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A STUDY OF FACTORS AFFECTING CONTROL OF BANG'S DISEASE IN CATTLE

A report submitted to the Bureau of Animal Industry of the U. S. Department of Agriculture by the Institute of Statistics of the University of North Carolina and the Field Research Laboratory, Bureau of Agricultural Economics, U. S. Department of Agriculture, Raleigh, North Carolina.

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A STUDY OF FACTORS AFFECTING CONTROL OF BANG'S DISEASE IN CATTLE

Preface

The campaign against Bang's disease in cattle has, for the past fifteen years, been one of the important activities of the Bureau of Animal Industry of the United States Department of Agriculture. In the course of the work, a large quantity of data has been accumulated, consisting chiefly of field and administrative records of tests made. The following report details the results of a study of a sample of those records. Two general objectives were (i) to answer some specific questions regarding Bang's disease control, and (ii) to assess the value of the available records for further research studies.

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Substantial contributions to the study were made by so many staff members of the Institute of Statistics, Bureau of Agricultural Economics, and Bureau of Animal Industry, that authorship of this report can not be attributed to any individual or small group of individuals.

The project was formulated by Drs. B. T. Simms, A. K. Kuttler and C. K. Mingle, of the Washington office of the Bureau of Animal Industry, and C. F. Sarle, of the Bureau of Agricultural Economics. Original data were provided by the veterinarians in charge of the Bureau of Animal Industry offices in the ten states studied, including Drs. T. H. Applewhite of Florida, N. H. Howlett of Illinois, E. C. Hughes of Louisiana, C. H. Hays of Michigan, F. C. Driver of Minnesota, G. W. Cronen of Montana, A. A. Husman of North

Carolina, J. P. Reidy of Pennsylvania, H. L. Fry of Tennessee, and A. F. Ranney of Vermont. Actual field collection of the data from state offices was done by A. L. Finkner, Bureau of Agricultural Economics, for all states except Minnesota and Montana. These two states were covered by Glenn D. Simpson, also of the Bureau of Agricultural Economics.

Analysis was under the direction of A. L. Finkner from June to October 1947; of Henry A. Salmela, also of the Bureau of Agricultural Economics, from October, 1947 to June, 1948; and of F. E. McVay, Institute of Statistics, from September, 1948 to July, 1949. The final report was prepared by F. E. McVay.

Advice and consultation on the study were generously given by R. L. Anderson and H. L. Lucas, of the Institute of Statistics, and by E. H. Jebe, A. L. Finkner, and W. A. Hendricks of the Bureau of Agricultural Economics, as well as by R. K. Waugh, F. E. Elliott, and C. D. Grinnells, of the Department of Animal Industry, North Carolina State College.

A STUDY OF FACTORS AFFECTING CONTROL OF BANG'S DISEASE IN CATTLE.

Section I. Introduction.

1. Historical note. The disease of cattle known variously as Bang's disease, Brucellosis, infectious or contagious abortion, is a manifestation of the activities of bacillus-type organisms of the genus Brucella. The same organisms cause undulant fever or Malta fever in humans. This genus includes several species, which are all communicable to humans, but whose natural hosts are cattle, goats, and swine. The organism is named for David Bruce, an English army surgeon, who isolated it in 1887 in Malta. He showed it to have been transmitted to soldiers, via milk consumption, from goats. Ten years later, Bernard Bang, a Danish scientist, isolated the bovine species, Brucella abortus. This species is by far the most important, from an economic standpoint, in the genus. 1/

2. Importance of the disease. In the period from 1934 to 1947, about 80 million head of cattle were tested for Bang's disease in the United States, and 3 1/2 million reacted positively to the test. 2/ There is no known cure. The organism can, however, be easily destroyed by heat. Milk from infected animals is, after pasteurization, perfectly safe for human consumption, and cooked meat from infected animals is similarly safe. The damaging effects of Bang's disease are mainly the death of fetuses and the premature initiation of the lactation cycle due to abortion, with a resulting loss in production. The calf crop may be reduced by as much as 40%, and milk production may be cut 25% in an infected

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1/ Information in this paragraph is from Eichhorn, A., and Crawford, A. B., Brucellosis of Cattle, Washington, U. S. Department of Agriculture, Farmer's Bulletin No. 1871, January 1946.

2/ U. S. D. A., Bureau of Animal Industry, Summary of Brucellosis (Bang's Disease) Control Program, July 1, 1934 to May 31, 1947. There is duplication in the number of head tested, as the same animal was in many cases tested several times over a period of years.

herd. Annual losses before the government control program was instituted in 1934, were estimated at $50,000,000, and 10% of all cattle in the country were estimated to have been infected.[3/] Although the disease is, in many areas, the most serious single threat to dairy herds, its effects are not confined to cattle owners.[4/] Every member of the community is affected directly, through an increased cost of dairy products following less efficient production, and through the possibility of contracting undulant fever, and the consequent necessity of bearing a part of the tax burden necessary to support a control program. Hence the importance of continued study of Bang's disease.

3. Characteristics.[5/] One of the more common ways in which the disease is transmitted in cattle is through the digestive tract, by means of contaminated feed and water. The organism is taken into the blood stream from the intestines, and is thence carried to the genital organs and udder, where it finds conditions best suited to its development. The germ may also be spread by direct contact. The belief that the female acquires the disease from the bull at the time of copulation is widespread, but apparently has been neither

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3/ Mohler, John R., Wight, A. E., and Lash, Elmer, Benefits of Eradicating Bang's Disease, Washington, U. S. Department of Agriculture, Miscellaneous Publication No. 384, 1940, pages 1 and 2.

4/ Moore, William, Grinnells, C. D., and Faulhaber, L. J., Bang's Abortion Disease in North Carolina, N. C. Agricultural Experiment Station and N. C. Department of Agriculture, Cooperating, Raleigh, N. C., Technical Bulletin No. 54, November 1937.

5/ This section is adapted from Eichhorn and Crawford, op. cit., and Diseases of Cattle, pp. 142 ff., by Drs. Atkinson et al., U. S. Department of Agriculture, Washington, 1942.

verified nor disproved.[6/]

Obvious symptoms of Bang's disease are practically non-existent until the infected animal aborts. As the health of the cow is not noticeably affected by the slow development of the disease, infection can become well established in a herd before its presence is suspected. Hence the importance of periodic testing. Abortion usually occurs between the third and seventh month of pregnancy. It is not unusual for an infected cow to give normal birth to a full-term live calf. Such calves, however, frequently die within a few days. Aborting animals often become temporarily, if not permanently, sterile.

The only certain way to determine whether an animal is infected is to isolate the causative micro-organism. A less sure but more convenient method, and in practice the method almost universally used, is a blood agglutination test. The agglutination test sometimes fails to detect cases of recent infection; it fails to differentiate clearly between infected animals and those which have spontaneously recovered from the disease; it does not distinguish infected from vaccinated adults, as both react positively to the test. Regarding this last point, neither the rate nor the extent of agglutinin disappearance in blood of adult-vaccinated cows is known. Thus, when a positive reaction to the agglutination test is obtained on a vaccinated animal, there

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6/ Evidence on this point is inconclusive. There are two possibilities: (i) the organism may be present externally on the genital organs of the bull, and be transferred from infected to healthy cows; (ii) the organism may be present in the semen. Regarding the first possibility, Atkinson, et. al. (op. cit., p. 143) state that, "the view that the disease is spread to any great degree in this way has been largely discredited." Neither they nor any other investigators known to this writer, however, are willing to say definitely that the disease is not so transmitted. On the second point, two Danish investigators, Bendixen and Blom (Veterinary Journal, 103: 337-345) report some apparent infection of healthy cows by infected semen, but their observations also are not conclusive. The same opinion is expressed by Eichhorn and Crawford (op. cit., p. 4). As contact at breeding is sometimes the only contact of a clean herd with other herds, the question of transmittal of the disease by bulls is of considerable importance, and should be more fully investigated.

is no way of determining whether the test is showing the presence of (i) the vaccine, or (ii) a real infection which occurred after the effectiveness of the vaccine had disappeared. The agglutination method is, nonetheless, sufficiently discriminant, convenient, and practical for field use on a large scale, that these weaknesses are tolerated.

The incidence of Bang's disease exhibits a noticeable seasonal movement, from highest in the warm weather months to lowest in the winter. The peaks occur in slightly different months in different regions of the country. 7/ See Table 1.

In the several regions studied, peak infection occurred as follows: in New England, in August; in Pennsylvania, New Jersey, North Carolina and Tennessee, in July; in Texas and Oklahoma, in June; and in Montana, Florida and Louisiana, in May. No seasonal peaks were observed in Minnesota, Michigan, Wisconsin, Colorado, Wyoming, and Idaho. Differences between monthly infection rates in the regions studied were significant.

4. Control. Control programs in the various states are administered under state laws, but usually in close cooperation with the Bureau of Animal Industry of the U. S. Department of Agriculture. Since the Bureau of Animal

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7/ Data upon which these statements are based come from the Bureau of Animal Industry's monthly "Summary of Brucellosis (Bang's Disease) Work in Cooperation with the Various States," available since the inception of the control program in 1934. Among other items, these summaries give, by states, the total number of cattle tested and the number of reactors, from which have been computed the percent of infection for the 144 months from 1936 to 1947, inclusive. It was assumed that the cattle tested in each month were a random sample of all cattle in the state. Although the percentages were not weighted, the number of observations on which each of them was based was of the order of 2,000, so weighting was not considered necessary. The distribution of the data did not depart markedly from normal. The 144 percentage values were treated as individual observations. An analysis of variance was used to examine the relationships reported.

Table 1.

Average Bang's Disease Infection Rates in Selected Regions, by Months, 1936-1947.

Average percent of positive reactors among all animals tested.

Regions	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Aver. Monthly Infection Rate
Colo., Idaho, Wyo.	4.8	5.2	5.3	4.9	5.1	5.0	5.0	4.8	4.9	4.6	4.4	5.3	4.9
Fla. and La.	3.3	3.3	3.8	4.8	5.1	4.4	4.1	3.4	3.7	2.9	2.6	2.8	3.7
Mich., Minn., Wis.	4.2	3.7	3.9	4.0	3.7	3.7	3.9	4.4	4.5	4.3	4.4	4.2	4.1
Montana	3.5	3.4	3.2	2.8	4.7	3.9	4.2	4.3	3.6	3.7	2.6	3.0	3.6
New England States	4.2	3.9	3.6	3.2	3.8	4.7	5.0	5.8	5.0	4.1	3.6	3.6	4.2
New Jersey, Pa.	2.7	2.8	3.0	3.2	3.0	3.0	3.9	3.7	3.2	3.1	2.9	2.8	3.1
N. C. and Tenn.	2.5	2.2	2.4	2.3	2.8	2.8	3.2	2.7	2.4	2.3	2.2	1.9	2.5
Okla., and Texas	3.8	4.4	3.9	3.7	3.8	5.0	3.7	4.1	3.5	3.0	2.9	3.4	3.8
U. S. (Porto Rico omitted)	4.0	3.8	3.9	4.0	3.9	4.3	4.3	4.3	4.1	3.8	3.7	3.8	4.0

Industry has no legal means to enforce uniformity, or even compliance, among the states, there is a wide variety of programs, some states operating several programs concurrently. Most of the state programs, however, come under one or more of the following types.

(i) Test and slaughter. Under this method, herds are tested repeatedly, and reactors are removed from the herd and slaughtered. As indicated above, beef from infected animals is safe for human consumption, so the loss from slaughtering a positive reactor is the difference between dairy and beef values. Part of the difference is, in many states, borne by the Federal and State governments. This cooperative program of indemnifying farmers, is used as a means to encourage control of the disease.

(ii) Test and segregation. This method also requires repeated testing, but calls for segregated retention, rather than for slaughter, of positive reactors. In large herds, where more than one barn is available, this method is practical, although great care must, of course, be exercised to avoid carrying the disease into the clean portion of the herd. The main advantage of this method is that immediate disposition of reactors, who may be valuable milk producers, is not necessary. Profits are thus less seriously affected.

(iii) Vaccination. When 4-to-8-month-old calves are vaccinated with Brucella of reduced virulence, they acquire a resistance to infection and abortion which usually persists throughout adulthood. The vaccination of adult animals is equally effective. After vaccination, agglutinin is formed in the blood: in calves, this substance disappears within a few months after vaccination; in adults, it persists for a much longer period. In the case of adults this is an important disadvantage, for as long as agglutinin is present in the blood, it is impossible by the agglutination test to distinguish a vaccinated cow from a truly infected cow, as has been indicated above.

(See page 5.)

(iv) Sanitary management. The importance of this method of control cannot be overemphasized. It is generally recognized by workers in the field that good management is not only an indispensable prerequisite to the success of other more specific programs, but also a positive force in itself. Sanitary management includes such procedures as (1) confining cows to individual stalls a week or ten days before, and a month after, calving; (2) carefully disinfecting all areas contaminated by abortion products; (3) exercising reasonable caution in bringing new animals into the herd — even if the new animal is not infected, she may acquire the disease more readily than animals raised in the herd, as the latter may have developed a resistance to a particular strain of the organism carried in the herd.

(v) Area testing vs. individual testing. Individual testing of herds is done on the initiative of the individual herd owner, while, under an area test plan, every owner in an area is required to have his herd tested. Area testing is especially effective, and is used in some cases on a large area like a state. There is at least one difficulty which arises in connection with the use of the area test. The area test system consists of a complete test, followed by periodic retests, at intervals sometimes as long as three years. The fewer herds infected on the first test, the less urgent, and hence the longer the interval until, the first retest. The complication arises from the fact that the biggest source of infection on retests is often observed to be herds that were clean on the original test. This will be discussed in greater detail below. (See page 20.)

The organized fight against Bang's disease began in the United States in 1934, when the U. S. Department of Agriculture, in cooperation with several of the states, inaugurated a control program based on test-and-slaughter. Between 1936, when the program had been well organized, and 1940,

the average infection rate in the United States dropped from 5.7% to 2.5%. In some areas, like Florida and Louisiana, where the drop was from 6.4% to 1.6%, the cleaning upprocess was even more spectacularly successful. After 1941, the U. S. rate edged up to 4.9% in 1945 and 1946, due in large part, it is thought, to inability of the Bureau of Animal Industry to obtain personnel with which adequately to staff the field offices during the war years. Since that time, however, the rate has begun to decline again. Data for several selected states are given in Appendix Table 3, page 50. There is little doubt of the influence of the control program upon these trends — the trends, in fact, are an argument for the very great importance of the control program. During the years since 1934, the types and methods of control described above, have been developed. From the records kept in the routine operation of these programs, the data for this study were obtained.

5. Description of available data, and objectives of this study. This study represents an attempt to use the administrative data from various states to obtain certain information on the control of Bang's disease. The available data are individual test records and herd summaries. There is a sheet in the field office file for each test of each herd. Each sheet, carrying the date of the test, contains a list of all cows tested, with the test reaction of each, and often a notation giving the number of other cows, calves, bulls, steers, or other bovines, on the farm, which were not tested. Summary cards, one for each herd, are also available. They contain summarized information from the individual test sheets, showing for each test the number tested, number reacting each way, etc. A sample of the summary cards, which provided the main body of the data, is shown in the Appendix Figure 1, page 51.

Large quantities of such records are available in the cooperative offices in the states, and it has been felt that they constituted a hitherto untapped

source of valuable research material. This project arose from the desire (1) to use this material to get some answers to specific questions concerning Bang's disease, and, (2) to draft some recommendations, if the data were not adapted to such use, for making records collected in the future operation of the program more useful as dual-purpose administrative-research records. The statistical services of the Bureau of Agricultural Economics were called upon to make the analyses. The Bureau assigned the project to its Raleigh Research Office in Agricultural Estimates, located at North Carolina State College, where the work has been carried forward in very close cooperation with the Institute of Statistics of the University of North Carolina.

Objectives of the study, as taken from the project outline, were to determine:

1. "The time required to eliminate the disease from an infected herd.
2. "Number and frequency of tests required.
3. "Number of animals that must be eliminated in the process.
4. "Effects of management and other factors, including vaccination practices, upon the above variables.
5. "The extent to which it is possible to predict from a preliminary examination of an infected herd:
    a. How long it will take to free the herd of the disease.
    b. How many successive tests must be made and the frequency with which they should be made.
    c. The total number of animals that will probably have to be eliminated during the clean-up process."

The principle method used was a multiple regression analysis. This type of analysis was to be used to develop estimating equations for predicting, for example, the time required to clean up a herd, when knowledge was available concerning such variables as the size of herd, initial percent of infected

and suspect animals, and interval between tests. There were two problems here: (i) to determine the variables which would contribute most to the reliability and accuracy of the estimating equation; (ii) to determine the effects of these variables, when acting together, upon the item to be predicted.

The work of the project fell into three phases, (i) analysis of a sample of herd records from a sample of states; (ii) analysis at a considerably more detailed level, involving individual cow records, of a sample from a single state; (iii) analysis of data taken in an area test of all herds in one county, Jersey County, Illinois, designed to provide information on management factors, which were not covered in the administrative records available in the states. Selection of the samples and details of analysis for each phase will be discussed in detail below.

Section II. Analysis of Herd Records from Ten States.

1. Selection of the sample. There were two immediate problems in the selection of the sample from the several states to be studied in the first phase of the project. These problems were: (i) what states should be covered, and (ii) what herds within each state should be selected? The first of these questions was answered by officials of the Bureau of Animal Industry of the United States Department of Agriculture, who selected, on the basis of experience and knowledge of various state programs, the ten states of Florida, Illinois, Louisiana, Michigan, Minnesota, Montana, North Carolina, Pennsylvania, Tennessee, and Vermont.

The following considerations governed selection of the herd samples within each state. To keep within the budget of the study, it was decided that not more than an average of 300 herd records per state could be obtained. From the standpoint of the analysis, it was agreed that fewer than 200 would be undesirable. These two figures, then, were the approximate limits to the size of the sample in each of the ten states. Wherever field office files were separated by type of control program, as they usually were in the case of area and individual testing, each type was sampled. When there was no such separation of the records, no stratification of the sample was attempted. The sample was drawn in such a way, however, that every control program could be expected to occur in the sample in the same proportion that it occurred in the file as a whole. For this phase of the work, herd summary data alone were used.

To be eligible for inclusion in the sample, a herd had to meet these requirements: (i) it must have shown some infection at some time; (ii) it must have been tested at least twice after the test showing initial infection.

The first step in the actual drawing of the sample was the decision on the number of records to be taken. Since this number could vary only within fairly narrow bounds, it could usually be tentatively set at the upper limit, 300. The files were then measured and their total length divided by 300. The value so obtained was the length of the interval between selected cards. Suppose a state's record cards filled fifteen 20-inch file drawers; the total length, 300 inches, divided by the number of records to be included in the sample, 300, equals 1 inch. Thus, one card per inch would be taken for the sample. If a selected card proved to be ineligible, the next ones were successively picked until an eligible was discovered. Table 2 gives a summary of the herd records selected for study.

Table 2. Summary of Herd Records from Ten Selected States. Bang's Disease Study, 1947.

State	Total no. of herd records collected	No. of herds having at least one period in which infection had been eliminated[a]	No. of herds never considered clean during the period studied	No. of herds containing less than ten head	No. of herds with ten or more head
Florida	201	171	30	17	184
Illinois	211	196	15	31	180
Louisiana	204	81	123	9	195
Michigan	274	256	18	60	214
Minnesota	262	219	43	27	235
Montana	181	144	37	39	142
North Carolina	188	182	6	27	161
Pennsylvania	302	266	36	53	249
Tennessee	202	182	20	17	185
Vermont	179	80	99	16	163
All States	2204	1777	427	296	1908

[a] Infection in a herd is said, for purposes of this study, to have been eradicated as of the date of the first wholly clean herd test, provided that this clean test was followed by two more consecutive clean tests made at intervals of not less than fifteen days. "Clean test" means a herd test which reveals no positive reactors or suspected positive reactors. The beginning of an infection period is said to date from the first herd test in which positive reactors or suspects are found following three or more clean tests. A herd thus can (and many of those studied did) go through several infection periods or cycles of infection — eradication — reinfection, etc.

2. Summary of programs for Bang's disease eradication in ten sample states. The cooperative programs for Bang's disease eradication in the states, administered jointly by the Bureau of Animal Industry of the U. S. Department of Agriculture, and by the State Departments of Agriculture, are in all cases operated in conformity with state laws rather than in accord with Federal directives. A variety of approaches to the control problem has therefore arisen. Each of these approaches undoubtedly has something to recommend it in the individual state, but, from the standpoint of an overall analysis, the disadvantage of lack of uniformity is serious. Further complications arise from the fact that in some states a given herd owner may shift from one type of program to another at will. The types of programs in effect in the ten sample states in 1947 are listed below.

Table 3. Types of Programs in Effect for the Eradication of Bang's Disease In Ten Selected States, 1947.

State	Programs in Effect in 1947
Florida	a.) Test and slaughter b.) Test and slaughter, with calfhood vaccination c.) Test and segregation, with or without calfhood vaccination d.) Vaccination of adult animals - no subsequent testing e.) Vaccination of calves - no subsequent testing
Illinois	a.) Test and slaughter, with or without calfhood vaccination b.) Calfhood vaccination, test once a year and retention of reactors c.) Vaccination of calves, (no blood test on the herd required) d.) Mature cow vaccination upon permit from regulatory official
Louisiana	a.) Vaccination, with or without test, and with or without slaughter of reactors
Michigan	a.) Area 1.) Test and slaughter 2.) Test and deferred slaughter (privilege retention of reactors), with calfhood vaccination in infected herds b.) Individual 1.) Test and slaughter 2.) Test and slaughter, with calfhood vaccination
Minnesota [a/]	a.) Area 1.) Test and removal of reactors (slaughter) with or without calfhood vaccination 2.) Test, calf vaccination, temporary retention of reactors until they can be disposed of for slaughter without excessive loss to the owner 3.) Test, adult vaccination of negative animals under special official written approval b.) Individual 1.) Test and removal of reactors (slaughter) with or without calf vaccination 2.) Test, calf vaccination, temporary retention of reactors until they can be disposed of for slaughter without excessive loss to the owner 3.) Calf vaccination without test of any part of the herd 4.) Test, adult vaccination of negative animals under special official written approval
Montana	a.) Individual test and slaughter 1.) With calfhood vaccination 2.) Without calfhood vaccination b.) Test and retention of reactors 1.) With calfhood vaccination 2.) Without calfhood vaccination

Table 3. (Cont'd.)

State	Programs in Effect in 1947
North Carolina	a.) Mainly test and slaughter b.) Very little calfhood vaccination c.) Adult vaccination rarely, only with approval of state veterinarian
Pennsylvania b/	a.) Area: test and slaughter b.) Individual 1.) Test and slaughter 2.) Test and slaughter, with calfhood vaccination 3.) Test and retention of reactors, with calfhood vaccination 4.) Calfhood vaccination and no test
Tennessee c/	a.) Test and slaughter b.) Test and slaughter, with calfhood vaccination c.) Test and retention of reactors, with calfhood vaccination
Vermont	a.) Calfhood vaccination and test, with elimination of reactors from the herd but not necessarily by slaughter b.) Calfhood vaccination - no subsequent testing

a/ All herd samples of milk and cream obtainable from creameries and cream stations in Minnesota are tested twice each year by the agglutination ring test method, followed soon thereafter by a blood test of herds that react positively thereto. This program was inaugurated in November, 1947.

b/ The Pennsylvania General Assembly in its last session appropriated " 2 1/4 million dollars to pay indemnities for animals slaughtered on account of tuberculosis, brucellosis, and the purchase and administration of brucella vaccine.....As a result thereof, present plans provide for a highly accelerated vaccination program in this state, which, it is hoped will be under way in the near future...." From Monthly Letter on Brucellosis Control and Eradication, May 6, 1949, from H. M. O'Rear, Veterinarian in Charge, to the Chief, Bureau of Animal Industry.

c/ Calfhood vaccination with deferred test of adults was initiated about January 1, 1948.

3. Length of time and number of tests required to clean an infected herd. The first two objectives of the study, the analysis of (i) time and (ii) number of tests required to clean a herd, are closely related. Table 4 shows for the ten states the number of herds actually cleaned after varying lengths of time and varying numbers of tests. Individual state data are given in Appendix Tables 1 and 2, pages 48 and 49.

Table 4. Frequency Distribution of Herds from which Bang's Disease was Eradicated, Showing the Required Lengths of Time and Numbers of Tests. Ten Selected States, 1947.

Number of the test on which the herd was reported clean[a]	Number of months between the first herd test showing infection and the subsequent herd test showing the herd to be clean									
	Less than 3	3 to 5.9	6 to 8.9	9 to 11.9	12 to 14.9	15 to 17.9	18 to 20.9	21 to 23.9	24 or more	All herds
	(number of herds)									
2	852	0	1	0	0	0	0	0	0	853
3	125	76	18	9	14	5	1	3	8	259
4	9	70	38	19	17	8	7	7	35	210
5	2	15	35	32	8	11	6	6	25	140
6	2	3	9	11	13	6	6	3	16	69
7	1	2	3	0	7	10	10	4	26	63
8	1	0	2	8	3	4	7	5	18	48
9 or more	0	0	1	2	2	9	8	12	101	135
All herds	992	166	107	81	64	53	45	40	229	1777

[a] The number of tests in this column begins with No. 2, since the first herd test was presumably the earliest possible report of infection. Control measures in infected herds were to be instituted following the first test, and the first opportunity to measure the effectiveness of control came on the second test, sometimes called the first retest.

These data show that Bang's disease can be eradicated in many cases in a short time and with a small number of tests.[8] Nearly one-half of the herds studied were clean on the first retest, within three months of the original

[8] A discussion of the reliability and practical value of these data, with specific reference to predictions, will be given below. See page 25.

herd test which had revealed the existence of infection. About one-third of the remainder were cleaned after two more tests, within an additional six months.

This reenforces the already well-developed faith of most investigators in the efficacy of known control methods. With test-and-slaughter, for example, the disease can be eliminated from a herd quickly, but at substantial cost if the infection is heavy. Because of the heavy costs, known control methods are sometimes not used as recommended, and new control methods, which are compromises with the old, are evolved. An obvious example is the development of test-and-segregation from test-and-slaughter.

Although data are not available to measure the degree to which the hypothesis holds, it is felt that much of the unexplained variation in time and number of tests required to clean a herd, could be accounted for by variations in herd management practices. Veterinarians, both in the field and in research, are virtually unanimous in their opinions that the key to the problem lies here. An attempt was made to explore the relationship of management practices to control when the special study of the Jersey County, Illinois, area test was undertaken. This will be described fully below. See page 34 ff.

In Table 5, data are given on the average number of tests required to clean a herd, the herds having been classified by size of herd and number of reactors on the first herd test.

Table 5. Average Number of Tests Required to Eliminate Bang's Disease from Herds of Varying Sizes and Degrees of Initial Infection. Ten Selected States, 1947.

Number of Reactors on Initial Test	Number of Cows per Herd [a/]									
	10-29		30-49		50-69		70 or more		All herds	
	No. of herds	Ave. No. of tests to clean herd	No. of herds	Ave. No. of tests to clean herd	No. of herds	Ave. No. of tests to clean herd	No. of herds	Ave. No. of tests to clean herd	No. of herds	Ave. No. of tests to clean herd
1 - 3	668	2.2	164	3.2	50	2.9	41	3.8	923	2.5
4 - 6	152	3.2	39	4.0	20	4.1	11	9.8	222	3.8
7 - 9	93	3.9	38	4.6	8	6.0	7	6.6	146	4.3
10 - 18	64	2.9	48	4.8	17	5.5	20	9.8	149	4.7
19 or more	2	2.5	13	8.3	14	7.6	32	10.4	61	9.0
All herds	979	2.5	302	4.0	109	4.3	111	7.6	1501	3.3

[a/] Excluding herds with less than 10 head.

The required number of tests seems to increase, both with herd size and with initial infection, although, as might have been anticipated, the increase appears greater with an increase in infection than with an increase in herd size. The average herd was clean after about three tests. Although these data are useful as overall indications, their possible uses to predict values for individual herds is limited. The mean number of tests required is 2.2, for example, to clean the 668 herds with from 10 to 29 head and from 1 to 3 reactors on the initial test. Although the mean number of tests required is 2.2, the actual number for individual herds ranged from one to thirty-nine. Prediction of individual values from a distribution as widely varying as this is hazardous. Further comment on the value of the data for prediction is contained in the description of the regression analysis, beginning on page 24.

4. Source of infection: from previously clean or previously infected herds? Veterinarians in the field have observed that, in area test regions, an important source of infection at a given time has been herds reported free from infection on previous tests. This contradicts the apparently logical expectation that clean herds would tend to remain clean, and that herds infected on one test would be most likely to show infection on subsequent tests. With the data at hand, it is possible only to check the accuracy of the veterinarians' observations in the area test states of the sample. The data do not lend themselves to an investigation of reasons for whatever verification of the observations may be provided.[9/] The three area test states in the

Table 6. Distribution of Infected Herd Tests in Three Area Test States, Classified by Infection Status on Preceding Complete Retest, 1947.

State	Tests of Herds Showing Infection on Complete Retest									
	Herds Infected on Preceding Retest		Herds Suspect on Preceding Retest		Herds Clean on Preceding Retest		Herds with no Record on Preceding Retest		Total Infected Herd Tests	
	No.	%	No.	%	No.	%	No.	%	No.	%
Michigan	363	22	-	-	927	57	340	21	1630	100
Minnesota[a/]	183	20[b/]	27	3	481	54	203	23	894	100
Pennsylvania	224	24	-	-	689	76	-	-	913	100
Three States	770	22	-	-	2097	61	-	-	3437	100

a/ Minnesota data from "A Study of the Control of Brucellosis in Cattle in Minnesota," unpublished manuscript by Fred C. Driver, dated September 17, 1947.

b/ Of the 20% infected on the preceding retest in Minnesota, 4% were allowed to retain reactors.

9/ This analysis was not one of the main objectives of the study, and was made either from secondary sources or in the field offices while the data for the main study were being collected. This explains the appearance of numbers of records different from those appearing elsewhere in the study.

sample, Minnesota, Michigan, and Pennsylvania, were studied.[10/]

Sixty-one percent of the infection observed on a given test appears to have originated in previously clean herds, as opposed to 22% which originated in previously infected herds. (The remainder are accounted for as Suspects and as herds having no records on the preceding test.) The observations of the veterinarians are thus apparently quite accurate.

While no reason for this situation can be adduced from the data available here, it seems reasonable to postulate that the system of following up area tests is, in part at least, responsible. When an area test is made, and the herds are classified as clean or infected, the followup testing is concentrated on the infected group. The infection in that group is brought under control, while the "clean" herds are left virtually unattended, or, at best, are retested at less frequent intervals. Infection in the previously clean herds may thus be allowed to gain a foothold.

5. Number of animals eliminated in eradicating Bang's disease infection from a herd. One of the major objectives of this study was to ascertain the number of animals that must be eliminated in the process of eradicating infection. This implies an efficiency concept, involving a minimum number of animals eliminated for a maximum degree of control at a minimum cost. Information bearing directly on this question is not available. Cost data have not been collected, and a much more exact description is needed of control results following various levels of elimination at various levels of initial infection than is now available. The best that can be done with available data is to describe the actual numbers of animals eliminated from sample

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10/ North Carolina is also on an area test basis, but the state is accredited as a Bang's-free area. The infection rate is so low that little information on this point is provided by the North Carolina data.

herds of varying sizes and levels of initial infection. This reduces the field of investigation to herds managed on a test and slaughter basis, since these are the only ones from which it is reasonably sure that reactors were eliminated. Vermont and Louisiana, having few herds on test-and-slaughter, could not be included in this phase of the study. Table 7 gives the total number of reactors found on all tests, from the first report that the herd was infected to the final report that it was clean. Since all the herds included in this tabulation were on a test-and-slaughter program, the number of reactors presumably equals the number of animals eliminated. 11/

Table 7. Average Number of Animals per Herd Eliminated in Eradicating Bang's Disease Infection from a Sample of the Herds of Eight Selected States, 1947.

Number of Reactors on Initial Test	Number of cows per herd									
	10-29		30-49		50-69		70 or more		All herds	
	No. of Herds	Ave. No. Head Eliminated	No. of Herds	Ave. No. Head Eliminated	No. of Herds	Ave. No. Head Eliminated	No. of Herds	Ave. No. Head Eliminated	No. of Herds	Ave. No. Head Eliminated
1-3	607	1.5	143	1.5	37	1.4	36	1.6	823	1.5
4-6	146	4.9	36	5.1	17	4.6	11	4.5	210	4.9
7-9	92	7.9	31	7.9	7	8.6	4	7.7	134	7.9
10-18	63	11.9	43	13.2	15	13.3	16	15.2	137	12.9
19 or more	2	24.5	12	20.8	14	25.3	28	40.2	56	31.8
All herds	910	3.4	265	5.5	90	8.3	95	15.9	1360	5.0

The relationships here appear to be about the same as those found in the tabulation of number of tests required to clean a herd, i.e., the number of head eliminated rises both with size of herd and number of reactors on the initial test. The average number of head removed, over all herd sizes and rates of initial infection, was five. It is important to note that the

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11/ The only known exception is Minnesota. See footnote b/ Table 6, above.

elimination rate is high, this, of course, being the reason for the difficulty in carrying out a test-and-slaughter program of control.

6. Regression Analysis. Another primary objective of this analysis was the development of prediction equations. In such equations the effects of several easily measured characteristics can be combined, and their total effect upon another variable, of which a prediction is desired, can be estimated. Unlike the tabular analyses given above, the regression type of analysis which follows can be used to get a measure of the reliability of the results. Wide variation in sizes of herds from test to test, and in intervals between tests, made necessary the use of individual herd-tests as the units of observation.

The model of one of the regression equations to be developed was

$$R_2 = a + b_1 R_1 + b_2 S_1 + b_3 T_\Delta + b_4 H_1 + b_5 H_\Delta + b_6 N$$

where:

R_2 = number of reactors on the test following the test upon which R_1 reactors were discovered.

R_1 = number of reactors on a given test. (To designate the two tests conveniently, say that R_1 reactors were found on the "first" test, and R_2, on the "second.")

S_1 = suspects on the "first" test

T_Δ = time in days between "first" and "second" tests

H_1 = initial herd size less R_1

H_Δ = change in herd size (not due to slaughter) between the "first" and "second" tests

N = number of the test among all tests of the herd

a and b's are constants computed from the data

The test-and-slaughter herds of nine of the ten sample states were selected for an analysis of this kind. The analysis here also was confined to test-and-slaughter, since this is generally considered to be the most effective control method. Louisiana, which has not had a test-and-slaughter program

in effect for several years, was not included in this part of the analysis. A prediction equation for the other nine sample states can be set up from the values given in Table 8, to predict the number of reactors on a given test from certain data obtained from the previous test.

In this analysis, the following restrictions were placed on the data: (i) herd tests showing no reactors were omitted; (ii) herd tests were omitted unless a previous test had been made within the preceding twelve months.

From Table 8, it is apparent that, although statistical significance can be attached to some of the predictors in practically all states, the practical value of predictions would be low. The coefficient of determination, (R^2), was as great as .40 in only three states. This means that only in those states was the variance in the original data reduced by as much as 40% by using all the given predictors.

Examination of the results of the Florida and North Carolina analyses indicated that T_Δ and N were contributing little, so they were dropped from subsequent prediction equations.

Table 8. Multiple Regression Analysis of Herd Tests for Bang's Disease in Nine States, 1947. [a]

State	Multiple regression coefficients							Standard errors of partial regression coefficients						[b] Coef. of det.
	a	b_1 (R_1)	b_2 (S_1)	b_3 (T_Δ)	b_4 (H_1)	b_5 (H_Δ)	b_6 (N)	s_{b_1}	s_{b_2}	s_{b_3}	s_{b_4}	s_{b_5}	s_{b_6}	R^2
Fla.	.710	.112	.492	.002	.004	.050	-.053	.029	.092	.004	.005	.018	.047	.440
N. C.	.709	.097	.504	.003	-.005	.032	-.005	.022	.063	.002	.003	.007	.015	.208
Ill.	.911	.054	.194	[c]	-.001	.067	[c]	.027	.078	[c]	.005	.021	[c]	.074
Mich.	.329	.150	.277		.017	.138		.028	.088		.007	.018		.275
Minn.	.883	.165	.136		.010	.039		.033	.079		.006	.019		.132
Mont.	.299	.266	-.064		.012	.064		.022	.087		.006	.018		.718
Pa.	.204	.080	.112		.005	.156		.038	.104		.005	.023		.191
Tenn.	.837	.129	.396		.013	.034		.026	.077		.004	.014		.191
Vt.	.385	.430	.213		.003	.188		.051	.092		.016	.025		.451

[a] The model regression equation is

$R_2 = a + b_1 R_1 + b_2 S_1 + \ldots b_6 N$. The values given in this table are used in prediction equations for all states as follows. Florida is given as an example:

$$R_2 = .710 + .112 R_1 + .492 S_1 + .002 T_\Delta + .004 H_1 + .050 H_\Delta - .053 N$$

The coefficients are computed from all herds and represent average values. To the extent that the average conditions hold, the equation can be used on individual herds. The values of R_1, S_1, etc. for the given herd are inserted, and the equation is solved for R_2. The standard errors are measures of variability in the data. The greater the variability with respect to a given regression coefficient, the less valuable as a predictor is that coefficient. It can be roughly stated that if the regression coefficient is twice as large as its standard error, the chance that the computed regression coefficient measures a relationship resulting from mere sampling variation is only about one in twenty. The larger the regression coefficient with respect to its standard error, the smaller this chance becomes.

[b] R^2, the coefficient of determination, is a measure of the percent of variability in the data which is accounted for by use of the given predictors. (Note the difference between R^2, the coefficient of determination, and R_2, the number of reactors.)

[c] T_Δ and N, since they appeared on the basis of the Florida and North Carolina computations to contribute so little to the analysis, were dropped from the analysis in the remaining states.

The most consistently significant predictors of R_2 were R_1 and H_Δ, the number of reactors on the previous test, and the change in herd size.

The small sizes of R^2 and the regression coefficients suggest, however, that, despite their statistical significance, they are of little practical importance.[12/] The regression coefficients of several of the predictors of R_2 are significantly different from state to state. This strengthens the belief that these variables are not the ones chiefly responsible for the variations in R_2. The data are not of a nature which would permit the measurement of other factors which might be useful as predictors; substantially all of the available data are used in this analysis. Account cannot be taken of the important factor of management.

The data, exhibiting such wide variability, were not used to set up other prediction equations. It is clear from the foregoing discussion that the "predictors" have little practical value in prediction.

In summary, it can be said that the regression analysis is not promising. It seems clear that there is a fairly consistent tendency for the number of reactors to be large in herds which a previous test has shown to have large numbers of reactors and suspects. There is likewise a positive relation between both size of herd and change in herd size, and number of reactors. These relationships are all small, however, and the prediction equation developed from the data is of less practical value than had been hoped.

12/ There must be no confusion between statistical and practical significance. Statistical significance measures the probability that the sample accurately represents the population from which it is drawn; it tells nothing about the practical importance of the relationships described. Thus, if an unimportant relationship exists in the population, and it is measured well by the sample, there can be high statistical significance in the results despite the absence of any practical significance.

Section III. Analysis of Tests of Individual Cows in Michigan.

In this section, attention is directed to a detailed study of individual cow tests, rather than to the herd tests analyzed in the preceding section. Since relationships of such limited value came from the analysis of herd data of the ten sample states, it was felt that another promising line of approach lay in analyzing more intensively the records of a smaller area, say one state. This would make possible the analysis of tests of individual cows, a possibility which, because of the magnitude of the task, could be no more than briefly considered in an area as large as ten states. Michigan was selected for such a study.

A type of problem inherent in an analysis of herd aggregates, but avoided when individual cows are considered, is stated as follows: "Actually, a farmer might have the same number of cows on two consecutive tests, but in the second test he might have any number of cows new to the herd. It is believed that if this actual change in cows could be introduced into the analysis the H_{Δ} coefficient could be increased considerably."[13/]

To trace the course of the disease, it was useful to study only herds which had been tested several times within a fairly short period. An arbitrary decision was made to use only those herds which had been tested four or more times within two years, and for which the first two of the four tests were within six months. The four tests within two years did not need to be the first four herd tests. For example, a herd may have been tested ten times over a period of fifteen years, but the first six tests may have been scattered over the first thirteen years. In such a case, the effect

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13/ Report of Progress on Cooperative Projects, Institute of Statistics of the University of North Carolina and the Bureau of Agricultural Economics, Section III, p. 10, mimeographed, February 1949.

of one test may have been lost before the next one was made. It is easy to visualize cases in which each of these tests would be a "first" test, in the sense that it affected mostly new cows brought into the herd since the last test. This difficulty, of course, became worse the longer the interval between tests. Any sequence of four tests, occurring within two years, the first two of which tests were within six months, was therefore used.

Taking all eligible records in the area test region (roughly the southern half of Michigan) yielded about 1,000 records. By selecting alternate records from this group the actual number of schedules to be analyzed was cut to 503, thus halving the computational burden without seriously reducing the information obtainable. These 503 records have provided the raw material for most of this part of the study. The only exception was that large herds were considered sufficiently important to warrant separate study. There were so few herds of over 30 head that, for a special study, all of them were used. The large herds, like other herds, had been approximately halved by selecting alternate records. For general studies, involving "all herds," the 50% sample was used. For the special investigation of large herds alone, however, all the large herd records were used.

The distribution of herds in the sample, by size of herd, is shown in the following table.

Table 9. Distribution of Herds by Size of Herds.
503 Sample Herds, Michigan, 1948.

Size of Herd (No. of head)	Number of Herds	Average Number of Cows per Herd
Less than 10	96	7
10-19	240	14
20-29	132	22
30 or more	35	42
All herds	503	17

To the independent variables used in the herd aggregate analysis, Number of Steers was added for the present study. Steers were not ordinarily tested for Bang's disease, and observation of several herd records seemed to suggest the possibility of a relationship between infection and the number of these untested animals present on a farm. Another addition to the analysis was the use of infection "Phase" within herds. If a herd had been tested four times, for example, the herd record was broken into three "Phases," consisting of Tests 1 and 2, 2 and 3, and 3 and 4, labelled Phase 1, 2, and 3, respectively. Within each Phase, there were, then, a first and a second test. These are the first and second tests to which reference is made in Tables 7 and 8. They correspond to the "first" and "second" tests upon which R_1 and R_2 reactors were observed, as reported in the analysis of the ten-state sample. Simple correlation coefficients were computed as a first step in setting up a multiple regression analysis and developing a prediction equation. The r's are shown in Table 10.

Table 10. Correlation Coefficients. 503 Michigan Herds, 1948

Variables	Correlation coefficients (r's): Numbers in parentheses at tops of columns identify variables similarly numbered at left.								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) No. of Reactors: 2nd Test	1.00	.28	.28	.03	.26	-.05	-.01	.19	-.08
(2) No. of Reactors: 1st Test		1.00	.22	.10	.35	-.44	-.21	.11	-.34
(3) No. of Suspects: 1st Test			1.00	.04	.33	-.26	-.17	.27	-.12
(4) No. of Steers: 1st Test				1.00	.21	-.07	-.04	.10	-.01
(5) Orig. Herd Size: No. of cows					1.00	-.34	-.09	.86	-.09
(6) Change in Herd Size: 1st to 2nd Test						1.00	.20	-.12	.21
(7) Interval 1st to 2nd Test							1.00	-.19	.35
(8) No. of Identical Cows: 1st and 2nd Tests								1.00	-.07
(9) Phase Number									1.00

From this table, it appears that important relationships are not being discovered. Even the number of identical cows carried over from test to test seems to bear little relation to the other variables. While it does not seem to be worthwhile to proceed with prediction equations on the basis of these data, one equation was set up and is given below to demonstrate the relationships.

$$R_2 = -.199 + .240\,R_1 + .387\,S_1 - .063\,A_1 + .070\,H_1 + .148H_\Delta + .006T_\Delta - .084B + .076P$$

Standard errors of regression coefficients	.017	.033	.013	.009	.009	.003	.011	.047

where

R_2 = number of reactors on the test following the test upon which R_1 reactors were discovered.

R_1 = number of reactors on a given test. (R_1 reactors on "first" test in a phase; R_2, on "second.")

S_1 = suspects on "first" test.

A_1 = number of untested steers in herd on "first" test.

H_1 = initial size of herd, less R_1.

H_Δ = change in herd size (not due to slaughter) between "first" and "second" tests.

T_Δ = interval between "first" and "second" test.

B = number of identical cows in "first" and "second" test.

P = phase number (see page 30 for complete definition.)

The multiple correlation coefficient is .53, and the coefficient of determination, $(.53)^2$ is .28. Although statistically highly significant, these value, like those computed for the ten-state sample, are of limited practical importance.

From a more homogeneous group of data, the herds of 30 or more cows, the r's were again computed. Results are given in Table 11. They are no better than those for all herds. No prediction equations based on these data were

computed.

Table 11. Correlation Coefficients. 64 Michigan Herds of 30 or More Head, 1948.

Variables	Correlation coefficients (r's): Numbers in parentheses at tops of columns identify similarly numbered variables at left.								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) No. of Reactors: 2nd Test	1.00	.21	.20	-.06	.14	.06	-.03	.13	-.10
(2) No. of Reactors: 1st Test		1.00	.27	-.01	.20	-.41	-.21	-.03	-.37
(3) No. of Suspects: 1st Test			1.00	-.06	.20	-.23	-.20	.19	-.08
(4) No. of Steers: 1st Test				1.00	.07	.02	.05	-.13	.07
(5) Orig. Herd Size: No. of Cows					1.00	-.39	-.11	.75	-.15
(6) Change in Herd Size: 1st to 2nd Test						1.00	.16	-.05	.21
(7) Interval: 1st to 2nd Test							1.00	-.21	.28
(8) No. of Identical Cows: 1st and 2nd Tests								1.00	-.14
(9) Phase Number									1.00

The results of the tabular analyses, the low correlation coefficients, and the large errors associated with the prediction equations, all indicate that the available data are not sufficient to produce the refined and accurate results desired. Large quantities of data are available, but they consist only of test records, showing for each herd (i) a list of the animals tested, with (ii) the test reaction of each, and (iii) the date of each test. Some gross relationships have been worked out, but it appears that the real causal factor underlying control of the disease is not frequency or number of tests, or any of the other variables of which measurements are available in this study; all indications point to herd management.[14/] The purpose of this project was not, of course, to find other variables which were more important than management. The purpose was, rather, to determine the extent to which data already

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14/ The factor called "management" is actually, of course, a composite of factors which would have to be identified and measured separately before "management" data could be used in predictions of the kind sought here. "Management" includes such specific items as use and possession of sanitary facilities, isolation of reactors, etc.

available in the field offices of the Bureau of Animal Industry could be used to predict the minimum time and effort required to clean up herds. When data are collected for one purpose, they are not always easily adapted to another use.

Section IV. Analysis of Jersey County, Illinois, Survey.

Another objective of this study was to measure the effects of management practices on control of Bang's disease. The importance of this factor has been suggested repeatedly at several previous points in this report.

The field office data used in the preceding analysis did not include information on management. To supply such information, a special survey schedule was prepared for use in conjunction with an area test of Jersey County, Illinois. All herds in that County were tested for Bang's disease in the summer of 1947, and the field veterinarians filled in the survey schedules for each herd at the time the test was made. About one thousand herd records were made available in this way. A sample of the schedule is shown as Appendix Figure 2, page

Quality of the Jersey County data was not high. A detailed analysis has therefore not been possible because the data would not support it.[15/] There was a five-year interval between the pre-vaccination period and the time of this survey. Fading memories of the respondents consequently made it difficult to get accurate information. Also, a rumor was circulated that the veterinarians were getting information to be used as a check on income tax returns. The result was a mass of data which were inconsistent in certain important items, and entirely lacking in others. These observable weaknesses cast grave doubt on the validity of the remaining data for which no check was readily available.

15/ The apparent inadequacy of the data was pointed out to Dr. N. H. Howlett, Inspector in Charge of the Illinois Bureau of Animal Industry Office, who directed the field work of the survey. His comment, in a letter to Dr. C. K. Mingle, dated December 15, 1948, included the following, "....the number of questions asked on the questionnaire covering pre-vaccination and post-vaccination status of the herds may have been too great for this type of survey." Furthermore, "The pre-vaccination period was five years from the survey time and many of the owners did not remember the conditions existing on their premises at that time, or possibly they had acquired the property recently. Therefore many of the questions had to be left blank." Also, "In Table No. (13) the figures are inclined to be inaccurate due to incorrect reporting by the farmer."

Tables 12 - 15 summarize the 986 herd records, with respect to (i) Disposition of Reactors, Suspects, and Aborters; (ii) Sources of Herd Replacements; (iii) Some Herd Management Practices; and, (iv) Vaccination of Calves at Beginning of Program and in 1947.

Of the 986 herd records, 146 contained insufficient data for tabulation. The tables are, therefore, based on the remaining 840 records, many of which also were deficient in varying degrees. The discussion below refers to Tables 12 through 15 which appear on pages 38 through 41 of this report.

Table 12. Disposition of Reactors, Suspects and Aborters. There seemed to be a tendency for the large herds to report heaviest infection: 53% (29 in 55) of the larger herds were reported as having reactors and/or suspects, as compared to 11% (31 in 284) of the smaller herds. Furthermore, among infected herds, the abortion rate seemed higher in the large herds. Thirty-two percent (29 in 92) of the large herds reported aborters, as compared with 19% (13 in 70) of the small herds. Isolation of suspects, reactors, or aborters, was almost never reported for herds of any size. The seemingly more healthful condition of small herds will receive further comment below, as will the failure to report isolation of diseased animals.

Table 13. Source of Herd Replacements. More than half of the herds were reported to be self-contained, i.e., they raised their own replacements. The smallest-sized herds approached most nearly to complete self-containment. The large herds were not only less self-contained, but they also, according to the data, imported fewer head, proportionately, than the small herds. In the group of 284 smallest herds, averaging 2 head per herd, 78 importing herds imported 127 head as replacements for the total of 156 head, a replacement rate of about 85%. During the same period, the 27 largest importing herds, averaging 35 head per herd, imported 227 head to replenish the total of 945

head, a rate of 24%. The rate of importing replacements thus appears to have been more than three times as high in the small herds as in the large herds. If the large herds neither imported nor were self-contained, one possible conclusion would be that they were not being maintained. This is supported by the following tabulation of mean sizes of identical herds in 1942 and 1947.

Number of Cows per Herd Classified by Herd Size in 1947	Mean Herd Size	
	1942 (No. of head)	1947 (No. of head)
Less than 5	2	4
5 - 9	7	9
10 - 14	12	12
15 - 29	20	18
30 or more	45	35

On the schedules there was a space for reporting cattle "exported" from the herds. Not one herd, of the 986 reported, showed any exporting. This is a noteworthy situation. Where did the 938 head reported to have been imported into Jersey County herds come from? They could, of course, have all been brought in from outside the county, but this seems unlikely. There were, in all likelihood, many instances of transfers among herds within the county. Since the records presumably cover all herds, these transfers should have appeared.

Table 14. Herd Management Practices. The biggest source of difficulty here was failure to define terms precisely. What were "good," as opposed to "poor" or "average" sanitary facilities? Did all the field men have the same standards in mind when they reported these items? It was practically impossible to distinguish between a negative answer and a failure to report on items like, "Do you have maternity stalls?" Further questions arose in

treating the reports of isolation of "known or suspected sick animals." There was no way of knowing how many field men included animals sick with Bang's disease. In any event, why did so many report isolation here, as compared to the negligible numbers reporting it in Table 12?

It is generally believed that large herds are better managed than small herds. This has shown up repeatedly on other studies, and is suggested by the data in Table 14. But it is not consistent with the data shown in Table 12, in which higher infection and abortion rates are found in the larger herds.

Table 15. Number of Calves Vaccinated. About twice as many calves were being vaccinated in 1947 as in 1942. Here again, assuming that vaccination is a good management practice, it appeared from the data that the larger herds were inferior to the smaller, for the larger herds reported smaller proportions of animals vaccinated.

These four tables showed enough inconsistencies, and the original schedules were in such poor condition, that it was soon decided to abandon the Jersey County material. This resulted from the unavoidable difficulties encountered in the field, as mentioned in an early paragraph of this section.

Table 12. Disposition of Reactors, Suspects, and Aborters.

Jersey County, Illinois, 1947.

Number of Cows per herd	Number of herds	Disposition of Reactors or Suspects			Disposition of Aborters		
		No. of herds reporting reactors or suspects	No. of herds reporting removal of reactors or suspects from herd	No. of herds reporting isolation of reactors or suspects within herd	No. of herds reporting aborters	No. of herds reporting removal of aborters from herd	No. of herds reporting Isolation of aborters within herd
Less than 5	284	31	15	1	9	3	0
5-9	191	39	26	9	4	0	0
10-14	162	40	23	0	11	2	0
15-29	148	63	39	1	16	6	6
30 or more	55	29	22	0	13	3	1
Not reported	146	--	--	-	--	-	-
TOTAL	986	202	125	11	53	14	7

Table 13. Source of Herd Replacements.

Jersey County, Illinois, 1947.

Number of Cows per Herd	Number of Herds	Sources of Herd Replacements				
		From within, i.e, Herd is self-contained	From without, i.e, imported from other herds			
			Number of herds		Number of animals	
			Reporting	Importing only from Bang's-free sources	From Bang's-free sources	From untested sources
Less than 5	284	206	76	2	6	121
5-9	191	111	73	4	6	158
10-14	162	94	63	2	4	204
15-29	148	71	67	8	23	189
30 or more	55	28	27	0	0	227
Not reported	146	--	--	-	-	-
TOTAL	986	510	306	16	39	899

Table 14. Herd Management Practices. Jersey County, Illinois 1947.

Number of Cows per Herd	Number of herds	General Sanitary Facilities				Maternity Stalls						Disinfection				Isolation of known or suspected sick animals			
		Good	Av.	Poor	Not Rptd.	Possession		Use											
		No. of herds	No. of herds	No. of herds	No. of herds	No. of herds with	Not Rptg.	Reg.	Occas.	Never	Not Rptg.	Reg.	Occas.	Never	Not Rptg.	Reg.	Occas.	Never	Not Rptg.
Less than 5	284	49	165	22	48	105	179	98	2	117	67	58	1	130	95	102	0	111	71
5 - 9	191	42	118	17	14	70	121	66	1	85	39	28	0	105	58	74	0	85	32
10 - 14	162	31	103	14	14	66	96	65	1	75	21	32	0	93	37	69	1	75	17
15 - 29	148	40	88	8	12	63	85	60	4	61	23	34	2	77	35	62	2	67	17
30 or more	55	22	26	1	6	31	24	27	2	19	7	14	2	27	12	27	1	19	8
Not Reported	146	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	986	184	500	62	94	335	505	316	10	357	157	166	5	432	237	334	4	357	145

Table 15. Numbers of Calves Vaccinated at Beginning of Testing Program in 1942, Compared with Numbers Vaccinated in 1947. Jersey County, Illinois

Number of Cows per Herd	Number of Herds	Calves Vaccinated (Ave. no. per herd)		Calves left Unvaccinated (Ave. no. per herd)	
		1942	1947	1942	1947
Less than 5	284	1.3	2.6	1.0	.9
5 - 9	191	1.7	3.3	1.2	1.8
10 - 14	162	1.9	3.8	1.5	1.5
15 - 29	148	2.7	5.3	1.4	2.7
30 or more	55	4.6	10.6	2.0	1.0
Not reported	146	-	-	-	-
TOTAL	986	2.5	4.3	1.4	1.8

Section V. Conclusions and Recommendations.

The following conclusions emerge from this study:

(i) Existing data are qualitavely inadequate to provide detailed and precise information on the questions raised in the objectives of the study.

(ii) One of the chief reasons for the inadequacy of existing data is probably the lack of information on management practices. Until this information is available, no final statement can be made concerning its importance. Several indications from the study itself, however, in addition to the expert opinion of all the veterinarians consulted, and a priori reasoning, unite in pointing to management as the crucial factor. No measure of management having been available, it is not surprising to find a lack of precision in the results of this study.

(iii) Despite difficulties, some interesting tendencies have been suggested by the study:

(a) A definite warm-weather seasonal peak occurs in the infection rate.

(b) The seasonal peak of infection is significantly different from state to state.

(c) The median herd was clean on the second retest, within three months of discovery of the infection.

(d) The average number of animals per herd eliminated in achieving control of the disease varied from three in herds of 10-29 head to seventeen in herds of 70 or more head.

(e) In the three states (Michigan, Minnesota, Pennsylvania) having adaptable data, over 60% of the herd infection observed on a given test occurred in herds reported clean on the previous test.

On the basis of experience gained in this study, the following observations and recommendations are advanced.

Management data, possibly the most significant factor explaining efficiency of Bang's disease control, can probably not, under present conditions, be obtained in the course of the routine operation of the Bureau of Animal Industry testing program. This is evident from a careful analysis of

available records, and from the disappointing results obtained (under conditions probably considerably better than could be regularly duplicated within the existing framework) from the Jersey County, Illinois, survey. Several questions are at once suggested:

(i) Should the present organization be changed in such a way that it can obtain the needed data?

(ii) If it should be changed, how?

(iii) If not, what are the alternatives?

These questions will be briefly considered from a technical standpoint. Administrative considerations are, of course, important, but they are obviously outside the scope of this report.

It does not appear advisable, on the basis of this study, to recommend any far-reaching changes in the operation of the present Bang's disease program. The existing records, as far as can be determined, seem satisfactory for the administrative purpose for which they were devised. To make the records useful in the type of research study attempted in this project would necessitate expanding them to such a degree that the collection of the data by existing personnel in the course of operation of the regular testing program appears impractical. Assuming the desirability of getting data suitable for research study, two possibilities are suggested: (a) to expand the field staff to enable it to cope with the problem of getting the additional data, or, (b) to gather the data in another way. Adoption of the first alternative would mean that the tail would be wagging the dog. The logical course of action seems to be to find ways of getting the needed research data outside the regular testing activities of the Bureau of Animal Industry.

Two alternatives present themselves: (a) a controlled experiment, (b) a survey specifically designed to get the desired information.

An experiment would produce definite answers, but at a very high cost. While the similarity of Bang's disease to foot-and-mouth disease is by no means perfect, some indication of the cost of a large-scale experimental program can perhaps be obtained by an examination of the proposals being made to set up such a program for the study of foot-and-mouth disease. Present plans are to obtain an island off the coast for a laboratory, and to spend an estimated thirty million dollars on the project. 16/

It is felt that an adequate Bang's disease study could be made much more cheaply. Data for the study could be obtained from a survey conducted for the sole purpose of gathering such data.

Such a survey now is feasible, from the technical standpoint. The method has been successfully used in countless instances to get data of greater complexity than that which would be necessary here. Excellent lists of herd owners are available in the present Bureau of Animal Industry files, thus making possible the use of highly efficient list sampling methods. Veterinarians who personally know the individuals who would be selected for study could greatly reduce one of the usually difficult problems in the use of list samples, i.e., finding the people whose names appear on the lists.

The survey would offer advantages in the form of lower cost and closer representation of actual field conditions. It would also be more efficient in picking up changes in practices by farmers in the field. There are two factors influencing farmers' actions in technical matters: (a) the level of available technical knowledge, and (b) the degree to which farmers make use of such knowledge. It may be of little importance in explaining the control of a disease to know that Treatment A will control the disease better than Treatment B, if farmers refuse to adopt Treatment A. Consequently, any

16/For details, see Control of Foot-and-Mouth Disease, Senate Document 211, 80th. Congress, 2nd. Session; and Second Deficiency Appropriation Bill, 1949, Report No. 401, 81st. Congress, 1st. Session.

movement of farmers toward adoption of Treatment A may be of utmost importance in a study of the control of the disease. The degree of persistence of farmers in using Treatment A, once it is adopted, is likewise of great significance.

These are the sorts of items which are more difficult to cover relevantly in an experiment than in a survey. Their pertinence to a study of Bang's disease is obvious. Test-and-slaughter is acknowledged to be the most efficient method of controlling infection, but, because of its cost to the farmer, it is often not followed closely. In many states, also, farmers move from test-and-slaughter to test-and-segregation, to some other program, and perhaps back to test-and slaughter. If there is any pattern to such movements, knowledge of it would be useful. This very movement from program to program may, in fact, be one of the components in the factor we have been calling "management."

The survey and the controlled experiment are, of course, not mutually exclusive. In setting up a long-range program, it might prove desirable to conduct the survey first, as a means for marking out the areas needing further study, and then to design an experiment to get information on some of these clearly defined points.

It has been suggested by veterinarians that the characteristics of the disease, and hence the nature of optimum control measures, may be different in the periods of "upswing" (increasing virulence) and "downswing" (decreasing virulence). Some thought was given to this problem, but no satisfactory test of the hypothesis could be devised because a satisfactory objective test of virulence does not seem to exist. Consideration of this question will therefore have to be postponed until the bacteriological problem has been worked out.

There are, in addition to the measurement of virulence, at least two other technical problems for which a solution is needed before a wholly adequate analysis of factors affecting control can be developed. These,

transmission of the disease by the bull, and rate of agglutinin disappearance from blood of vaccinated animals, have been mentioned above. (See pages 4 and 5.)

The observations and recommendations so far made have been of a rather general nature. They can be summarized and made more specific as follows:

(i) Data for a detailed study of Bang's disease control can probably best be obtained from a survey specifically designed to get such information.

(ii) The form of such a survey will, of course, be determined by the objectives of the study. If the objectives remain substantially as they were in this study, however, the schedule used in the Jersey County study could provide a useful point of departure. That schedule, most of all, needs to be made quantitative. For example, instead of asking, "Did you use maternity stalls occasionally, frequently, or constantly during the past year?" the question could be worded, " How many of your cows calved in maternity stalls in the past year?"

(iii) A separate survey is needed for each state, because the diversity among states makes general statements covering several states practically meaningless. The diversity among states is of two forms: (a) institutional and (b) biophysical. An instance of the institutional diversity is seen in the wide differences in state laws governing control; of the biophysical, in the significant differences in the seasonal peaks of infection observed between states.

These recommendations are in no sense final, but if they are followed, there is reason to hope and expect that a valuable increase in the latitude and precision of the conclusions of this study will follow.

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Appendix Table 1. Percent of Herds Clean After Specified Numbers of Tests for Bang's Disease. Ten States, 1947.

State	Number of Herds	Number of Test after Which Herds were Reported Clean								
		1	2	3	4	5	6	7	8 or more	Totals
		(Percent of herds in each state)								
Florida	171	40	12	13	9	3	4	5	14	100
Illinois	196	45	15	10	11	7	5	2	5	100
Louisiana	81	41	26	17	5	5	2	3	1	100
Michigan	256	54	15	12	5	2	4	3	5	100
Minnesota	219	55	11	13	9	5	3	2	2	100
Montana	144	64	11	11	3	1	3	3	4	100
North Carolina	182	44	15	10	8	3	4	2	14	100
Pennsylvania	266	46	11	11	9	5	4	2	12	100
Tennessee	182	41	14	11	9	7	3	4	11	100
Vermont	80	45	24	21	8	0	0	1	1	100
Total number of herds	1777	(856)	(255)	(212)	(138)	(70)	(63)	(48)	(135)	

Appendix Table 2. Percent of Herds Clean After Specified Intervals Following Initial Test for Bang's Disease. Ten States, 1947.

State	No. of Herds	Interval from Initial Test to Report of Herds' Being Clean							
		Less than 3 mo.	3 to 5.9 mo.	6 to 8.9 mo.	9 to 11.9 mo.	12 to 17.9 mo.	18 to 23.9 mo.	24 or more mo.	Totals
		(Percent of herds in each state)							
Florida	171	49	11	5	5	9	4	17	100
Illinois	196	53	13	9	4	7	6	8	100
Louisiana	81	49	11	6	7	7	8	12	100
Michigan	256	61	10	4	3	6	4	12	100
Minnesota	219	63	8	8	5	7	2	7	100
Montana	144	71	6	4	3	5	3	8	100
North Carolina	182	58	8	6	3	5	3	17	100
Pennsylvania	266	50	8	5	5	6	7	19	100
Tennessee	182	52	9	6	8	5	4	14	100
Vermont	80	46	4	1	1	16	10	22	100
Total number of herds	1777	(995)	(161)	(101)	(79)	(120)	(83)	(238)	—

Appendix Table 3. Average Bang's Disease Infection Rates by Years, for a Selected Sample of States Grouped by Region, 1936-1947.[a]

States	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	Aver. Yearly Infection Rate
Colo., Idaho, Wyo.	7.165	5.650	4.087	2.666	2.523	3.902	5.276	6.479	5.469	5.671	5.893	4.404	4.932
Fla. and La.	6.398	4.509	3.285	1.605	1.590	1.615	2.640	3.197	3.080	5.000	5.052	5.992	3.664
Mich., Minn., Wis.	4.670	4.621	3.815	3.313	3.002	2.672	3.503	3.586	4.382	5.056	5.527	4.769	4.076
Montana	5.900	3.847	3.367	2.595	2.710	3.014	4.140	4.416	4.243	4.162	2.662	1.948	3.584
New England States	5.652	4.921	4.568	3.612	3.216	5.588	3.753	4.347	4.215	3.822	3.397	3.397	4.207
New Jersey and Pa.	4.171	4.156	3.652	2.024	3.009	3.011	2.803	2.675	2.862	3.159	2.861	2.843	3.102
N. C. and Tenn.	5.666	3.239	2.488	1.726	1.598	1.433	1.672	1.889	2.738	2.245	2.509	2.374	2.465
Okla. and Texas	6.359	4.222	3.125	1.710	1.986	2.199	2.479	3.385	3.621	4.172	5.184	6.730	3.764
U. S. with Porto Rico omitted	5.676	4.473	3.564	2.570	2.548	2.774	3.369	4.131	4.515	4.873	4.852	4.476	3.985

[a] Data adapted from various issues of the monthly "Summary of Brucellosis (Bang's Disease) Work in Cooperation with the Various States," U. S. Department of Agriculture, Bureau of Animal Industry, Washington.

Figure 1. Sample of Summary Data Card of the Type Which Provided the Major Source of Information for this Study.

T. E. Form 5
(Revised)

U. S. DEPARTMENT OF AGRICULTURE
BUREAU OF ANIMAL INDUSTRY

TUBERCULIN TEST—HERD RECORD

BREED _____ **Station** _____

Owner _____ **Town** _____ **County** _____ **State** _____

DATE OF TEST	NUMBER PASSED		NUMBER REACTED		NUMBER SUSPICIOUS		TOTAL TESTED		METHOD OF TEST	INSPECTOR	REMARKS
	Pure-bred	Grades	Pure-bred	Grades	Pure-bred	Grades	Pure-bred	Grades			

GPO 8—3833

Note: Although titled "Tuberculin Test-Herd Record," this form is also used for recording data on tests for Bang's disease.

Figure 2. Sample of Schedule Used in Jersey County, Illinois, Survey.

Page 1

1. OWNER's NAME AND ADDRESS_____

2. LOCATION OF FARM_____TOWNSHIP_____

3. SIZE OF FARM:_____acres.

4. A. BRUCELLOSIS STATUS (PRE-VACCINATION)
   1. NO. OF REACTORS ON 1942 PRE-VACCINAL TEST_____
   2. DISPOSITION OF REACTORS AND SUSPECTS:
      a. Immediate removal from herd_____
      b. Delayed removal from herd_____
      c. Held in herd
         1. Isolated_____
         2. Not isolated_____
   3. NO. OF ABORTIONS BY YEARS_____
   4. PROCEDURE FOR HANDLING ABORTERS:
      a. Test and immediate removal from herd, if reactors_____
      b. Delayed removal from herd, if reactors_____
      c. Indefinite retention in herd, if reactors_____
         1. With isolation_____
         2. Without isolation_____
   5. NO. OF RETAINED AFTERBIRTHS_____
   6. AVERAGE YEARLY MILK PRODUCTION PER COW FOR DAIRY HERDS; IF RECORDS AVAILABLE_____
   7. DEGREE OF STERILITY OBSERVED IN HERD
      a. High_____
      b. Medium_____
      c. Low_____

5. HERD DETAILS COVERING THE POST-VACCINATION PERIOD FROM 1942 to PRESENT:
   A. Type of cattle
      (1) Dairy_____Predominant Breed_____P.B._____Grade_____
      (2) Beef_____Predominant Breed_____P.B._____Grade_____
   B. Size of herd.
      (1) At time vaccination was started_____
      (2) At present time_____
   C. Nature of herd operations:
      (1) Self-contained _____
      (2) Flying_____
         a. Importing.
            1. No. of animals brought into the herd from outside sources each year_____
            2. Were these always introduced on a brucellosis-free test basis?_____
         b. Exporting.
            1. No. of animals sold into other herds each year_____
   D. Management.
      (1) No. of years herd has been under same ownership_____
      (2) No. of years herd has been under same management_____
      (3) How is herd managed?
         a. Owner?_____
         b. Employee_____
      (4) Sanitary facilities.
         a. General.
            1. Good_____
            2. Average_____
            3. Poor_____
         b. Specific
            1. Maternity Stalls _____
               (a) Adequate or Inadequate_____
      (5) Sanitary Practices.
         a. Maternity Stalls_____
            1. Use.
               (a) Regularly_____
               (b) Occasionally_____
               (c) Never_____
            2. Disinfected after use.
               (a) Regularly_____
               (b) Occasionally_____
               (c) Never_____

b. Isolation of known or suspected sick animals.
1. Regularly practiced_____
2. Occasionally practiced_____
3. Never practiced_____

E. BRUCELLOSIS STATUS (POST-VACCINATION)

1. Number of calves vaccinated by years.
a. 1942_____; b. 1943_____; c. 1944_____; 1945_____;
e. 1946_____; f. 1947_____.

2. No. of calves left unvaccinated during the same years.
a. 1942_____; b. 1943_____; c. 1944_____; d. 1945_____;
e. 1946_____; f. 1947_____.

3. No. of reactors in unvaccinated stock by years.
a. 1942_____; b. 1943_____; c. 1944_____; d. 1945_____;
e. 1946_____; f. 1947_____.

4. Disposition of unvaccinated reactor suspect animals.
a. Immediate removal from herd_____
b. Delayed removal from herd_____
c. Held in herd_____
1. Under isolation_____; 2. Without isolation_____.

5. No. of reactors and suspects at the present time in each year's vaccinated group.
a. 1942_____; b. 1943_____; c. 1944_____; d. 1945_____;
e. 1946_____; f. 1947_____.

6. No. of abortions by years.
a. 1942_____; b. 1943_____; c. 1944_____; d. 1945_____;
e. 1946_____; f. 1947_____.
1. No. occurring in vaccinated animals:
a. 1942_____; b. 1943_____; c. 1944_____; d. 1945_____;
e. 1946_____; f. 1947_____.
2. No. occurring in unvaccinated animals:
a. 1942_____; b. 1943_____; c. 1944_____; d. 1945_____;
e. 1946_____; f. 1947_____.

7. Procedure for handling aborters:
a. Immediate removal from herd_____
b. Delayed removal from herd_____
c. Indefinite retention in herd_____
1. Under isolation_____2. Without isolation_____

8. Average yearly milk production per cow for dairy herds where records are available_____

9. Degree of sterility observed in herd.
a. High_____; b. Medium_____; c. Low_____

10. Have any adults been vaccinated since inception of program?_____
If so, what were the results?
a. Good_____
b. Bad_____
c. No. of abortions in cows vaccinated as adults_____

11. Have male calves been vaccinated in the herd?_____

12. As owner of this herd, what is your opinion regarding the merits of the vaccination program _____
_____
_____

13. Would you make a price differential on a vaccinated animal?_____
If so, approximately how much and which way?_____
_____

14. Are there any swine on the premises?_____
a. If so, how many?_____
b. Are they in close contact with the cattle?_____
c. Has the swine herd ever been tested for brucellosis?_____
If so, give number that reacted_____and total no. tested_____
d. Have you experienced an undue number of abortions in your swine?____
_____

1. No. of sows bred during past year_____
(a) No. of normal farrowings_____
(1) No. of healthy pigs farrowed_____
(2) No. of weak pigs farrowed_____
(3) No. of dead pigs farrowed_____
(b) No. of abortions_____

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