meat and wool and meat and milk. On the chart, the shorter the bar, the more efficient is the class of animal as a feed converter.

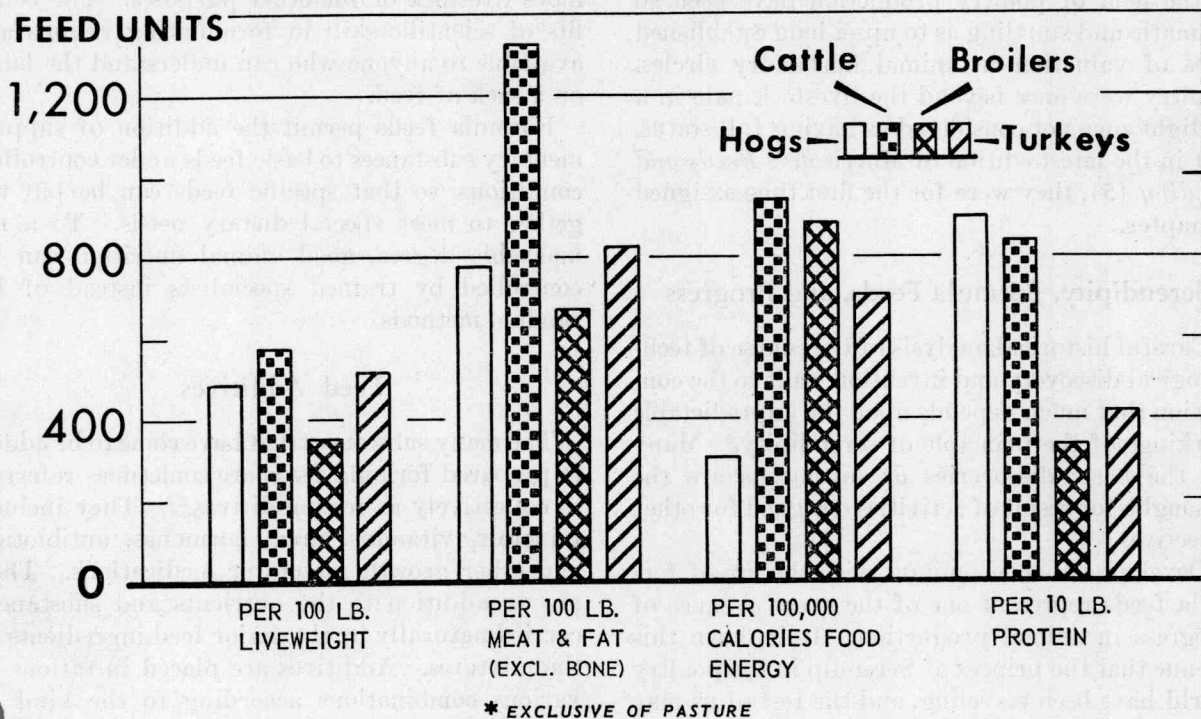
TABLE 2.—*Feed conversion efficiency, by kind of livestock, 1949-53*¹

Kind of livestock	Feed units consumed per—			
	100 pounds liveweight	100 pounds meat and fat, excluding bone	100,000 calories food energy	Pound of protein
	Including pasture			
Hogs-----	515	819	324	95
Cattle and calves-----	952	2, 186	1, 552	138
Broilers ² -----	359	674	834	34
Turkeys-----	543	885	740	44
	Excluding pasture			
Hogs-----	490	779	309	90
Cattle and calves-----	577	1, 325	940	84
Broilers ² -----	359	674	884	34
Turkeys-----	518	828	706	42

¹ Data subject to revision, Production Economics Research Branch, Agricultural Research Service, U. S. Department of Agriculture.

² Broiler data do not include feed consumed in producing "hatching" eggs. Correction for this would add about 5 percent to the data shown.

FEED CONVERSION EFFICIENCY BY KINDS OF LIVESTOCK, 1949-53*



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Figure 1

By any of the measures used, beef cattle consume more feed units per unit of product than any of the other three kinds of meat animals. If pasture inputs are excluded, they take a little less feed per pound of protein produced than do hogs. Hogs consume the smallest quantity of feed per calorie of food energy produced. Except for production of food energy, broilers take the smallest quantity of feed per unit of production, even if pasture inputs are excluded. Turkeys are in an intermediate position; they use somewhat more feed units per unit of production than hogs, except in production of protein. These recent estimates reflect sharp upward changes in feed conversion efficiency by broilers, partly as a result of improved rations.

Signs of Emerging Progress

The average rate of feed conversion for all livestock production has changed little over the last

30 years or so. But this apparent stability represents an average of many divergent tendencies and trends for different kinds of production. Marked progress in some directions has been offset partly by diminishing returns and other considerations, leaving a net of little change.

Developments in commercial broiler production in recent years have resulted in substantial gains in efficiency of feed conversion. Between 1940-41 and 1953-54, the estimated national average feed consumption per pound of broiler produced decreased from 4.2 to 3.0 pounds. In terms of output per pound of feed this is an increase of about a third. Under experimental conditions broilers have been produced on less than 2 pounds of feed per pound of broiler. Some of this gain is attained through improved breeding and management, but innovations in feeds are responsible for much of it.

Signs are now accumulating that progress in animal technology may be speeding up. The phenomenal growth of the commercial broiler industry in recent years is an illustration of what may be in store. Advances in applied technology in the field of poultry production have been so dramatic and startling as to upset long established lines of valuation in animal husbandry circles. Poultry were once beyond the livestock pale in a twilight zone not considered as having full status. But in the latest edition of Morrisons's *Feeds and Feeding* (5), they were for the first time assigned a chapter.

Serendipity, Formula Feeds, and Progress

Careful historical analysis of the course of technological discovery and invention leads to the conclusion that much depends upon the unpredictable workings of the principle of serendipity.² Many of the basic discoveries or inventions are the unsought-for result of activities designed for other objectives.

Developments concomitant with the use of formula feeds represent one of the great avenues of progress in animal production. It is down this avenue that the princes of Serendip in the poultry world have been traveling, and the rest of us may well profit by their example.

Formula feeds manufactured by the commercial feed industry are certainly one of the keystones in the new feed technology. The industry had its beginnings early in this century, but did not become important until the 1920's. By 1939 about 12 million tons of prepared poultry and livestock feeds were manufactured annually, according to the census. This volume increased sharply during World War II and by 1954 was nearly 3 times as much as in 1939, or about 30 percent of the total of all grain and concentrates fed livestock. A large percentage of poultry and dairy feed now consists of formula feeds and the volume of formula feeds used for other kinds of livestock is increasing.

Formula feeds, and the technological changes that have come with them, have economic signifi-

² Serendipity is the gift or ability of finding valuable or agreeable things not sought for. The word was coined by Horace Walpole in allusion to the story of *The Three Princes of Serendip*, who in their travels were always finding, by chance or sagacity, things they did not seek.

cance in several ways. They represent a transfer from farm to urban industry of an important part of the work and required knowledge in the preparation and compounding of livestock rations. Farm labor thus released is available for keeping more livestock or for other purposes. The benefits of scientific skill in formulating rations are available to anyone who can understand the label on a sack of feed.

Formula feeds permit the addition of supplementary substances to basic feeds under controlled conditions, so that specific feeds can be put together to meet special dietary needs. To a remarkable degree, good animal nutrition can be controlled by trained specialists instead of by random methods.

Feed Additives

The many substances that have come to be added to prepared formula feeds are sometimes referred to collectively as feed additives.^{3 4} They include minerals, vitamins, urea, hormones, antibiotics, and other growth factors or medications. They are an addition to the nutrients and substances carried naturally by the major feed ingredients in the mixtures. Additives are placed in rations in various combinations according to the kind of ration. Technical and economic effects have to be considered separately and in terms of the general effects of the whole clusters of innovations. A brief review of some of the individual items may be helpful.

Minerals like calcium and salt were among the first items to be added to concentrate feeds. Later other minerals including trace elements missing in feeds grown on certain soils were added to make up known deficiencies.

As *vitamins* were discovered and as research revealed their particular roles in the nutrition of animals in different types of production, they were also added to prepared feeds. Some vitamins overcame deficiencies leading to disease; others

³ No definition of feed additives has proved acceptable to specialists in animal nutrition. The various nutrients, micro-nutrients, and nonnutrients that are included under the term are usually added to the ration formula in very small quantities. They frequently increase feed efficiency greatly. Many of them occur naturally in certain feeds and in this sense are not additives.

⁴ A recent review of feed additives is given in *Symposium on Medicated Feeds* (8), published this year.

merely made the animal stronger and more productive. Modern methods of poultry production in confinement became possible only as vitamin D was put into poultry rations.

Urea is a nitrogen compound that can be converted into the protein of microorganisms living in the rumen of the cow, the sheep, or the goat. The bodies of the microorganisms in turn provide protein for the ruminant. In this unique complementary process, the microorganisms must be provided with a source of feed energy also. A conventional expression for the relationship is that 1 pound of urea plus 6 pounds of grain will replace about 7 pounds of oilmeal containing 41 percent protein.

Sometimes urea makes it possible to utilize more low value roughages to supply part of the energy. It can be used to supply indirectly part of the protein needs of ruminants when price relationships make it profitable to do so. It thus becomes a cost-reducing substitute for protein. The cost of urea is a minor part of the cost of the total ration and the significant substitution relationship is between cost of the protein feed replaced by protein from bacteria, and cost of the carbohydrate feed needed to supply the energy for bacterial growth and for that contained in the replaced protein feed.

Urea is toxic in large quantities. Not more than a third of the total nitrogen in the diet should be in the form of urea. The quantity fed must be carefully controlled and thoroughly mixed, and most of the urea fed is supplied in formula feeds.

Antibiotics are among the more recent arrivals in formula feeds. Added in quantities below therapeutic levels they operate to prevent disease and subclinical conditions that impede assimilation of food and retard growth. The exact mechanism of operation is not as yet fully understood. Antibiotics serve to reduce death losses, and to increase output per unit of feed.

Antibiotics are now included in about 90 percent of commercially mixed poultry and turkey starter, grower, and broiler feeds, and in about half the layer and breeder feeds (2). They are included in about three-fourths of pig and hog formula feeds, but in only about 5 percent of dairy and beef formula feeds.

According to the National Research Council, antibiotics in rations of young pigs may increase the growth rate from 10 to 20 percent, and increase

feed conversion efficiency by as much as 5 percent. Antibiotics reduce scouring and the proportion of runt pigs. The effect of the antibiotics is greatest where improved sanitation practices are lacking. Addition of antibiotics to creep-feeding rations may increase pig-weights by 5 to 10 pounds at 8 weeks of age. Preliminary research findings indicate that antibiotics may improve efficiency in feeding beef and dairy cattle and sheep. The value of antibiotics in rations for young dairy calves is well established.

Hormones are also recent arrivals. Much of the work with hormones is still experimental. *Stilbestrol* by implantation and *dienestrol diacetate* have been used in the production of caponettes for several years. But *stilbestrol* for beef cattle feeding is the one that has received most attention. Licensed by Food and Drug Administration for commercial use in November 1954, its use has spread rapidly and it has been estimated that as many as half the cattle on feed⁵ in 1955 received rations containing it. Experiment station studies of beef cattle feeding show average savings attributable to stilbestrol of 10-15 percent in feed and an increase in average daily rate of gain of about a third of a pound a day. But to obtain equivalent grade and quality, stilbestrol-fed cattle must apparently be carried to heavier weights. Thus, the length of feeding period is not shortened and about the same total feed is consumed, but more beef per head is produced.

A few of the other common additives are listed below:

Arsenicals are sometimes added to poultry rations as growth stimulants. They are thought to benefit the animal in about the same way as antibiotics.

Antioxidants. These are chemical preservatives added to feeds to help conserve the fat-soluble vitamins and to retard the rancidity of added fats in the ration.

Surfactants, or *detergents*, are occasionally added to rations. It is thought they may have an effect similar to the antibiotics, or some physiological action that aids the digestive process.

⁵ "Cattle on feed" refers to those cattle being fattened for market as a more or less distinct farm enterprise, and excludes small operations incidental to dairying or general farming as well as grass-fed cattle that are marketed without finishing. Grain-fed cattle comprise about a third of all mature cattle slaughtered.

Coccidiostats are often used in poultry rations to control the organisms causing coccidiosis.

Fats are sometimes added to rations as a source of energy. They also make feeds less dusty and enhance their appearance, texture, and palatability. At present about half the 4 to 5 percent fat in most commercial broiler rations comes from added grease or lard. The other half occurs naturally in other ingredients.

Amino acids. The supply of these essential constituents of proteins in the ration is often supplemented by animal proteins, fish meal, and vegetable proteins enriched with the synthetic amino acid methionine.

Unknown factors. There are unidentified factors that are important to nutrition, and whose action is not explainable at present. Three of these that are of recognized importance in poultry nutrition are the "whey factor," the "fish factor," and the "alfalfa factor." Various ingredients may be added to rations to supply these factors.

Effect of Additives on Production Relationships

In general, additives considered as a group influence the economic problem of feed resource management in two ways. The most important effect is the one characteristic of most innovations, that is, they cause a shift in the whole livestock production function. Output per unit of feed tends to increase all along the line. But they also influence the marginal rates of substitution between feeds. In this respect they have an effect somewhat similar to that of urea.

The substitution effect of additives is illustrated by an experimental test of prewar and present-day broiler rations (table 3). Use of additives has permitted the replacement of more expensive animal sources of protein by soybean meal, B₁₂, and methionine; and replacement of wheat by cheaper grains. Many other changes have been made. In this experiment, the improved ration alone has reduced the time needed to produce a 3-pound broiler by 1 week, and reduced the feed required from 10.26 pounds to 8.16. Yet, at 1954 prices, the ingredient cost of 100 pounds of the old ration was \$6.12 compared with \$6.00 for the superior present day one (6). Although the price of some of the additives is very high per unit of weight, the cost

TABLE 3.—*Ingredients included in prewar and present-day rations compared in Beltsville tests*

Ingredients	Prewar ration	Present-day ration
Carbohydrates:	<i>Percent</i>	<i>Percent</i>
Ground corn.....	39.0	49.3
Ground wheat.....	22.0	.0
Protein:		
Soybean meal.....	.0	32.0
Meat meal.....	10.0	.0
Dried buttermilk.....	10.0	.0
Corn gluten meal.....	10.0	.0
Miscellaneous:		
Steamed bone meal.....	3.0	3.0
Ground limestone.....	.0	1.0
Salt ¹.....	.5	.5
Alfalfa meal.....	2.5	5.0
Dried brewers' yeast.....	2.0	.0
Vitamin A & D oil ²	1.0	.3
"New" Ingredients: ³		
Choline Hcl.....	.0	.1
Folic acid.....	.0	1.8 gm./ton
Lard.....	.0	4.0
DL-methionine ⁴.....	.0	.1
Vitamin B-12 [supplement].....	.0	.1
Fish solubles ⁵.....	.0	4.0
Butyl fermentation solubles ⁶.....	.0	.6
Crystalline chlortetracycline ⁷.....	.0	18.0 gm./ton
3-nitro, 4 hydroxyphenylarsonic acid ⁸.....	.0	45.0 gm./ton
Total.....	100.0	100.0
Analysis (calculated)		
Protein.....	19.6	20.6
Productive energy (calories per pound).....	887.0	882.0
Fiber.....	3.0	4.6

¹ 96 parts NaCl; 4 parts MnSO₄·4H₂O.

² 1,200 A; 400 D.

³ Ingredients added to the broiler diet since World War II.

⁴ Methionine is an essential amino acid.

⁵ Fish solubles are added to supply the "fish factor."

⁶ Butyl fermentation solubles are added to supply riboflavin.

⁷ Chlortetracycline is an antibiotic.

⁸ 3-nitro, 4 hydroxyphenylarsonic acid is one of the arsenicals.

Reproduced from ARS Special Report, "Ingredients in the Modern Broiler Diet." (6)

of the quantities used per ton of feed is very low because only spoonful quantities are necessary.

Effects of Improved Feed Technology on Livestock Production

The foregoing brief description of several types of additives suggests a considerable diversity of individual effects on livestock production. Nearly all of them work toward more output per unit of feed. The extent of the immediate effect on output expansion differs considerably. For example, urea may simply permit substitution of

carbohydrates for proteins, whereas stilbestrol results in immediate increases in output from the same cattle.

A general view of the longer run economic effects of expanded use of formula feeds and the associated additives leads to a consideration of the following:

1. Further division of labor and shift of functions from farm to feed dealer and factory.
2. Interregional and interenterprise shifts.
3. Changing scale of operation.
4. Effect on total production of livestock.

The movement toward the use of more formula feeds, as with many other phases of technology applied to agriculture, means a shift of some functions from the farm to the city with accompanying advantages—and some disadvantages—of specialized effort. Just as in the classic illustration given by Adam Smith of the division of labor in the primitive pin factory, so here the division of labor makes for significant gains in efficiency and the development of special products not even possible before.

The commercial broiler enterprise owes much of its rapid development to the formula feed industry and the services associated with it, including managerial advice and credit. A recent South Carolina study showed that from a third to more than half of the farmers interviewed delegated to feed dealers important management decisions relating to choice of ration, choice of breed, when and to whom to sell, and what price to ask (4).

This delegation of part of the entrepreneurial function into fewer hands means that the special abilities of trained technicians can be obtained and focused more effectively on major problems. The practical elimination of large elements of risk and uncertainty means also that the producer can specialize, increase his scale of operations, and become generally more efficient in the conduct of the functions remaining within his sphere of decision and action.

Formerly the geographic location and distribution of livestock production was largely determined by the location of feed production. Even concentrate feeds were bulky and expensive to move as compared with the resulting livestock products. Consequently, comparative advantage was strongly tied to the location of feed production. This is still true with respect to the utili-

zation of pasture and forage resources. But formula feeds have changed the situation with respect to concentrate feeds, and made them available everywhere at smaller regional and area price differentials.

Manufacturers of formula feeds are continually seeking to reduce costs of rations by substituting one feed for another as prices change and as technology improves. Expansion of the formula feeds industry will thus act as a stabilizing influence by tending to keep prices of alternative feeds more nearly in line with their marginal feed substitution values.⁶

With geographic differences in prices of concentrate feeds less marked, livestock production tends to gravitate more toward locations in which other resources are available on the most advantageous terms. This principle can be seen operating in the commercial broiler industry in which geographic concentrations of production appear to have developed initially around pools of underemployed labor resources (fig. 2). Once having commenced, other economies associated with the area integration of services for credit, supplies, baby chicks, and processing have developed in the same areas.

Some of the same advantages may have been important in explaining the location and growth of the fluid milk industry in certain areas in the Northeast, on the Pacific Coast, and elsewhere. Certainly formula feeds have played a part. Future location of cattle feeding and hog feeding operations may be influenced by the greater flexibility possible with improved formula feeds.

Scale of operations is obviously influenced by use of formula feeds and by some of the additives. The same labor force and the same overhead can produce more final product. Reduction in death losses in young animals means that more animals are carried to maturity. Savings in feed all along the line can be used to increase total livestock output per farm.

Competition between livestock enterprises may be affected in several ways. In general, innovations that increase the advantage of concentrate feeds more than roughage feeds will favor the animals that consume most concentrates. Poultry and hogs benefit more from these changes than

⁶ For prices of competitive feeds to reach a new equilibrium after a change in the conditions of supply or demand, the ratios between prices must be inversely proportional to the marginal rates of substitution between the feeds.

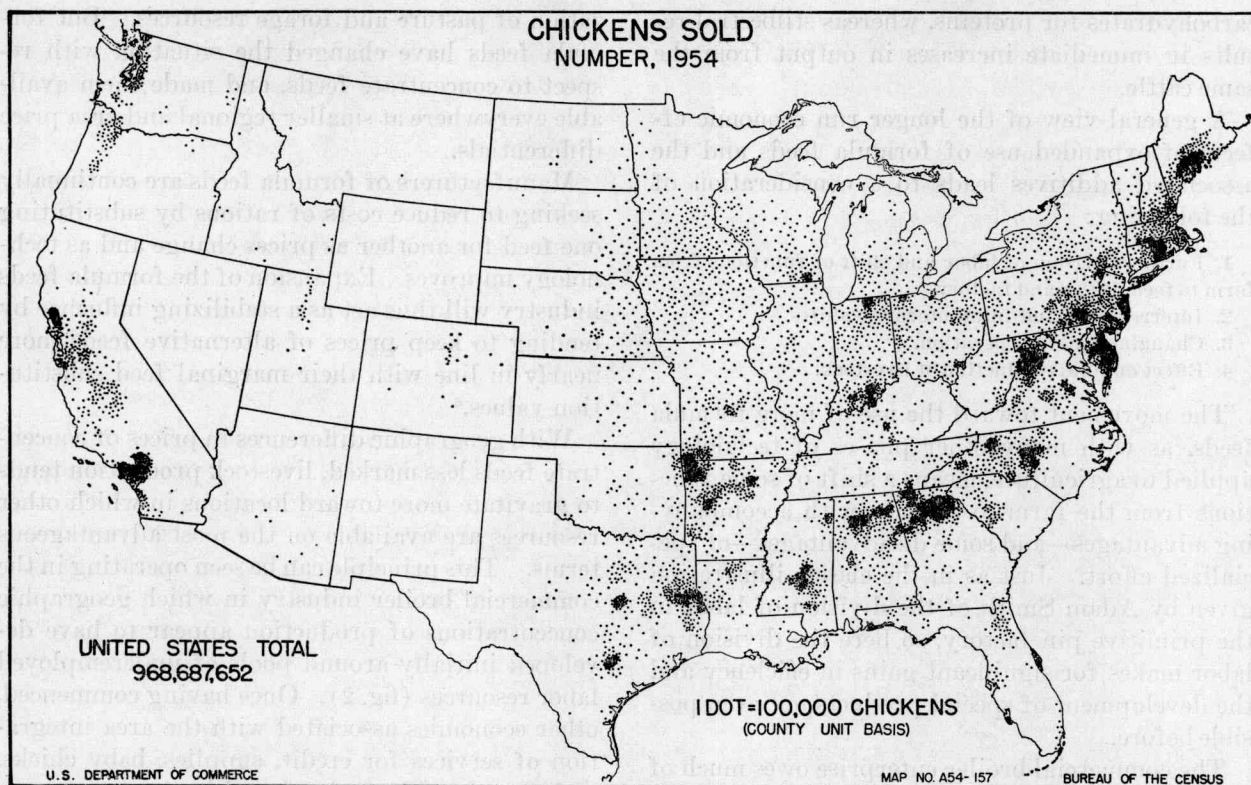


FIGURE 2.

do the roughage consuming animals. Poultry production has already been greatly affected; hogs may be next—the expected shift toward a meat-type hog may be accelerated.

Most feed improvements it appears will increase output on the individual farm and in the aggregate. Output-increasing innovations always raise the economic question of who gets the benefits. In the shortrun, those farmers who first adopt the innovation reduce their unit costs and increase output and profits. But as the new technique passes into general use, the aggregate expansion causes the price to decline. If the demand for the product is inelastic (usually so in the shortrun), the value of the total production will decline and farmers' incomes may actually be lower than before the advent of the new technology.

An additive like stilbestrol quickly put into use through formula feeds rapidly adds to output. Within about a year after it was licensed for feeding beef cattle, it was being fed to about half the beef cattle on feed in the United States. This indicates the speed with which an innovation can be accepted when the decision to adopt it needs to be

made by only a few individuals—in this case the formula-feed makers. In contrast, the rate of adoption of hybrid seed corn depended upon the individual decisions of thousands of producers and it was at least 10 years after a successful hybrid became available before half the corn acreage in the Corn Belt was planted to hybrids. Of course there have also been improvements in the communication of new ideas since the advent of the corn hybrids.

The questions of the degree of elasticity of demand for livestock products and of the probable growth of demand over the next decade or so are therefore crucial. Merely to convert crop surpluses into livestock surpluses as a result of new technology might be of little ultimate help. The first effect, of course, may be helpful because livestock products use up several times the resources to produce as much total food nutrients, as do food crops.

Fortunately, continued growth of consumer demand appears assured by rising population. Elasticity of demand for livestock products is greater than for most crop products. Elasticity

of demand over time also appears to be greater than in the shortrun for at least certain of the major livestock items. Recent studies reported by Elmer Working (9), for example, indicate an overall long-time demand elasticity for all meats of about -1.2 , more than unity. This contrasts with a relatively inelastic short-time demand elasticity of about -0.8 .

Conclusion

This brief review of the state of technology in animal production suggests that after a long period of little change we may now be on the verge of a period of unusual progress that will be marked by increased efficiency in feed conversion. The role of feed additives is especially interesting because many of them do not raise an economic problem with respect to whether it pays to use them. The cost is usually minor and the production effects are often considerable. The physical or biological optimum rate of use is practically identical with the economic optimum.

But beyond the immediate effects lie significant economic consequences with respect to the organization of production on farms and the division of responsibility among farmers, dealers, financiers, and others who share in entrepreneurship. Important shifts in interregional and interenterprise location of production may be expected. The influence of technology on scale of operations and

the general efficiency of livestock production will affect all phases of the industry. Livestock production will become more and more a manufacturing operation, geared to convert feedstuffs into food in the most efficient fashion. These changes will be helpful in shifting the balance between crops and livestock in the aggregate agricultural economy in the right direction.

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