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The microflora of churns and its importance in the deterioration of butter

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THE MICROFLORA OF CHURNS AND ITS IMPORTANCE IN THE DETERIORATION OF BUTTER

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INTRODUCTION

The contamination of butter from churns has long been recognized as a serious problem and this realization has prompted investigators to study its importance under various conditions and to attempt to find methods for its control. Proper pasteurization eliminates the yeasts and molds from cream and reduces the bacterial content to a minimum but recontamination from several sources, principally the piping, pumps and churns, may cancel the good effects of such treatment. The piping and pumps respond readily to treatment with heat or chemicals but the churns, because of their construction, present difficulties which have made it impossible to eliminate them as a source of the contamination of butter.

Butter is ordinarily held for varying periods before being consumed and during this holding the activity of organisms present may result in serious deterioration. Since salt in butter has a restraining action on many organisms, the present tendency toward the manufacture of unsalted and low salted butters emphasizes the importance of controlling the contamination. Previous investigations on churn sanitation have dealt largely with yeast and mold contamination; the greater importance of bacteria in butter deterioration emphasizes the need for extensive investigations on the sources of bacterial contamination of butter and methods for its control.

STATEMENT OF PROBLEM

The work herein reported involved (a) methods for estimating the contamination from churns, (b) the determination of the extent of contamination from churns, (c) a study of the efficiencies of various churn cleaning methods in reducing churn contamination, (d) the effect of contamination from churns on the keeping quality of butter, and (e) a study of the creamery air as a factor in churn contamination.

REVIEW OF LITERATURE

Lund (11) attributed the presence of large numbers of yeasts which he found in pasteurized cream butter to contamination following the pasteurization because, as he had previously shown (10) yeasts were killed by proper pasteurization. He stated that infected churns are an important source of yeasts and molds and that neither treatment which chloride of lime nor with "scalding hot water" were effective in removing the infection. He found that treatment with hot freshly prepared milk of lime along with occasional repacking of stuffing boxes was effective in reducing the yeast count on the butter to less than 10 per ml. In a later study (12) on 337 lots of Canadian butter Lund found the majority of the mold counts ran below 10 per ml. while the majority of the yeast counts were 1000 per ml. or over. He stated that "where extensive contamination by yeasts occurs probably even heavier contamination by bacteria takes place at the same time." In a more recent article (13) Lund gave data on 537 lots of "Storch negative" creamery butter which showed that over 50 per cent of the lots had yeast and mold counts between 1000 and 99,000 per ml. His investigations led him to conclude that where high yeast counts were the regular thing, nine times out of ten the trouble was due to a yeast infected churn. It is also of significance that he found a distinct correlation between high yeast counts and high bacterial counts in butter made without starter.

The work of Gregory (2) shows that the churn may be an important source of contamination and that ordinary cleaning methods do not eliminate their infection. He determined the amount of infection remaining after various cleaning treatments by adding about 200 gallons of water to the churn, revolving it in high gear for 30 minutes and determining, by plate counts, the number of organisms added by the churn. The churns were used every day except Sunday and each trial was run immediately after churning. The methods used and results obtained from six trials with each method are as follows:

In method A the churn was filled about one-fourth full of water at 180° to 190°F., 2½ pounds of "Wyandotte" were added, the churn revolved in high gear for 10 minutes and then drained and dried. Just before the next churning the churn was rinsed by filling it about one-third full of hydrant water and rotating in high gear for five minutes. This method gave a great variation in the results, indicating that it is unreliable. The number of organisms that would have been added to the cream by this method averaged 278,148 per ml., 10,583 of which were acid tolerant (largely yeasts and molds).

Method B was the same as method A except that the churn was given a preliminary rinsing with 40 gallons of water at 160° to 170°F. for five minutes. The variations in results were not as great as with method A and the additional washing effected a 38 per cent reduction in the total number of microorganisms and a 42 per cent reduction in the acid tolerant organisms as compared to method A.

Method C differed from method B in that just before churning about 40 gallons of water at 180° to 190°F. and about one pound of "Wyandotte" were added and the churn rotated in high gear for five minutes and then drained. It was then filled one-fourth full of water at about 60°F. and rotated for three minutes and drained. This method gave much more uniform results than either of the two previous ones and resulted in an 82 per cent reduction in total number of microorganisms and a 60 per cent reduction in the acid tolerant ones as compared to method B.

Method D differed from method C only in the addition of two ounces of commercial germicide to the cold water rinse just before churning. The counts secured with this method were not only low, but exceedingly uniform throughout. With it an average of 9,666 microorganisms per ml., 1,433 of which were acid tolerant, would have been added to the cream.

In method E the churn was washed as in method B and immediately treated with a suspension of two pounds of hydrated lime in four gallons of water. The churn was rotated a few turns in order to distribute the suspension over the interior and then allowed to stand with the door open and without draining until the following day when it was given two good rinsings with water at about 60°F. just before churning. The results secured with this method were unsatisfactory, the numbers of the microorganisms in the rinse water being only slightly less than with method B. The only advantage of the lime was that it improved the odor of the churn.

In method F hot water was substituted for the first of the last two cold water rinses in method E. With method F there was an 89 per cent reduction in the total number of organisms and a 72 per cent reduction in the acid tolerant ones as compared to method E.

It is evident from the above data that with ordinary methods of washing churns considerable numbers of microorganisms are added to the cream during the churning process and that even with careful cleaning methods the churns are far from sterile. The far greater numbers of bacteria than of acid tolerant organisms, which are largely yeasts and molds, emphasizes the importance of the former.

Bouska and Brown (1) state that the churn may be an important source of yeasts and Oidia in pasteurized cream butter unless it is carefully treated. They state that the working of butter added more yeasts than the churning because of the organisms forced out of the fixtures of the workers during the working process. They found that they could predict, with a fair degree of accuracy, the keeping quality of butter from the yeast and mold counts because the butter with high counts generally did not keep well; no data to support this contention were presented.

Stiritz (22) suggested that yeast and mold counts should be used as an index to the whole buttermaking process rather than to the pasteurization only because of the possibilities for contamination following pasteurization. He mentioned the churn as an especially important source of yeasts and molds.

The importance of churn sanitation in relation to the keeping quality of butter is emphasized by the work of Shutt (20). From a study of 21 samples of pasteurized cream butter held in cold storage at 10°F. for about six months it appeared that butter made from pasteurized cream churned with the least possible contamination held its grade to a better advantage than butter made from pasteurized cream contaminated during the churning process.

In a later study Shutt (21) demonstrated the extensive contamination in certain churns and reported data to show the effectiveness of various sterilizing media in reducing this contamination. A one per cent peptone solution, instead of sterile water, was used as a rinse after the various chemical treatments in order to eliminate any residual germicidal effect of such chemicals. Physiological salt solution was used for dilution of the samples and plating was made on milk powder agar. Several churns of one, two and eight gallon capacities, all excessively contaminated by exposure to sour cream, were used. With an eight gallon churn, successive rinsing resulted in a decided reduction in the microflora. In the first trial, the first rinse showed 5,495,000 bacteria and 285,000 molds per ml. while the fourth rinse showed 763,000 bacteria and 57,000 molds per ml. In a second trial the first rinse showed 3,650,000 bacteria and 215,000 molds per ml. while the fourth rinse showed 378,000 bacteria and 24,500 molds per ml. With the one gallon churn, after exposure to boiling water for two minutes, the first rinse showed 219,000 bacteria and the fourth 7,650 bacteria per ml.

A two gallon churn showed considerable contamination after it had been treated as follows: It was filled partly full of saturated lime solution which was heated to boiling for five minutes and then diluted to the capacity of the churn. The churn was then allowed to stand for three days without draining. Boiling the solution for 30 minutes before diluting eliminated the molds and reduced the bacteria to 359 per ml. of rinse water. The data showed that the use of a 0.3 per cent sulphuric acid solution for 5 minutes reduced the bacteria from 42,933,333 to 1,980 and the molds from 1,100,000 to 31,500 per ml. of rinse water. These results discouraged further investigations on the use of this chemical.

Two commercial germicides were tried on the three gallon churn. A solution of seven grams of "Sterilac" in one gallon of water exposed for five minutes reduced the bacteria from 1,954,330 to 173 and the molds from 32,250 to 170 per ml. of rinse water while a 30 minute exposure reduced the bacteria from 25,525,000 to 425 per ml. A 2 per cent solution of "Montanin" when used cold for 30 minutes tended to decrease the bacteria and molds considerably, but the number of each remaining was still too high to recommend its use. When used in hot solution, however, there was a marked decrease in both bacteria and molds, especially in the latter. In this case the bacteria were reduced from 6,060,000 to 1,300 and the molds from 6,500 to 30 per ml. of rinse water.

Due to the unsuitability of the churn used the results secured on hyperactive iodine in concentrations ranging from 0.10 to o.229 per cent were very inconsistent. The data secured with a different churn in one of the experiments, however, showed that the hyperactive iodine had a decided germicidal effect upon the bacteria and molds. The data also showed that hyperactive iodine can penetrate fat very readily--a very significant factor in the sterilization of greasy churns.

Ruehle (18) emphasizes the difficulties involved in churn sanitation by stating: "The churn is perhaps the most difficult of all utensils to sterilize, because it is made of wood, which is certain to be more or less porous." He mentioned that churns in constant use should be sterilized frequently and suggested that overnight soaking followed by hot and cold rinsing should be sufficient. For new churns and old ones which had stood idle he suggested soaking for three days with milk of lime. No data were reported.

The results reported by Haglund, Barthel and Waller (4) show no significant improvement in the keeping quality of butter as a result of the introduction of modifications in the churn cleaning methods then used in well-managed Swedish creameries. These investigators ran a series of tests in 14 well-managed dairies in which samples of the test churnings were examined after 10 and 20 days of storage. Check samples of each batch of cream were churned in a sterile small metal churn. Four churn cleaning methods were tried: (1) Hot water alone, (2) hot water and coating of lime, (3) hot milk of lime, and (4) water heated to boiling with steam. They found that the last named method was most effective in that with it they could produce yeast---and mold-free butter. The churn became infected again after standing from three to five days. This emphasized the need for regular treatment in the care of a churn. A comparison of the scores on the butter from churns receiving ordinary treatment with the scores on the butter from churns receiving special treatment showed that the butter from the "sterilized" churns was of somewhat better quality, the average difference in 14 trials being 0.9 points after 10 days storage and 1.6 points after 20 days according to the Swedish scoring system.

Hood and White (7) presented data showing that a temperature of 185°F. for 10 minutes destroyed all the yeasts and molds in cream. They mentioned the churn as the most troublesome source of contamination of cream subsequent to pasteurization but reported that contamination from churns was not serious if a new churn was used and liming was practiced regularly.

Quam (17) compared the efficiency of chemical sterilizers for churn treatment with the ordinary methods with hot water and milk of lime which he refers to as the "old method". This "old method" was as follows: The fat was rinsed out with warm water. The churn was then filled one-third full of water to which was added one gallon of 15 per cent milk of lime. After heating the mixture to as high a temperature as practical with steam the churn was revolved for a period, drained and dried. The effeciencies of the various churn cleaning treatments were determined by plating water used to rinse the churn just before churning and after the churn had been previously rinsed with 40 gallons of tap water. Ten liters of sterile water were exposed to the churn for five minutes and then the bacterial content of the water was then determined by plating on standard agar and incubating the plates for 48 hours at 37°C. and the yeasts and molds were determined by plating on acidulated whey agar and incubating the plates for five days at room temperature. The results were expressed as the number of microorganisms per churn.

The fourteen trials reported on the "old method" of treatment show an average of 12,787,000,000 bacteria per churn. Since the capacity of the churn was calculated as approximately 1,000,000 ml. this treatment would have resulted in an average of 12,787 organisms being added per ml. of cream. In seven trials, a significant decrease in microorganisms was noted when the "old method" was followed by a 5 minute exposure to 10 gallons of water containing $\frac{1}{2}$ oz. of "Diversol" (a tri-sodium phosphate-sodium hypochlorite mixture). With this added treatment the organisms per churn were reduced to 2,688,500,000 bacteria and 293,000,000 yeasts and molds. In a series of 4 trials the same chemical was used as the sole means of treating the churn. The chemical was added at the rate of one ounce per gallon to 50 gallons of water at temperature between 120° and 125°F. and the solutions were exposed to the churn for five minutes. The results show an average of 2,532,500,000 bacteria and 137,000,000 yeasts and molds per churn.

The best results were obtained by following the "old method" with a rinse of 10 gallons of water containing chlorinated lime. In three trials a concentration of two ounces in 10 gallons showed an average of 2,135,000,000 bacteria and 390,000,000 yeasts and molds per churn. In series of 7 trials a concentration of four ounces in 10 gallons gave an average of 804,500,000 bacteria and 125,000,000 yeasts and molds per churn. In another series of seven trials where six ounces in 10 gallons were used the average counts showed only 177,000,000 bacteria and 7,795,000 yeasts and molds per churn. Only two trials were reported in which a concentrations of eight ounces per 10 gallons was used. The average count for these was 529,775,000 bacteria and 30,000,000 yeasts and molds per churn; the author suggests that laxity on the part of the persons washing the churn probably accounted for the count being high in one of these trials. The above data show that contamination from a churn was negligible when the "old method" of washing was followed by a rinse with 10 gallons of water containing six ounces of chlorinated lime.

The butter maker complained of the churn sticking after the different chemical treatments but no attempt was made to determine whether or not the complaints were well founded.

Groth (3) stated that churns are the greatest source of the contamination of pasteurized cream but that if proper washing procedures are used it is possible to keep them practically free from yeasts and molds. His method for "sterilizing" a churn was to rinse it for 5 minutes with 30 gallons of hot water followed by a 15 minute exposure to from 100 to 150 gallons of water at a temperature of not less than 180°F.

The results obtained by Macy and Combs (14) indicate that raw cream, pipes, pumps and churns stand out as the most serious potential sources of mold in butter. They mention churns as perhaps the worst of all creamery equipment from the standpoint of mold contamination because of the difficulty of cleaning. Butter produced in a churn which had stood idle for some time was found to be very badly molded after a few weeks while a second and a third churning showed diminishing numbers of molds. This illustrates the importance of regular treatment in controlling molds. In one of sixteen commercial creameries investigated, the churn and also the pipes, pumps, etc., proved to be fertile sources of mold infection. A later visit revealed that all the sources of contamination had been eliminated except the churn which, on account of its age and condition, was impossible to clean. In two other creameries the churns were badly infected but responded readily to careful treatment.

Schmidt (19) gives an account of Swedish and Danish experiments on churn treatment. In the Swedish experiments the churns were cleaned in the customary manner and a counts was made on the hot rinse waters at the end of the exposures. The churns were filled from 6.8 to 12.9 per cent full of water at temperatures ranging from 72° to 95°C. and the periods of exposure varied from 6 to 17 minutes. The counts on the water at the end of the exposures ranged from 5,300 to 876,000 bacteria per ml., showing that considerable numbers of bacteria survive such treatment. In the Danish experiments five methods of cleaning were used and counts were made on the butter and buttermilk from the churns. In every case a control churning was made in a steril small metal churn. The results showed that only the treatment with water heated to boiling with steam was effective in destroying harmful bacteria. The data also show that the butter made in a carefully cleaned churn scored higher after storage than did the butter from a churn cleaned by ordinary methods. The differences in score after 10 days storage ranged from 0.0 to 3.5 points and after 20 days from 1.0 to 6.5 points. These results emphasize the importance of a clean churn in the production of butter of good keeping quality.

James (8) showed that the churn may be a source of contamination of butter and that it is difficult to entirely eliminate contamination from churns. He used two churns of 300 lb. and 450 lb. capacities. In the first series 11 trials were run to determine the extent of contamination from churns which had been cleaned rather thoroughly. The churns were rinsed with hot water and then filled one-third full of hot water with washing soda added and revolved for 15 minutes in high gear. They were finally rinsed with steaming hot water, drained and turned with the doors up, after which the doors were covered with muslin. Before use each time the churns were filled one-third full of water heated with steam and revolved in high gear for 15 minutes and then drained and cooled. The churns were limed once every two weeks, the lime solution being left in the churns over night. The extent of contamination was estimated by introducing 12 gallons of sterile water into each churn and plating the rinse water on malt agar after revolving the churn in high gear for 15 minutes with the rollers working. The yeast and mold counts on this rinse water ranged from 13 to 312 per ml.; with one sample showing so many colonies on the plates that they were uncountable. No bacterial counts were run in this series.

In the second series 16 trials were run using different cleaning and sterilizing methods. Four factors were considered, namely, (1) the sterilizing agent, (2) the amount of sterilizing medium, (3) the temperature and (4) the time of exposure. Two sterilizing media were considered--heat and a chemical. In the heat treatment the water in the churn was heated with steam and the churn was then closed and run or allowed to stand for different periods. In the latter case it was turned over two or three times during the holding period to insure exposure of all parts to the hot water. The chemical used was labelled as containing 10 per cent available chlorine. Various dilutions of this were tried and the churn was handled as with the heat treatment.

Two amounts of sterilizing medium were used, the churn being filled two-thirds full in some runs and one-third full in the others. When heat was used as a sterilizing agent the temperature of the water at the end of the exposure varied from 172° to 192°F. and when chlorine solutions were used the temperature varied from that of tap water to 176°F. The periods of exposure to the different treatments varied from 10 minutes to 3 hours. The yeast and mold counts were determined as in the previous series. In 12 of the 16 trials bacterial counts were also run by plating on standard agar. The data show that in the 12 trials in which both yeast and mold and bacterial counts were determined the churn was rendered yeast and mold free seven times but in all cases still yielded some bacteria to the sterile rinse water. For the 12 trials in which both counts were made, the yeast and mold counts ranged from 0 to 11 and averaged 2.7 per ml. while the bacterial counts ranged from 161 to 17,750 and averaged 4,653 per ml.

In both heat and chemical treatments the sterilizing medium was most efficient when the churns were filled two-thirds full. Higher temperatures and longer exposures greatly favored the chemical treatment and as a whole the results from this type of treatment were rather successful. The small amount of chlorine carried over in the plating may have had an inhibitory effect, and therefore the results may have been somewhat low. In the four trials in which the bacterial counts were not reported the yeast and mold counts were very high, ranging from 24 to 255 per ml. These high counts were obtained with the churn filled only one-third full of the sterilizing medium and with either the time of exposure short or the temperature of the medium low. Temperature of medium, fullness of churn and time of exposure were apparently the cardinal factors to be considered in churn cleaning. The fact that microorganisms were discharged into sterile water even after rather severe sterilizing treatment suggests that they must have been lodged in inaccessable places in the churn and freed during the churning and working processes. James suggested that the churns are not rendered sterile because the sterilizing agent does not come in contact with the organisms.

In the third series of experiments the efficiencies of various chemical sterilizers in destroying microorganisms in rinse water from a churn were determined. In the 14 experiments samples of water contaminated by exposure to a churn, or, in three cases, with yeast and mold types originally obtained from a churn, were treated for 10 minutes with the chemicals and then plated for yeasts and molds as in the previous trials. Sterilizer A, an alkaline chloramine mixture was used in a 1:160 dilution and failed in all six trials to render the solution sterile. Solution B, containing 8.13 grams of available chlorine per 100 ml. of solution, was effective 12 times out of 17 trials using dilutions ranging from 1:160 to 1:1000. In the 5 remaining trials the reductions in organisms ranged from 95 to 99 per cent. Solution C, a hypochlorite solution containing 3.86 grams of available chlorine per 100 ml. of solution, was entirely effective in all 15 trails using dilutions of 1:100 to 1:1000. Solution D, a home-made hypochlorite containing 4.67 grams of available chlorine per 100 ml. of solution, was effective 7 times in 13 trials in dilutions of 1:100 to 1:1000. In the six remaining trials the reductions varied from 95 to 99 per cent. Solution E, containing 2.23 grams of available chlorine per 100 ml.

of solution, was effective 9 times in 10 trials in dilutions ranging from 1:100 to 1:1000. In the remaining trial only one mold colony was found on the plates whereas the untreated water had a count of 675 yeasts and molds per ml. From the above data it is evident that chemical sterilizers are effective when in direct contact with the contamination but it must be borne in mind that the small amount of germicide carried over in the plating may have had an inhibitory effect on the growth in the plates.

Libbert (9) showed the possibility of yeast and mold growth on the wood of churns. He isolated 47 yeasts, 9 molds and one "Fusarium" from churns under different sanitary conditions by rinsing with tap water and plating the rinsings on malt agar. Of the 57 organisms, only three of the yeast types failed to grow on a medium made up of water, 2.5 per cent agar and 3 per cent ground fir wood, which is the wood commonly used in churn construction.. The organisms also grew on water containing 2.5 per cent agar but these cultures died within 10 days while those grown on the medium containing ground fir wood remained viable for at least six weeks. Libbert stated that in churns the pitted condition of the wood which soon develops and the imperfect closure of seams and joints offer favorable harbors for bacteria, yeasts and molds. He found evidence not only of the accumula- tion of debris in the joints, etc. but also of growth. Attempts to isolate the organisms responsible for the growth failed.

The difficulty of rendering churns sterile is emphasized by the work of Morrison, Macy, and Combs (16) on the efficiency of various churn cleaning methods. They used a churn which had a high natural contamination and which they contaminated excessively by the addition of broth cultures of species of molds commonly found in churns. In general, before each treatment, the churn was rinsed with three gallons of tap water. It was then subjected to various treatments, using hot water, steam, hypochlorites or chloramines as sterilizing media, following which the churn was rinsed with one gallon of sterile skim milk. This material provided a good medium for the growth of any surviving organisms and in instances where chemicals were used, it absorbed excess chlorine, thus eliminating any residual effect of the chlorine on the plates. Representative samples of the rinse water from the churn before treatment and of the skim milk rinse after treatment were taken for plating. The samples were plated directly on whey agar and the plates for mold counts were acidulated with tartaric acid. The results were expressed qualitatively rather than quantitatively to give a relative idea of the amount of infection.

In five trials with hot water treatment temperatures of 85° to 88°C. and periods of exposure ranging from 5 to 60 minutes were ineffective in reducing either the bacterial or mold infection of the churn. The churn was filled one-sixth to one-third full in these five trials. In one trial in which the churn was filled one-third full of water at 96°C. and exposed for a period of 30 minutes, the mold infection was entirely eliminated but the data indicate no apparent reduction in the numbers of bacteria. In three trials in which the churn was filled full of water at 97.2° to 97.7°C. and exposed for a period of 180 minutes, the mold infection was eliminated and there was an appreciable reduction in the numbers of bacteria. These three trials were run on successive days and from the data it is apparent that regular treatment was effective in controlling mold infection. Upon standing idle, however, the churn was soon again infected with molds.

In the steam treatments, the steam was allowed to flow slowly into the churn for a period of three hours. In four trials the molds were entirely eliminated and on the third consecutive day of the steam treatment the bacterial count was markedly decreased. Normal fructification of the molds began again after the churn had stood idle for several days.

Four trials were run with sodium hypochlorite solutions using concentrations ranging from 35 to 265 ppm. and periods of exposure ranging from one-half to 18 hours. The churn was filled one-third full of solution at 15.6°C. in two trials and full of solution at 10°C. in the other two. From the data, there was no apparent reduction in either molds or bacteria in any of the trials.

Four trials were run with a hypochlorite in combination with tri-sodium phosphate, using concentrations of available chlorine ranging from 53 to 283 ppm. and temperatures ranging from 10° to 15.6°C. The churn was filled full in two trials and two-thirds full in the other two. In two of the trials the periods of exposure were 2 hours and in the other two 18 hours. In only one of the trials was there any significant reduction in molds. In this case the churn was filled full of solution containing 274 ppm. of available chlorine, the temperature of the solution was 12.2°C. and the period of exposure was 18 hours. None of these treatments was effective in reducing the infection with bacteria.

Four trials with chloramine-T solutions were reported. The available chlorine concentrations ranged from 46 to 350 ppm., the temperature from 48.8° to 51.6°C. and the periods of exposure were 2 hours in two trials and 18 hours the other two. The churn was filled one-third full in one trial, five-ninths full in another and full in the other two. In one of the trials, in which the churn was filled five-ninths full of a solution containing 46 ppm. of available chlorine, at a temperature of 51.6°C. and exposed to the solution for 18 hours there was a significant decrease in molds but none of the other treatments had any such effect. In none of these trials was there a significant reduction in the numbers of bacteria, thus indicating, as with all the other treatments, that bacteria are much more difficult to eliminate than molds.

A summary of the results secured by Morrison, Macy and Combs indicates that, of the methods used, sufficient exposures to hot watter and sufficient exposures to free flowing steam were the most satisfactory. The authors state very definitely that "solutions of sodium hypochlorite, alkaline crystalline hypochlorite and chloramine-T were ineffective."

In studies on the rate of heat penetration of wood the investigators found that when the surface of wood from a churn was exposed to boiling water it required a period of an hour and a half for the heat to penetrate the wood to a depth of 1-3/8 inches and raise the temperature to 62.2°C.

Macy, Combs and Morrison (15) showed that numerous infection foci exist in churns. Their work involved the dismantling of two churns: Churn A, which had been in service in a commercial creamery for about 10 years and had been treated in an ordinary way and churn B, which had been in service in the University of Minnesota creamery for about 3 years and had been regularly subjected to careful treatment. Scrapings or blocks of wood were taken from every conceivable place as the churns were dismantled and altogether 230 samples from churn A and 73 samples from churn B were secured. The presence of infection in the various foci was determined by immersing the samples in sterile water over night and plating 1 ml. of the fluid on acidulated whey agar and incubating for five days at room temperature. The results, which were expressed qualitatively, showed that of the total of 230 samples taken from churn A, 192 carried molds while of the 73 samples from churn B only 22 showed mold infection and only five of these produced more than two mold colonies per plate. This shows the advantage of regular and efficient cleaning in preventing the mold mycelium from penetrating the cracks and crevices and gaining a foothold there. The wood at the joints up to a depth of 1 inch and at other points somewhat removed from the action of any sterilizing medium were found to be infected with molds. The authors state: "While this report does not concern itself with yeasts or bacteria in the churn, it might be mentioned that the former were quite consistently present in the great majority of cases and the latter always, sometimes in large numbers." This statement suggests the great importance of the churn as a source of bacteria.

METHODS

A. Method for determining the microbiologic conditions of churns

1. Rinse method

A method which is commonly used in studying churn contamination is to rinse the churn with water, milk or other liquid and then determine the bacterial content of the rinse. This is designated as the rinse method; the details as used in this investigation are as follows:

Ten gallons of water are added to the churn and the churn revolved in high gear, usually for 10 minutes. At first the water was "sterilized" in 10 gallon cans by heating to nearly boiling with steam and cooling over night. Later ordinary tap water was used because the counts on it were found to run consistently low. In either case a sample of rinse before exposure to the churn is always plated so that the organisms added by the churn can be calculated.

After exposure to the churn a sample of the rinse is taken with a sterile 5 ml. pipette and placed in a sterile cotton stoppered test tube. As soon as possible the sample is plated on beef infusion agar for the determination of the bacterial content and on acidulated malt agar (pH. 3.5) for the determination of the yeast and mold content. Unless the sample can be plated immediately it is held in ice water until plated but in no case is a sample held for more than four hours. The plates are incubated at room temperature (about 70°F.) for four days and then counted with the aid of a hand lens. Occasionally it is necessary to count the malt agar plates at the end of two or three days if the molds are very numerous because in such cases the plates soon become overgrown with a mass of mold mycelium which make accurate counting impossible.

In the chlorine treatment studies 99 ml. sterile, litmus milk blanks are used in diluting the samples of rinse water for plating; this is done in order to eliminate any residual chlorine in the water used to rinse the churn after treatment. The litmus milk blanks are incubated for some time before being used in order to establish their sterility.

2. Agar disc method

A method for studying the contamination from churns, designated as the agar disc method, was reported by Hammer and Olson (6). The procedure involves allowing a small amount of special agar medium to solidify in contact with the surface to be studied, the transferring of the disc thus formed to a sterile petri dish, and finally the counting of the colonies that develop on incubation.

a. <u>General steps in the method</u>

1. A tube of special agar medium (about 10 ml.) is melted and cooled to from 105° to 110°F.
2. A small area of the surface of the interior of the

churn is moistened with sterile water, using a sterile cotton swab.

3. The medium is poured on the moistened area and allowed to solidify.
4. The disc thus formed is picked up with a sterile spatula and tipped into a sterile petri dish so that the side of the disc which was next to the wood will be toward the top of the dish.
5. The disc is incubated at 70°F. for four days; in case the colonies are so numerous that there is danger of them growing together the incubation period is reduced.
6. The colonies appearing on a measured area of the disc are counted and the results expressed as the number per square centimeter.

b. Detailed steps in the method for surfaces nearly horizontal

1. The medium used is beef infusion agar containing 2.5 per cent of air dried agar. This high concentration of agar is used because when discs of a suitable size (5 to 8 cm. in diameter) are prepared with a medium containing only 1.5 per cent of air dried agar they usually break when an attempt is made to transfer them from the churn surface to the petri dish. The medium containing 2.5 per cent of agar is somewhat more difficult to prepare than that containing only 1.5 per cent

agar; a convenient method is to make up the 1.5 per cent infusion agar and then add the remaining 1.0 per cent of agar and incorporate it by autoclaving. The medium is stored in test tubes, approximately 10 ml. to each tube. The tubes of medium needed for the churn or churns to be examined are melted, cooled in water to 105° to 110°F. then held at this temperature.

2. Very satisfactory discs can be prepared by having the surface of the churn cool and dry and then moistening, with sterile water, the exact area to be covered just before the agar is poured on. The agar flows freely over the moist surface and thus the size and shape of the disc can be controlled. When the entire surface is wet the medium flows freely in all directions and, as a result, a disc too thin to be handled and of an unsatisfactory shape will likely result, while when the surface is dry the disc may be of a very irregular shape and generally adheres so firmly to the wood that it tears or breaks when an attempt is made to remove it. A circular area 5 to 8 cm. in diameter is moistened with a sterile cotton swab which has been dipped in sterile water. The swab is conveniently prepared by wrapping a small amount of absorbent cotton around a piece of wood, as

for a throat swab, or around a piece of stiff wire, putting this in a test tube, stoppering the test tube with cotton and then sterilizing. The water is also conveniently sterilized in a test tube.

3. The mouth of the test tube containing the agar is thoroughly flamed and the agar carefully poured on the moistened surface. If the surface is not horizontal, as shown by the spreading of the agar, the churn can be tilted slightly so that the disc formed will be reasonably uniform in thickness.

4. The disc is picked up with a sterile spatula and tipped into a sterile petri dish so that the side of the disc which was exposed to the wood will be toward the top of the dish. Before attempting to remove the disc from the surface of the wood it is necessary to first completely loosen it in order to prevent any portion of it from adhering to the surface and breaking off. This is easily done by placing the blade of the spatula flat on the surface of the wood and running it half way under the disc and then repeating this operation from the other side. A spatula with a thin flexible blade that is rather large and rounded at the tip is most satisfactory. There should be no sharp edges since these tend to cut into the disc. Paper may be

used for wrapping the spatula for sterilization or where several spatulas are to be sterilized a metal container with an easily removable lid, such as a pipette case, may be used. A thin coating of vaseline or similar material will largely prevent the rusting of the blade during the sterilization and subsequent holding of the spatula.

5. The usual incubation for the disc is 70°F. for four days. It is advisable to examine the disc each day and consider the incubation period complete in less than four days if the colonies are so numerous they are beginning to fuse.

6. At the end of the incubation period the colonies on a measured area are counted. A convenient area, which depends on the size and shape of the disc, is ruled off on the bottom of the petri dish with a wax pencil, and the colonies within this area are counted with the aid of a hand lens. Small colonies on crowded plates are likely to be missed unless a lens is used. The number of colonies per square centimeter is calculated from the number counted and the area over which these are distributed. Where the colonies are very numerous it is necessary to depend on approximate counts or even estimates; for this it may be advantageous to

rule the desired area into fractions of a square centimeter.

c. <u>The method for surfaces not nearly horizontal</u>

While undoubtedly a fairly satisfactory idea of the microbiologic condition of a churn can be secured by preparing discs on surfaces that can be gotten nearly horizontal (e.g. a shelf, a roller, a door, etc.) the procedure can be used on surfaces that are not nearly horizontal such as the ends of a churn. The method involves the pouring of the special medium behind a glass plate held a short distance from the surface by a gasket so that an agar preparation, comparable to the discs obtained on nearly horizontal surfaces, can be secured.

Since an agar preparation with an area of 20 sq. cm. is very convenient the glass plates and gaskets were originally designed on this basis. Glass plates approximately 5 x 6.5 cm. were cut from heavy window glass. The glass must be so heavy that it can be held firmly against the gasket without danger of breaking or part of it being found too close to the surface being studied. The gaskets were made from thick (2 to 3 mm.) pulp board secured from strong packing boxes, by cutting out rectangles 6.5 x 8.5 cm., removing a rectangular section 4 x 5 cm. from each so that a border 1.25 to 1.75 cm. in width was left and then cutting a section out of the border at one end to provide an opening through which the medium could be poured. The gaskets must be made from pulp board which will retain its shape on sterilization; some of the board tried split into layers when it was heated. The cut surfaces of the gaskets with which the agar comes in contact should be very smooth so that the agar can be split from them easily. The glass plates and gaskets may be sterilized after wrapping in paper, or the glass plates may be sterilized in a petri dish and the gaskets in a beaker covered with half of a petri dish.

The exact procedure used for securing an agar preparation from a vertical surface is as follows: A circular area about 7 cm. in diameter is moistened with sterile water using a sterile swab. The sterile gasket is removed from its container with sterile forceps and placed over the moistened area so that the end of the gasket from which a section has been removed is at the top. The glass plate is taken from its container with sterile forceps and placed over the gasket. With the glass plate held firmly against the gasket, the agar is poured through the opening in the gasket until the enclosed space is full. The whole is held firmly in place until the medium is thoroughly solidified. If the glass plate is chilled in a refrigerator just previous to use and the churn is quite cool solidification requires only a short time. With a clean churn the firm agar will ordinarily hold the glass and gasket in place, but when the churn has been carelessly cleaned so that the surface has retained some fat the preparation may fall unless it is supported. The glass plate is removed by slipping it along the gasket, after which the gasket is removed by running the blade of a sterile spatula between the agar and the gasket and lifting the gasket from the surface of the churn. The agar is then removed with a sterile spatula and put into a sterile petri dish, so that the portion which was next to the wood is toward the top of the dish. The agar preparations are incubated and the colonies that develop are counted by the methods already given for discs prepared on nearly horizontal surfaces.

d. Advantages of the method

The agar disc method gives a general picture, from the standpoint of the microorganisms present, of the churn surface with which the cream and butter come in contact. The results secured appear to be more understandable by butter plant employees and more applicable to the problem of contamination from churns than the results secured by the rinse method.

Comparatively little equipment is necessary to carry out the procedure, all of which is readily available and easily transported. The preparations are completed at the churn itself, and it is not necessary to take rinse water or some such material to a laboratory and work with it there. For these reasons the method is particularly adapted to work in the field where it may be desirable to examine churns in a number of plants on one trip. Moreover, the temperature of incubation suggested is such that during much of the year ordinary room temperature is quite satisfactory.

e. Rating of the conditions of churns on the basis of the agar disc counts

From the results obtained in the examination of churns in Iowa creameries and from numerous counts made on other churns under various sanitary conditions the following arbitrary classification, based on the number of colonies developing, per square centimeter of the agar discs, has been developed: <10, very satisfactory; 10 to 49, satisfactory; 50 to 249, rather unsatisfactory; 250 to 999, unsatisfactory; and >1,000, very unsatisfactory.

f. The use of the method for yeast and mold counts on churns

The agar disc method was originally intended for the study of bacteria in churns, but many species of yeasts and molds develop on the medium used. While the molds are rather easily differentiated the differentiation of the yeasts would require detailed microscopic study of the colonies or preferably of stained preparations made from them. The method can be applied directly to the study of yeasts and molds in churns by using a medium comparable to those employed in the determination of yeasts and molds in butter. In these investigations whey agar containing 2.5 per cent of air-dried agar and acidulated, just before pouring, to pH 3.5 with 5 per cent sterile lactic acid, was used. The discs are incubated and counted the same as for bacterial counts.

g. The use of the method on churns treated with chlorine solutions

In applying the agar disc method to churns treated with chlorine solutions, sterile litmus milk is used to moisten the surface to be studied in order to eliminate the residual effect of the chlorine remaining on the wood.

h. Application of the method to field work

The agar disc method may be used in field work where it is desirable to examine a number of churns in different creameries. The procedure for such field work is as follows:

Enough material to examine the desired number of churns is packed in some suitable carrying case. The sterile petri dishes are wrapped in paper to avoid air contamination and the spatulas are either wrapped in paper or placed in a pipette case for sterilization and subsequent packing. Since the cotton stoppers in the sterile water tubes are likely to become saturated, rubber stoppers are used. The sterile lactic acid for acidulating the whey agar is contained in a small bottle stoppered with a sterile cork. The rest of the equipment is prepared as described in the details of the method. The agar is melted and cooled in a metal cup and a small alcohol lamp is used to flame the mouths of the test tubes, the forceps and the spatulas. Only one spatula is used on each churn but it is flamed thoroughly before transferring each disc. From four to seven preparations are commonly secured from each churn, the usual number being five. These are taken from several places such as the ends, rollers, shelves and barrel.

i. Observations on the method

The best results are obtained with the method outlined when the surface is cool and dry. A disc too large and too thin, as a result of the churn being warm or the surface wet, can frequently be used by trimming it with a sterile spatula or scalpel and transferring the desired portion. A reasonably cool churn is also important when a preparation is to be secured from a surface that is not nearly horizontal because the glass plate and gasket must be held in place until the medium is completely solidified.

In the comparisons carried out the numbers and types of microorganisms from various portions of a churn have been much the same, but some variations have been noted, and it seems advisable to secure preparations from several surfaces unless only general results are desired. In the variations encountered there was a tendency for the number of organisms per square centimeter to be slightly less on the ends and rollers than on the shelves and barrels.

Hammer and Olson give results obtained in a number of trials in which the agar disc method was compared with the rinse method of estimating the organisms in churns. In these comparisons agar disc preparations were first made from various places in a churn and then 10 gallons of sterile water were revolved in the churn for 15 minutes after which the rinse water was plated on beef infusion agar and the plates incubated for four days at room temperature before counting. In five trials with one churn the ratio between the number of colonies per square centimeter on the agar preparation and the number per ml. of rinse water varied from 1 to 1,051 to 1 to 4,167 and in 10 trials with another churn it ranged from 1 to 222 to 1 to 8,097. The ratio between the average number of colonies per square centimeter of the agar preparations (for the 15 trials) and average number of organisms per ml. of rinse water (for the 15 trials) was 1 to 1,650.

A close relationship between the results of the two procedures would not be expected if what is being measured by each is considered. In the case of the agar preparations there is no reason to believe that each colony develops from a single bacterial cell and a number of trials in which several discs were secured as rapidly as possible from the same area showed very definitely that not all of the organisms are picked up from the wood by the agar. Each disc showed decreasing numbers of colonies but some organisms were still picked up after several discs had been prepared. The colonies developing from the rinse water probably include many that represent a group of organisms and the rinse water cannot be expected to dislodge all the organisms from the surface of the churn.

B. Method for determining the available chlorine concentrations in chlorine solutions

The method used for determining the available chlorine in chlorine solutions is as follows: An approximately tenth normal solution of sodium thiosulfate is prepared and a 50 ml. sample of this is titrated against standard potassium dichromate solution using one per cent starch paste as an indicator. The standard sodium thiosulfate solution is stored in brown bottles as a stock solution and is titrated against standard potassium dichromate solution from time to time in order to avoid errors due to decomposition. Before each available chlorine determination a portion of the stock solution is diluted with the proper amount of distilled water to make a hundredth normal solution. This latter strength solution deteriorates quite rapidly and so a fresh solution of it is made up each time it is to be used.

In making the determinations a 50 ml. sample of the chlorine solution is placed in a 500 ml. flask containing 10 ml. of a 15 per cent potassium iodide solution and 200 ml. of distilled water. Five ml. of concentrated HCl (Sp. gr. 1.18) are added and mixed with the contents of the flask. After standing for two minutes out of the direct sunlight the iodine liberated by the chlorine is titrated against the hundredth normal sodium thiosulfate solution. One ml. of a one per cent starch paste is added to the flask near the end of the titration as an indicator and the sodium thiosulfate solution is added until the dark blue color changes to a faint blue. The parts per million available chlorine are calculated by multiplying the number of mls. of hundredth normal sodium thiosulfate used by 7.1.

EXPERIMENTAL

A. Extent of contamination of churns in commercial use

The extent of the contamination of churns in commercial use was studied in 24 Iowa butter plants, using the agar disc method. The period covered was from November 7, 1930 to May 18, 1931. A total of 27 churns were examined; some of them were examined twice so that the data cover 33 examinations. Information as to the size of each churn, years in service and usual washing procedure was obtained from the plant manager. Observations on the condition and apparent cleanliness of each churn were made in order to attempt to correlate these with the numbers and types of microorganisms found.

1. Results of agar disc counts

The agar disc counts and the microflora of the churns studied are recorded in table 1; each count represents an average of several discs prepared from a churn. The 33 bacterial counts ranged from 1.3 to $>$2,000 per sq. cm.

Ten churns had bacterial counts of less than 10 per sq. cm. and were classified as very satisfactory (see methods). The organisms in these churns usually included very few types and were chiefly members of the genus Bacillus. With three of the churns the washing procedures involved the use of washing powder, with four lime was used, with two both washing powder and lime were used and with one neither of these materials was

Table 1

Agar disc counts and microflora of churns in commercial use

Creamery and Churn*	Date of Exam.	No. of Discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Microflora
Aa	11/7/30	5	1.7		.2	Bacillus types predominant; few others.
Aa	4/13/31	4	6.5	.03	.3	Almost exclusively Bacillus types.
Ab	4/13/31	5	8.3	.13	1.7	Bacillus types predominant; several others.
B	11/7/30	2	63		.2	Many types; yellow cocci predominant.
B	4/13/31	5	307	1.2	2.2	Many types including a predominance of yellow and white cocci. Many Bacillus types.
C	11/7/30	6	228		4.9	Many types; cocci predominant.
C	4/13/31	5	36	.1	.7	Bacillus types predominant; several others. Few cocci.
D	11/7/30	4	7.8		1.4	Few organisms but many types. Cocci types predominant.

Table 1 (continued)

Creamery and Churn*	Date of Exam.	No. of Discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Microflora
D	4/13/31	4	20	.3	3.7	Yellow cocci predominant; several Bacillus types. Many Oidium lactis.
E	11/7/30	6	9.2		.9	Chiefly Bacillus types; few others.
F	11/28/30	4	>2,000			All preparations very heavily seeded. Yellow cocci highly predominant; A few Bacillus types.
G	11/28/30	5	>2,000			All preparations very heavily seeded. Largely yellow cocci.
H	11/28/30	5	>1,000			All preparations heavily seeded. Yellow cocci highly predominant.
I	11/28/30	5	64.	.1	.4	Several types non-chromogenic cocci predominant.
J	11/28/30	5	3.3	.1	.3	Few organisms and few types. Yellow cocci predominant.

Table 1 (continued)

Creamery and Churn*	Date of Exam.	No. of Discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Microflora
Ka	11/28/30	4	21	.4	.4	Several types; many yellow cocci.
Kb	11/28/30	2	8.9	.9	1.2	Few organisms and few types; cocci predominant.
L	3/2/31	5	800 (Est.)			Several types; yellow cocci predominant. Several Bacillus types.
L	4/13/31	5	834 (Est.)			Several types; yellow cocci probably predominant. Several Bacillus types.
M	3/2/31	5	>2,000			Yellow cocci predominant; several other types.
N	3/2/31	5	490			Many types present.
O	3/2/31	7	37	.2	1.3	Bacillus types predominant; several others.
Pa	3/23/31	5	730			Bacillus types predominant; several others.
Pb	3/23/31	3	492	.06	6.5	Bacillus types predominant; several others.

Table 1 (continued)

Creamery and Churn*	Date of Exam.	No. of Discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Microflora
Q	3/23/31	5	68	.1	.06	Yellow cocci predominant; several other types including a few Bacillus types.
R	3/23/31	5	1.3	.02	.1	Very few organisms. Chiefly Bacillus and yellow coccus types.
S	3/23/31	4	32	.04	.4	Several types; yellow cocci predominant.
T	3/23/31	5	297	.03	.1	Several types; yellow and greyish white cocci predominant.
U	5/18/31	5	$\geq$1,200	.1	.2	Several types; yellow cocci highly predominant.
V	5/18/31	5	9.6	0	5.5	Bacillus types predominant; few others.
W	5/18/31	5	3.5	0	.3	Bacillus types predominant; few others.
Xa	5/18/31	5	47	.3	5.4	Bacillus types highly predominant; very few others.

Table 1 (continued)

Creamery and Churn*	Date of Exam.	No. of Discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Microflora
Xb	5/18/31	4	33	.3	3.3	Bacillus types highly predominant. A few other types but very few yellow cocci.

* The capital letters designate the creameries and the small letters designate the churns in creameries with more than one churn.

employed. The temperatures used ranged from 150° to 200°F. and the periods of exposure from 5 to 30 minutes. Three of the counts were from churns which had been treated with chlorine compounds as an additional procedure and with one churn the washing procedure included the rinsing out of the fat by adding water at about 120°F. and revolving for 20 minutes. The churns in this group had been in service for from six months to eight years; all except one were in good condition and they were all apparently in a satisfactory or very satisfactory sanitary condition.

Seven churns had bacterial counts between 10 and 49 per sq. cm. and were classified as satisfactory. The organisms generally included several types, with the Bacillus types predominant. A larger proportion of cocci were noted among the organisms from the churns in this group than among those from the churns in the preceding group. With three of the churns the washing procedures involved the use of lime, with two washing powder and lime were used and with two neither of these materials was employed. The temperatures used ranged from 180° to 200°F. and the periods of exposure from 5 to 30 minutes. With the churn in creamery C, the treatment with common salt was apparently responsible for a decided reduction in microorganisms as shown by a comparison of the count obtained when the salt treatment was being used with the count obtained in a previous examination when the salt treatment was not being used. All except one of the churns was in good or fair condition and this one had been in service for 18 years; the range of years in service was from 5 to 18. All of the churns were apparently in a satisfactory or rather satisfactory sanitary condition.

Four churns had bacterial counts between 50 and 249 per sq. cm. and were classified as rather unsatisfactory. The organisms in these churns generally included many types, with yellow coccus types predominant. A considerable number of chromogenic bacteria were usually present and the Bacillus types were generally in the minority. Of the washing procedures used on these churns, one involved a weekly treatment with lime while the rest involved the use of lime or washing powder only occasionally. The temperatures used in washing ranged from 170° to about 200°F. and the periods of exposure from 3 or 4 minutes to 10 or 15 minutes. The procedure used on one of the churns included the rinsing out of the fat by filling one-sixth full of water at about 130°F. and revolving for 5 to 10 minutes. The churns in this group had been in service from 3 to 10 years and all were in fair to good condition. All except one had more or less grease on the surface and in one curd and brine were oozing from the cracks between the staves. Three were apparently in a satisfactory sanitary condition while one was rather unsatisfactory.

Seven churns had bacterial counts between 250 and 999 and were classified as unsatisfactory. In general the microflora from these churns included several types, with the yellow coccus types predominant. A considerable number of Bacillus types were generally present and in two churns from one plant these were predominant. None of the washing procedures used on the churns in this group could be considered as adequate. One churn was subjected to a weekly treatment with lime while the remainder were either only occasionally or never treated with washing powder or lime. The temperatures used ranged from 170° to 200°F. and the periods of exposure from 3 or 4 minutes to 15 or 20 minutes. Two of the churns were treated occasionally with chlorine compounds. The churns had been in service from 3 to 14 years; six of them were in a fair condition while one was in a poor condition. All showed more or less grease on the surface and three showed an accumulation of curd in the crevices. Five were apparently in an unsatisfactory sanitary condition, one was apparently rather unsatisfactory, and the remaining churn had not been used for a year or more. Three of the churns had a slight odor, presumably due to bacterial development.

Five churns had bacterial counts of over 1000 per sq. cm. and were classed as very unsatisfactory. The agar discs from all of these churns were very heavily seeded with bacteria and none of them could be counted with any degree of accuracy. In every case the yellow coccus types were highly predominant; several other types were generally present, particularly members of the genus Bacillus. One of the churns was washed regularly with either washing powder or lime, while the others were either washed without these materials or they were used only occasionally. The temperatures employed ranged from 150°F. to "real hot" and the periods of exposure ranged from 4 or 5 minutes to 20 or 25 minutes. These churns had been in service from 1 to 15 years. Two were in good condition, one was in fair condition and two were in poor condition. They all showed more or less grease on the surface. In regard to the apparent sanitary condition, one was fairly satisfactory, two were unsatisfactory and two were very unsatisfactory. Four of the churns showed an accumulation of curd in the crevices and in one a slight odor was noted.

2. Washing procedures used and history and condition of each churn

The general procedure for washing the churns in commercial plants in Iowa is as follows:

1. The butter fat is rinsed out with a small amount of warm water.
2. The churn is filled one-third to one-half full of hot water, revolved in high gear for a short period and drained and dried; if cleaning agents, such as washing powder or lime, are used they are added to the hot water in the churn.
3. Just before the next churning the churn is rinsed with

cold tap water.

The information obtained from the plant managers and the observations made at the time of examination are recorded in tables 2 and 3. Table 2 gives the details of the second step in the washing procedure outlined above and any variations from the general method. From this table it can be readily seen that the washing procedures used in many of the plants could not be considered adequate for properly cleansing a churn. With very few of the procedures were the temperatures used high enough or the exposures long enough to insure satisfactory reduction of the bacterial content of the churn. The temperatures and periods of exposure recorded were approximated by the plant manager and therefore may have been exaggerated in many cases. Very few of the washing procedures involved the regular use of washing powder and lime and in quite a number of plants these materials were never used. A chlorine compound was used on only four of the churns examined and on only one of these was it used regularly.

The history and condition of each churn studied are recorded in table 3. The capacities ranged from 600 to 1200 pounds, the majority being of from 800 to 1,000 pounds. The periods of service ranged from 6 months to 18 years. In general, the older churns were in poorer condition than the newer churns but some of them were in very good condition while some

Table 2

Washing procedures following rinsing out of fat

Creamery and Churn*	Date of Exam.	Fullness of Churn	Temp. of water °F.	Washing Powder	Lime	Period of Exposure. Minutes.	Additional Washing Procedure
Aa	11/7/30	1/4	"near boiling"	None	2 lbs. once a week	4-5	None
Aa	4/13/31	1/4	" "	"	" "	" "	Rinsed once a week with 10 gallons of water containing about 100 ppm. available chlorine.
Ab	4/13/31	1/4	" "	"	" "	" "	Same as above.
B	11/7/30	1/4	170	2 lbs. every 3 or 4 weeks	None	3-4	None
B	4/13/31	1/4	170	" " "	"	"	None
C	11/7/30	1/4	180-200	None	2 lbs. once a week	5	None
C	4/13/31	1/3-1/2	180-200	Rollers brushed with washing powder solution.	" " "	5	Once a week a brine (80 gals. water and 40 lbs. butter salt) was heated to nearly boiling

Table 2 (continued)

Creamery and Churn*	Date of Exam.	Fullness of Churn	Temp. of water °F.	Washing Powder	Lime	Period of Exposure. Minutes.	Additional Washing Procedure
							with steam and revolved in churn for 5 minutes. Drained and dried.
D	11/7/30	1/3	"near boiling"	2 lbs. once a week	None	10-30	None
D	4/13/31	1/3	" "	" " " "	"	"	"
E	11/7/30	1/4	" "	None	"	5-10	"
F	11/28/30	1/3	"real hot"	2 lbs. every 2-3 mos.	2 lbs. every 2-3 mos.	5-10	"
G	11/28/30	1/2	"hot"	2 lbs. (or lime)	5 lbs. (or washing powder)	20-25	"
H	11/28/30	1/3	175	2 lbs. occasionally	None	4-5	"
I	11/28/30	1/3	"real hot"	2 lbs. every 2 weeks	"	5-10	"

Table 2 (continued)

Creamery and Churn*	Date of Exam.	Fullness of Churn	Temp. of water °F.	Washing Powder	Lime	Period of Exposure. Minutes.	Additional Washing Procedure
J	11/28/30	1/6	150	2 lbs.	None	5-10	Filled 1/6 full of hot water, 5 to 6 oz. 2.5% sodium hypochlorite added, heated with steam and revolved 10-15 minutes.
Ka	11/28/30	1/3-1/2	180	None	4 lbs.	10-15	None
Kb	11/28/30	1/3-1/2	180	None	4 lbs.	10-15	None
L	3/2/31	1/3-1/2	180	None	None	15-20	Rinsed every 2 weeks with 50 gallons of water containing 1 quart of 2.5% sodium hypochlorite.
L	4/13/31	1/3-1/2	180	None	None	15-20	None
M	3/2/31	1/3-1/2	160-170	None	None	15	None
N	3/2/31	1/3	"hot"	2 lbs. twice a month	None	15-20	2 lbs. NaOcl - Na_3Po_4 mixture added to hot rinse about twice a week.

Table 2 (continued)

Creamery and Churn*	Date of Exam.	Fullness of Churn	Temp. of water °F.	Washing Powder	Lime	Period of Exposure. Minutes.	Additional Washing Procedure
O	3/2/31	1/3	180	None	2 lbs. every 2 weeks	10-15	None
Pa	3/23/31	1/4	185-190	2 lbs. once a week	2 lbs. once a week	15	None
Pb	3/23/31	Had not been used for about a year.					
Q	3/23/31	1/3-1/2	190-200	None	2 lbs. occasionally	10-15	Fat rinsed out with 25-30 gals. water at about 130°F. Revolved 5-10 min.
R	3/23/31	1/3-1/2	190-200	None	3 lbs.	5	Fat first rinsed out by filling 1/3 full water at about 120°F., adding the lime and revolving 5 min.
S	3/23/31	1/3-1/2	190-200	2 lbs. once or twice a week	None	5	None

Table 2 (continued)

Creamery and Churn*	Date of Exam.	Fullness of Churn	Temp. of water °F.	Washing Powder	Lime	Period of Exposure. Minutes.	Additional Washing Procedure
T	3/23/31	1/3-1/2	190-200	None	1 lb. once a week	5-10	None
U	5/18/31	1/3-1/2	150	None	None	15-20	None
V	5/18/31	1/3-1/2	160-170	2 lbs.	None	5-10	Whenever the butter stuck the churn was treated with 1 lb. of lye in 80 gals. water. Revolved 10 minutes.
W	5/18/31	1/3	180	2 lbs.	occasionally	20-30	Two lbs. of lime added to hot rinse when butter stuck.
Xa	5/18/31	1/3	180	None	None	5-10	None
Xb	5/18/31	1/3	180	None	None	5-10	None

* The capital letters designate the creameries and the small letters designate the churns in creameries with more than one churn.

Table 3

History and condition of each churn

Creamery and Churn*	Date of Exam.	History of Churn: Capacity in lbs. butter	Yrs. in Service	Condition	How long since washed. Days	Apparent Sanitary Condition
Aa	11/7/30	600	5	Fair. Rollers and shelves cracked. Wood smooth; slightly greasy.	1	Satisfactory. Some dry curd in crevices.
Aa	4/13/31	600	5	Same as above	2	Same as above
Ab	4/13/31	1200	2	Good. Wood fairly smooth; slightly rough on ends.	2	Satisfactory.
B	11/7/30	900	10	Fair. Shelves and rollers loose. Wood fairly smooth but slightly greasy.	Just washed	Rather unsatisfactory. Moist putrid curd lodged in corners and crevices.
B	4/13/31	900	10	Same as above	2	Unsatisfactory but somewhat better than previously. Curd in crevices.
C	11/7/30	800	5	Fair. Wood fairly smooth but staves splintered in places. Wood quite greasy in spots.	1	Fairly satisfactory. Curd and salt brine oozing from cracks between staves.

Table 3 (continued)

Creamery and Churn*	Date of Exam.	History of Churn			How long since washed. Days	Apparent Sanitary Condition
		Capacity in lbs. butter	Yrs. in Service	Condition		
C	4/13/31	800	5	Same as above, but not quite so greasy. Surfaces coated with salt.	2	Same as above
D	11/7/30	900	6	Good. Wood smooth but somewhat greasy.	1	Quite satisfactory. Dry curd in crevices.
D	4/13/31	900	6	Good. Wood smooth but somewhat greasy.	1	Same as above
E	4/13/31	1200	½	Excellent. Wood free from grease.	2	Satisfactory.
F	11/28/30	1900	3	Good. Wood fairly smooth and only slightly greasy.	2	Fairly satisfactory. A little curd in corners and crevices.
G	11/28/30	700	15	Poor. Badly worn. Rollers and shelves loose. Wood smooth but rather greasy.	3	Very unsatisfactory. Moist curd in crevices and corners. Slight odor. Churn somewhat moist.

Table 3 (continued)

Creamery and Churn*	Date of Exam.	History of Churn: Capacity in lbs. butter	History of Churn: Yrs. in Service	History of Churn: Condition	How long since washed. Days	Apparent Sanitary Condition
H	11/28/30	1000	12	Poor. Rollers and shelves loose and cracked. Wood somewhat rough and rather greasy.	3	Rather unsatisfactory. Moist curd in corners and crevices.
I	11/28/30	1000	3	Good. Wood smooth, free from excess grease.	1	Satisfactory.
J	11/28/30	1000	8	Good. Wood smooth and free from grease.	1	Very satisfactory.
Ka	11/28/30	900	12	Good. Wood smooth and almost free from grease.	1	Satisfactory. Air in plant very moist. Condensed water in churn.
Kb	11/28/30	900	18	Good. Wood smooth and almost free from grease.	1	Satisfactory.
L	3/2/31	1200	3	Fair. Roller cracked and splintered, but rest of wood fairly smooth. Rather greasy.	2	Rather unsatisfactory. Grease and curd in crevices.

Table 3 (continued)

Creamery and Churn*	Date of Exam.	History of Churn: Capacity in lbs. butter	Yrs. in Service	Condition	How long since washed. Days	Apparent Sanitary Condition
L	4/13/31	1200	3	Fair. Wood fairly smooth, but surfaces rather greasy.	2	Unsatisfactory. Count probably high. Slight odor.
M	3/2/31	1000	1	Very good. Wood smooth but slightly greasy.	2	Very unsatisfactory. Churn damp, doors closed. Slight odor. Probably very heavily infected.
N	3/2/31	700	14	Poor. Badly worn. Rollers and shelves loose. Wood pitted and rather greasy.	Just washed)	Unsatisfactory. Curd in crevices. Churn still damp when examined.
O	3/2/31	900	5	Good. Wood smooth and almost free from grease.	2	Satisfactory.
Pa	3/23/31	1000	3	Fair. Wood somewhat rough and rather greasy in spots.	2	Unsatisfactory. Churn rather moist. Slight odor.

Table 3 (continued)

Creamery and Churn*	Date of Exam.	History of Churn: Capacity in lbs. butter	Yrs. in Service	Condition	How long since washed. Days	Apparent Sanitary Condition
Pb	3/23/31	1000	8	Had not been used for a year. Thoroughly dried out. Wood badly cracked.	7	
Q	3/23/31	1000	3	Good. Wood very smooth and only slightly greasy.	2	Satisfactory.
R	3/23/31	1000	4	Good. Wood slightly pitted but free from grease.	Just washed.	Very satisfactory.
S	3/23/31	1000	6	Good. Wood slightly rough but fairly free from grease.	1	Satisfactory.
T	3/23/31	700	9	Fairly good. Wood smooth but somewhat greasy.	1	Unsatisfactory. Slight odor.
U	5/18/31	1200	3	Good. Wood fairly smooth but rather greasy. Butter often sticks.	2	Unsatisfactory. Slight odor.
V	5/18/31	900	5	Poor. Rollers cracked, shelves loose. Wood somewhat rough and slightly greasy.	2	Satisfactory.

Table 3 (continued)

Creamery and Churn*	Date of Exam.	History of Churn: Capacity in lbs. butter	Yrs. in Service	Condition	How long since washed. Days	Apparent Sanitary Condition
W	5/18/31	900	1	Very good. Wood smooth and free from grease.	Just washed	Very satisfactory. No grease or curd.
Xa	5/18/31	800	8	Fair. Wood fairly smooth but slightly greasy.	2	Fairly satisfactory.
Xb	5/18/31	800	18	Very poor. Rollers and staves cracked, shelves loose, large openings around bolt heads in shelves. Wood rather rough and pitted. Slightly greasy.	2	Fairly satisfactory.

* The capital letters designate the creameries and the small letters designate the churns in creameries with more than one churn.

of the newer ones were in poor condition. The wood in the older churns was commonly rougher and more pitted than that in the newer ones. In general, the churns which were washed without washing powder or lime showed more grease on the surface of the wood than those which were subject to regular treatments with these compounds. A notable exception is the churn in creamery E which was washed without these materials and which showed no accumulation of grease on the wood. This churn, however, had been in use for only six months. There was no apparent correlation between the use of lime or washing powder and the smoothness of the wood.

Quite a number of the churns examined were apparently in a fairly satisfactory sanitary condition but very few were classed as very satisfactory and many were classed as unsatisfactory. In the older churns especially, curd was lodged in the corners and crevices but where the churn had been quite carefully treated this curd was dry and odorless while in churns which had apparently been handled carelessly the curd was generally moist and putrid. Several churns were rather moist inside and in these a slight odor indicative of bacterial development was generally noted.

3. Discussion

The results indicate that there was a wide variation in the agar disc counts on churns in commercial use and that comparatively few of the churns examined were in a satisfactory sanitary condition. The organisms from churns with low counts generally included few types, chiefly members of the genus Bacillus, while the organisms from the churns with high counts generally included many types, largely cocci and other non-spore forming organisms. Some yeast and mold counts were made; these were always lower than the bacterial counts but were usually roughly proportional to them.

The washing procedures used differed widely and few of them could be considered as adequate for properly cleaning a churn. Many of the churns were washed without washing powder or lime and in these there was commonly a film of grease on the interior surfaces. Accumulations of curd in the corners and crevices were common in many churns; in carefully treated churns this curd was usually hard and dry and of no sanitary significance while in carelessly treated churns it was frequently moist and putrid.

There was apparently a closer correlation between the counts on the churns and the general sanitary conditions of the plants than there was between the counts on the churns and any of the other factors, such as capacities, years in service and general conditions of the churns.

B. Efficiencies of various methods of cleaning churns

The data obtained in the examination of churns in Iowa creameries gave little information as to the efficiencies of the various washing procedures used because there was no close correlation between these procedures and the counts on the churns. Probably the chief reason for this lack of correlation was that the temperatures and periods of exposure used were not based on careful determinations but were estimated by the plant managers. The efficiencies of various washing procedures were studied by subjecting the churns in the Iowa State College creamery to various treatments.

1. Normal procedure

The procedure regularly used in the Iowa State College creamery is designated the normal procedure and is as follows:

1. The excess fat is rinsed out with a little warm water.
2. The churn is filled one-third to one-half full of water (150 to 200 gallons) at 170° to 180°F., two pounds of soda ash added and the churn revolved in high gear for about 15 minutes and then drained.
3. The churn is filled about one-half full of water at 180° to over 200°F. and revolved in high gear for 15 to 20 minutes. It is then drained thoroughly and turned so that the door opening is about two-thirds of the way up; this results in stronger convection currents than if the churn is turned so that the open door is at the extreme

top. After the churn is thoroughly dry the door opening is covered with a piece of door screen on a frame which fits into the door opening. In some of the later trials a piece of muslin was used over the screen as an additional protection from air contamination. The churns were always very hot after washing with the normal procedure and the strong convection current set up aided in drying the churns rapidly. Once a week two pounds of lime are added to the last hot rinse. The churn is rinsed before each churning by filling one-third to one-half full of tap water at about 50°F. and revolving in high gear for about five minutes.

During the period from October 13, 1930 to April 4, 1932 agar disc counts were run from time to time on two churns washed with the normal procedure. Two churns, A and B, were used in this study. Churn A was a two roller type of 600 pounds capacity. It had been in service for five years and was in very good mechanical condition. The surface of the wood on the interior was slightly slivered in places but it was free from curd and grease. Churn B was a single roller type of 600 pounds capacity. It had been in service for four years and was in very good mechanical condition. The surface of the wood on the interior of this churn was slightly rough but it was not slivered and was free from grease and curd. Both of these churns were always in an apparently satisfactory sanitary condition.

Table 4 gives 53 counts on churn A. The bacterial counts ranged from .4 to 88 per sq. cm. and averaged 17.1. Using the arbitrary rating established in the details of the agar disc method, 24 counts were very satisfactory, 26 were satisfactory and 3 were rather unsatisfactory. The microflora generally included very few types and these were chiefly members of the genus Bacillus. The higher counts generally included more types and frequently some of the yellow coccus types. The yeast counts ranged from 0 to .25 per sq. cm. and averaged .04 and the mold counts ranged from 0 to 2.6 per sq. cm. and averaged .28. The counts recorded as zero are to be interpreted as meaning that no colonies developed on any of the whey agar discs prepared and not as meaning that there were no yeasts or molds in the churn. It is probable that the yeasts and molds were derived from contamination from the air after washing since the yeast and mold counts obtained after the churn had stood a day or two were commonly higher than those taken soon after washing. This contention is also borne out by the fact that the discs prepared from the ends of the churn and the barrel, which are not likely to be contaminated from the air, seldom showed any yeasts or molds while the shelves, which are subject to air contamination, nearly always showed yeasts or molds or both.

Ninety-two counts on churn B are recorded in table 5. The bacterial counts ranged from .3 to 685 per sq. cm. and averaged

Table 4

Agar disc counts on churn A after washing
with the normal procedure

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
1	1/5/31	2	41	0	0	Just washed
2	1/7/31	3	18	0	.04	Stood 1 day
3	1/8/31	3	16	0	0	Just washed
4	1/9/31	4	7.7	0	.05	Just washed
5	1/12/31	1	32	0	0	Just washed
6	1/13/31	3	20	0	.14	Just washed
7	1/15/31	3	28	.05	.03	Just washed
8	1/20/31	3	3.3	0	.15	Just washed
9	1/22/31	3	1.2	0	.63	Just washed
10	1/24/31	3	2.7	.01	.20	Just washed
11	1/26/31	3	47	0	.06	Just washed
12	1/27/31	2	28	.02	.06	Just washed
13	1/28/31	3	18	0	.10	Just washed

Table 4 (continued)

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
14	1/29/31	3	19	.20	.05	Just washed
15	2/5/31	2	27	.22	.10	Just washed
16	2/9/31	1	29	.25	.40	Stood 2 days
17	2/10/31	3	33	.10	.04	Just washed
18	2/11/31	2	33	0	.08	Just washed
19	2/14/31	4	2.3	.03	.08	Just washed
20	2/16/31	4	9.4	.10	0	Just washed
21	2/19/31	3	41	0	0	Just washed
22	2/26/31	4	14	.04	.07	Just washed
23	3/19/31	4	7.5	0	0	Just washed
24	3/26/31	4	57	0	.05	Just washed
25	3/28/31	4	34	.02	.04	Just washed
26	3/30/31	4	32	0	.14	Just washed
27	3/31/31	3	19	0	.02	Just washed
28	4/2/31	4	12	.02	.08	Just washed

Table 4 (continued)

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
29	4/4/31	4	14	.04	.04	Just washed
30	4/6/31	3	20	0	.10	Just washed
31	4/9/31	4	27	0	0	Just washed
32	4/10/31	4	14	.04	.07	Just washed
33	5/11/31	3	88	.1	.30	Just washed
34	6/9/31	3	20	.04	.56	Just washed
35	9/24/31	6	4.5	0	.73	Just washed
36	9/28/31	3	1.9	0	1.05	Just washed
37	9/29/31	5	1.1	.15	1.1	Just washed
38	10/1/31	5	1.4	0	1.60	Just washed
39	10/2/31	5	1.3	.15	1.03	Just washed
40	10/6/31	3	.8	0	.22	Just washed
41	10/7/31	4	5.4	.12	.37	Just washed
42	10/9/31	3	2.8	.04	.23	Just washed
43	10/12/31	4	.9	0	.26	Just washed

Table 4 (continued)

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
44	10/14/31	4	.4	0	.36	Just washed
45	11/2/31	3	11	0	.28	Just washed
46	11/3/31	4	55	0	.25	Just washed
47	11/4/31	4	9.8	0	.10	Just washed
48	11/10/31	4	2.4	.10	.13	Just washed
49	11/11/31	4	1.7	0	.42	Stood 1 day
50	11/17/31	3	1.0	.14	2.6	Stood 1 day
51	11/18/31	4	3.8	.03	.04	Just washed
52	11/20/31	4	2.2	.20	.46	Stood 1 day
53	11/25/31	2	1.5	0	.03	Just washed
	Average		17.1	.04	.28	

Table 5

Agar disc counts on churn B after washing with the normal procedure

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
1	10/13/30	6	9		.43	Just washed
2	10/16/30	4	24		.05	Just washed
3	10/18/30	7	18		.04	Just washed
4	10/23/30	3	43			
5	11/12/30	3	23		0	Stood 1 day
6	11/13/30	3	20		.50	Just washed
7	11/20/30	6	10	.21	1.05	Stood 2 days
8	12/12/30	3	9.7	.06	.44	Stood 1 day
9	1/5/31	4	18	0	0	Just washed
10	1/6/31	5	5	0	.06	Just washed
11	1/8/31	3	8	0	.03	Just washed
12	1/9/31	2	13	0	.15	Stood 1 day
13	1/12/31	1	27	.13	1.2	Stood 3 days

Table 5 (continued)

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
14	1/26/31	4	17	0	0	Just washed
15	1/27/31	3	18	.13	.25	Stood 1 day
16	1/29/31	1	20	.15	.8	Stood 3 days
17	2/3/31	4	11	.06	.06	Just washed
18	2/9/31	5	27	.08	.39	Stood 2 days
19	2/10/31	3	5.3	0	.08	Just washed
20	2/11/31	4	7.7	0	0	Just washed
21	2/12/31	1	2.0	0	.1	Just washed very carefully
22	2/14/31	5	13	.03	0	Just washed and limed
23	2/19/31	3	41	0	0	Just washed
24	2/21/31	5	2.8	0	.15	Just washed
25	2/23/31	5	44	0	0	Just washed
26	2/25/31	6	13	.1	.33	Stood 1 day
27	2/28/31	6	3.7	0	.01	Just washed
28	3/3/31	6	27	.02	.07	Just washed

Table 5 (continued)

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
29	3/5/31	7	9.8	.06	.22	Just washed
30	3/7/31	6	13	.06	.30	Just washed
31	3/9/31	6	29	.12	.03	Just washed
32	3/12/31	6	28	.08	.14	Just washed
33	3/16/31	6	44	0	.07	Just washed
34	3/24/31	6	9.4	0	.02	Just washed
35	3/28/31	6	19	.03	.04	Just washed
36	3/31/31	5	12	.03	.06	Just washed
37	4/6/31	4	15	.01	.04	Just washed
38	4/20/31	4	13	0	.02	Just washed
39	4/21/31	5	2.9	.02	.03	Just washed
40	4/24/31	5	6.8	0	.17	Stood 1 day
41	4/28/31	4	13	0	.06	Stood 1 day
42	4/30/31	5	2.8	0	.46	Stood 1 day
43	5/4/31	5	12	.12	.04	Just washed

Table 5 (continued)

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
44	5/5/31	5	4.9	0	.07	Just washed
45	5/11/31	4	1.8	.05	.22	Just washed
46	5/12/31	5	5.1	0	.27	Just washed
47	5/14/31	5	6.3	0	.19	Just washed
48	5/25/31	5	110	0	.04	Just washed
49	5/28/31	5	151	.03	.16	Just washed
50	5/29/31	5	86	0	.37	Just washed
51	6/1/31	5	18	.05	.71	Just washed
52	6/3/31	5	66	0	.02	Just washed
53	6/4/31	5	29	.05	1.04	Just washed
54	6/5/31	5	3.8	0	.13	Just washed
55	6/9/31	5	5.8	.13	.6	Just washed
56	6/10/31	5	13	.03	.14	Just washed
57	6/11/31	5	7.6	0	.10	Just washed
58	6/12/31	5	2.1	.04	.14	Just washed

Table 5 (continued)

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
59	6/18/31	5	5.2	0	.1	Just washed
60	6/24/31	5	6.0	0	.15	Stood 1 day
61	6/25/31	5	23	0	.13	Stood 1 day
62	6/26/31	5	10	0	.1	Stood 1 day
63	6/27/31	5	29	0	.1	Stood 1 day
64	6/17/31	5	16	0	.1	Stood 1 day
65	9/23/31	6	4.9	0	.86	Stood 1 day
66	9/29/31	5	1.4	.07	.7	Just washed
67	10/5/31	6	2.5	.04	1.0	Just washed
68	10/6/31	5	1.1	.08	.28	Just washed
69	10/7/31	5	1.0	.10	.32	Just washed
70	10/9/31	5	.5	.04	.26	Just washed
71	10/12/31	6	.3	0	.27	Just washed
72	10/20/31	4	1.0	.06	.28	Just washed
73	10/21/31	5	.5	0	1.17	Stood 1 day

Table 5 (continued)

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
74	10/27/31	6	21	.04	1.0	Stood 1 day
75	11/2/31	6	685	0	.4	Stood 2 days
76	11/4/31	6	10	.1	.16	Just washed
77	11/10/31	6	14	.03	.08	Just washed
78	11/11/31	6	1.3	0	.05	Just washed
79	11/12/31	6	2.3	.16	.18	Stood 1 day
80	11/17/31	6	1.5	.03	.19	Just washed
81	11/18/31	6	1.4	.03	.19	Stood 1 day
82	11/20/31	6	1.6	.05	.44	Stood 1 day
83	11/24/31	6	2.3	0	.01	Just washed
84	11/26/31	6	1.0	.03	.12	Stood 1 day
85	12/7/31	6	.6	0	.07	Just washed
86	12/9/31	6	1.1	0	.26	Stood 1 day
87	12/11/31	6	1.7	0	.01	Stood 1 day
88	12/15/31	5	.6	.01	.38	Just washed

Table 5 (continued)

Trial	Date of Exam.	No. of discs	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Remarks
89	1/6/32	6	2.3	0	.23	Stood 1 day
90	1/21/32	6	1.0	0	.14	Stood 1 day
91	3/9/32	4	2.2	.04	.09	Stood 1 day
92	4/4/32	4	9.8	.07	.39	Just washed
	Average		22	.03	.27	

22. Excluding one count (Nov. 2, 1931) which is excessively high for no apparent reason the range was from .3 to 151 per sq. cm. and the average 15.4. Forty-nine of the counts were very satisfactory, 38 were satisfactory, four were rather unsatisfactory and one was very unsatisfactory. The microflora of this churn was very much the same as that of churn A in that it included very few types, chiefly organisms belonging to the genus Bacillus. Also, the higher counts generally included more types than the lower counts. The yeast counts from churn B ranged from 0 to .21 and averaged .03 and the mold counts ranged from 0 to 1.2 and averaged .27. Here also, as with churn A, there was evidence that the yeasts and molds appearing on the agar discs were derived chiefly from the air and not from the survival of resistant types. Excluding the one high value (churn B, Nov. 2, 1931) the average bacterial count on churns A and B is 16.1 per sq. cm. Seventy-three of the counts were very satisfactory, 64 were satisfactory, and 7 were rather unsatisfactory. These counts are much lower than most of those obtained on churns in commercial plants even though many of the washing procedures used on these latter churns were apparently as adequate as the normal procedure used at the Iowa State College creamery. Not only was the average count low but the counts were uniform and the microflora was much the same in every case. Often the microflora from the discs looked

almost like a pure culture of one of the Bacillus types.

2. Treatment of normally washed churns

The routine agar disc counts made on the churns in the Iowa State College creamery after washing with the normal procedure showed that, even though the churns were usually in a satisfactory sanitary condition, a number of organisms, particularly spore forming bacteria, were still present. Experiments were conducted in which the normally washed churns were treated with various compounds in an attempt to reduce the numbers of organisms present in these churns.

a. Use of chlorine compounds on normally washed churns

Chlorine compounds have been used successfully in the sterilization of various pieces of dairy equipment but they have not been used extensively in churn treatment. The data obtained in the examination of churns in commercial plants involved four counts on chlorine treated churns. Three of the chlorine treated churns were classed as very satisfactory and the other one was unsatisfactory. In order to throw more light on the efficiency of chlorine compounds in churn treatment experiments were conducted with three chlorine compounds, namely, sodium hypochlorite, chlorinated lime and calcium hypochlorite, in order to determine whether or not these were capable of reducing the numbers of organisms left in the churn after treatment with the normal procedure.

A stock solution of sodium hypochlorite was prepared according to the method outlined by Zoller (23). It contained about 3 per cent of available chlorine. The chlorinated lime was purchased in sealed one pound cans; the labels stated the product contained over 30 per cent of available chlorine. A calcium hypochlorite stock solution was prepared from a powdered commercial product labeled as containing 65 per cent of available chlorine; the stock solution contained about 2.5 per cent available chlorine.

The method used for the chlorine treatments was as follows:

The quantity of chlorine compound calculated to give the desired concentration of available chlorine was thoroughly mixed with 10 gallons of tap water and heated to the desired temperature with steam. A sample was taken for the determination of the available chlorine and the solution then added to the churn. The churn was revolved in high gear for the desired time and a sample of the chlorine rinse taken for the determination of the available chlorine remaining in the solution after exposure. The temperatures after exposure, in the trials in which these were recorded, were also taken at this time.

Agar disc counts were run on the churns before the chlorine treatments and again after they had been thoroughly drained and dried following treatment. Sterile litmus milk was used to moisten the surfaces examined in order to eliminate any residual chlorine (see methods).

1. Sodium hypochlorite

The results of treating normally washed churns with sodium hypochlorite solutions are shown in table 6. Churns A and B (see treatment with normal procedure) were used. In 4 of the 11 trials solutions containing from 56 to 60 ppm. available chlorine and at temperatures ranging from 118° to 122°F. were exposed to the churn for 15 minutes. The concentrations of available chlorine after exposure in these four trials ranged from 9 to 20 ppm. In three other trials the concentrations of available chlorine ranged from 60 to 63 ppm., the temperatures from 70° to 76°F. and the periods of exposure were 15 minutes. After exposure the available chlorine in two of these trials was 12 and 15 ppm.; in the other trial the sample taken for titration was lost. In two trials solutions containing 102 and 96 ppm. available chlorine and at temperatures of 115° and 120°F., respectively, were exposed to churn B for 15 minutes; the concentrations of available chlorine after exposure were 22 and 24 ppm., respectively. In one trial a solution containing 60 ppm. available chlorine at a temperature of 120°F. was exposed for 45 minutes. The available chlorine after exposure in this trial was 5 ppm. In the remaining trial a solution containing 98 ppm. available chlorine and at a temperature of 70°F. was exposed to the churn for 30 minutes. After exposure the available chlorine content was 30 ppm.

The bacterial counts before treatment with chlorine ranged

Table

Treatment of normally washed chu

Trial	Date	Churn	Avail. chlorine before exposure ppm.	Period of exposure min.	Temp. before exposure °F.	Avail. chlorine after exposure ppm.	Agar disc counts chlorine treat: Bacteria per sq. cm.	Yeasts per sq. cm.
1	2/19/31	A	58	15	120	14	41	0
2	2/21/31	B	60	15	122	20	2.8	0
3	2/25/31	B	56	15	118	16	13	.1
4	2/26/31	A	63	15	76		14	.04
5	2/28/31	B	63	15	70	12	3.7	0
6	3/3/31	B	60	15	120	9	27	.02
7	3/5/31	B	60	45	120	5	9.8	.06
8	3/7/31	B	60	15	70	15	13	.06
9	3/9/31	B	98	30	70	30	29	.12
10	3/12/31	B	102	15	115	22	28	.08
11	3/16/31	B	96	15	120	24	44	0
						Average	20.5	.04

Table 6

f normally washed churns with sodium hypochlorite

.. ne re	Agar disc counts before chlorine treatment			Agar disc counts after chlorine treatment			Rinse water exposed before chlorine treatment		Bact per chlo solu expo
	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Period of exposure min.	Bacteria per ml.	
	41	0	0	.6	0	0	5	10,000	
	2.8	0	.15	.2	0	0	5	13,700	
	13	.1	.3	.5	0	.03	5	10,800	
	14	.04	.07	1.2	0	.02	15	37,500	1
	3.7	0	.01	.06	0	0	15	5,500	
	27	.02	.07	.3	0	.04	15	6,000	
	9.8	.06	.2	1.3	0	.1	15	35,000	
	13	.06	.3	2.4	.01	.03	15	41,000	
	29	.12	.03	.4	0	.12	15	52,000	
	28	.08	.14	1.7	.02	.02	15	200,000	
	44	0	.07	.3	0	0	15	16,600	
	20.5	.04	.12	.81	.003	.03		38,909	

Table 6

ed churns with sodium hypochlorite

counts before treatment		Agar disc counts after chlorine treatment			Rinse water exposed before chlorine treatment		Bacteria per ml. of chlorine solution after exposure
easts per . cm.	Molds per sq. cm.	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Period of exposure	Bacteria per ml.	
					min.		
0	0	.6	0	0	5	10,000	72
0	.15	.2	0	0	5	13,700	10
.1	.3	.5	0	.03	5	10,800	22
.04	.07	1.2	0	.02	15	37,500	101
0	.01	.06	0	0	15	5,500	25
.02	.07	.3	0	.04	15	6,000	30
.06	.2	1.3	0	.1	15	35,000	49
.06	.3	2.4	.01	.03	15	41,000	20
.12	.03	.4	0	.12	15	52,000	10
.08	.14	1.7	.02	.02	15	200,000	7
0	.07	.3	0	0	15	16,600	20
.04	.12	.81	.003	.03		38,909	33.3

from 2.8 to 44 per sq. cm. and averaged 20.5 while those obtained after the chlorine treatment ranged from .06 to 2.4 and averaged .81. The yeast counts before treatment ranged from 0 to .12 per sq. cm. and averaged .04 while after treatment no yeast colonies were detected on the agar discs in nine of the trials and in the other two trials the counts were only .01 and .02. The mold counts before treatment ranged from 0 to .3 per sq. cm. and averaged .12, and after treatment from 0 to .12 and averaged .03. The lowest bacterial count following the use of chlorine was obtained when the churn had been treated for 15 minutes with a solution containing 63 ppm. available chlorine and at a temperature of 70°F. and the highest count following the use of chlorine was obtained when the churn had been treated in very nearly the same manner. The bacterial counts obtained by the rinse method before the chlorine treatments ranged from 5,500 to 200,000 per ml. and averaged 38,909 (using 10 gallons of water per churn) while the bacterial counts on the chlorine solution after exposure to the churn ranged from 7 to 101 per ml. and averaged 33.3.

2. Chlorinated lime

Table 7 gives the results of the treatment of a normally washed churn (churn B. See treatment with normal procedure) with chlorinated lime. The concentrations of available chlorine used were very much the same in all of the 11 trials, ranging from 88 to 105 ppm. In nine of the trials the temperatures of

Table

Treatment of a normally washed

Trial	Date	Avail. chlorine before exposure ppm.	Period of exposure min.	Temp. before exposure °F.	Avail. chlorine after exposure ppm.	Agar disc coun chlorine tre: Bacteria per sq. cm.	Yeast per sq. cm
1	4/20/31	102	15	108	23	13	0
2	4/21/31	105	5	115	30	2.9	.02
3	4/24/31	104	15	115	12	6.8	0
4	4/28/31	88	20	110	8	13	0
5	4/30/31	97	10	108	28	2.8	0
6	5/4/31	97	15	110	10	12	.03
7	5/5/31	100	5	80	42	4.9	0
8	5/11/31	98	15	110	15	1.8	.01
9	5/12/31	104	10	112	27	5.1	0
10	5/14/31	104	23	114	11	6.5	0
11	5/25/31	98	20	139	6	110	0
					Average	16.2	.00

Table 7

Treatment of a normally washed churn with chlorinated lime

Temp. before exposure °F.	Avail. chlorine after exposure ppm.	Agar disc counts before chlorine treatment			Agar disc counts after chlorine treatment		
		Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.
108	23	13	0	.02	.06	0	.01
115	30	2.9	.02	.03	.02	0	.03
115	12	6.8	0	.17	.36	0	.03
110	8	13	0	.06	.22	0	.09
108	28	2.8	0	.46	.12	0	.1
110	10	12	.03	.14	.26	0	.04
80	42	4.9	0	.07	.19	0	.07
110	15	1.8	.01	.22	.06	0	.03
112	27	5.1	0	.27	.13	0	.09
114	11	6.3	0	.19	.14	0	.12
139	6	110	0	.04	.76	0	.02
	Average	16.2	.006	.15	.22	0	.06

the solution ranged from 108° to 115°F. and in the other two trials the temperatures were 80° and 139°F. The periods of exposure varied from 5 to 23 minutes. After exposure the available chlorine concentrations in the solutions ranged from 6 to 42 ppm. The bacterial counts before treatment with chlorinated lime ranged from 1.8 to 110 per sq. cm. and averaged 16.2 while the counts after the chlorine treatment ranged from .02 to .76 per sq. cm. and averaged .22. Only three trials showed any yeasts before the chlorine treatment and in these the counts were .02, .03 and .01 per sq. cm. while after treatment there were no yeasts on any of the discs. The mold counts before treatment ranged from .02 to .46 per sq. cm. and averaged .15 and after treatment they ranged from .01 to .12 per sq. cm. and averaged .06.

3. Calcium hypochlorite

The results of 11 trials in which calcium hypochlorite solutions were used to treat a normally washed churn (churn B. See treatments with normal procedure) are shown in table 8. The concentrations of available chlorine in the solutions before exposure to the churn ranged from 95 to 122 ppm., the temperatures ranged from 80° to 135°F. and the periods of exposure ranged from 13 to 18 minutes. In nine of these trials the temperatures before exposure were very much the same, ranging from 118° to 125°F. After exposure the concentrations of available chlorine

Table

Treatment of a normally washed chu

Trial	Date	Avail. chlorine before exposure ppm.	Period of exposure min.	Temp. before exposure °F.	Avail. chlorine after exposure ppm.	Temp. after exposure °F.	Agar ch Bacte per sq. (
1	5/28/31	104	18	122	7	92	151
2	5/29/31	99	18	124	9	95	86
3	6/1/31	110	15	120	9	93	18
4	6/3/31	100	15	80	10		66
5	6/4/31	105	15	122	14	95	29
6	6/5/31	95	16	121	12	90	3.
7	6/9/31	105	18	122	6	104	5.
8	6/10/31	113	13	135	11	106	13
9	6/11/31	100	18	121	6	104	7.
10	6/12/31	122	17	125	13	98	2.
11	6/18/31	115	18	118	9	96	5.
					Average		35.

Table 8

tment of a normally washed churn with calcium hypochlorite

Avail. chlorine after exposure ppm.	Temp. after exposure °F.	Agar disc counts before chlorine treatment: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Agar disc counts after chlorine treatment: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.
7	92	151	.03	.16	.10	0	.12
9	95	86	0	.37	.13	0	.12
9	93	18	.05	.71	.35	0	.2
10		66	0	.02	.05	0	.07
14	95	29	.05	1.2	.08	0	.13
12	90	3.8	0	.13	0	0	.05
6	104	5.8	.05	.60	.24	.01	.34
11	106	13	.03	.14	.17	0	.09
6	104	7.6	0	.10	.23	.03	.35
13	98	2.1	.04	.14	.02	0	.07
9	96	5.2	0	.1	.83	0	.05
Average		35.2	.02	.33	.2	.004	.14

ranged from 6 to 14 ppm., and the temperatures ranged from 90° to 106°F. in 10 of the trials and in the other trial it was not taken. The bacterial counts before treatment ranged from 2.1 to 151 per sq. cm. and averaged 35.2 while after treatment they ranged from 0 to .83 per sq. cm. and averaged .2. The yeast counts before treatment ranged from 0 to .05 per sq. cm. and averaged .02 while after treatment the count was 0 in 9 trials and in the other two they were .01 and .03 per sq. cm. The mold counts before treatment ranged from .02 to 1.2 per sq. cm. and averaged .33 while after treatment they ranged from .05 to .35 per sq. cm. and averaged .14.

4. Discussion

The results indicate that treatments with solutions of sodium hypochlorite, chlorinated lime and calcium hypochlorite resulted in significant reductions in the organisms in normally washed churns. The counts after treatment were all so low and the variations so small that no definite conclusions could be drawn as to the effects on the final counts of variations in concentration of available chlorine and temperature and periods of exposure; there was apparently less correlation between these factors and the count following treatment than between the counts before and after treatment. There was evidently no difference in the efficiencies of the three chlorine compounds used. In general, the decreases in available chlorine during the exposures to the churns were greater when the temperatures were comparatively high and the periods of exposure comparatively long. In the treatments with sodium hypochlorite, where the counts by the rinse method were also run, the counts on the chlorine rinse after exposure to the churn were all very low as compared to the counts on the water used to rinse the churn before treatment. Since nothing was used to counteract the chlorine carried over in plating, the residual chlorine may have had an inhibitory effect on the organisms in the plates.

b. Use of sodium chloride on normally washed churns

The restraining effect of sodium chloride on the organisms contained in butter suggested that this substance might be used in controlling the microflora of churns. Inasmuch as the usual concentration of sodium chloride in the serum of butter is from 15 to 18 per cent while a saturated aqueous solution contains from 35.7 to 39.8 per cent, it was thought that the use of a saturated aqueous solution might be effective in reducing the numbers of organisms in a churn.

In the investigations on the extent of contamination of churns in commercial use a count was obtained on one churn (creamery C) after it had been treated with the usual procedure and then another count a few months later after it had been treated with salt solution. The procedure for this salt treatment involved rinsing out the fat, adding 80 gallons of water and 40 pounds of butter salt to the churn, heating the solution to nearly boiling with steam and revolving the churn for five minutes in high gear. After the churn had been drained and dried the entire inner surface was found to be covered with a layer of salt crystals. Agar disc counts taken before this treatment was used showed an average of 228 bacteria, and 4.9 molds per sq. cm., while the counts taken later when the salt treatment had been used showed only 36 bacteria and .7 molds per sq. cm. These results suggest that the salt treatment was effective.

Several trials were run to determine the effect of saturated salt solutions on the organisms in a normally washed churn (churn A. See normal procedure). The saturated solution was prepared by placing about four gallons of water in a five gallon stone jar and adding an excess of butter salt. The mixture was stirred thoroughly and allowed to stand over night before being used in order to insure saturation. Agar discs were prepared from the normally washed churn and it was then treated by adding three gallons of saturated salt solution and revolving in high gear for five minutes with the rollers working. The churn was then drained and dried and allowed to stand from 6 to 48 hours before agar discs were again prepared from it. An experiment was conducted to determine whether or not the salt picked up by the discs from the surface of the churn had any inhibitory effect on the development of the organisms on the disc. The following procedure was used: The churn, after treatment with the normal procedure, was rinsed for 10 minutes with 10 gallons of tap water and a sample of the rinse water plated on beef infusion agar. Two sets of plates were poured; to each plate in one set 1 ml. of sterile saturated sodium chloride solution was added. After incubation for four days at room temperature, no apparent difference between the counts on the two sets of plates could be detected. The results secured in seven trials in which a normally washed churn (churn A. See normal procedure) was treated with saturated sodium chloride solutions are shown in table 9. The bacterial counts before treatment ranged from 14 to 57 per sq. cm. and averaged 28.1 while after treatment they ranged from 11 to 41 per sq. cm. and averaged 27.1. The yeast counts before treatment ranged from 0 to .05 per sq. cm. and averaged .02 while the counts after treatment ranged from 0 to .08 per sq. cm. and averaged .03. The mold counts before treatment ranged from 0 to .14 per sq. cm. and averaged .06 while after treatment they ranged from .03 to .28 per sq. cm. and averaged .16.

The results indicate that saturated salt solutions did not significantly reduce the numbers of bacteria in a normally washed churn. The organisms left after the hot water treatment were apparently predominantly of the resistant types; the salt solution could not be expected to be as effective against these as it would against the non-resistant types commonly found in highly contaminated churns. The microflora of the agar discs showed

Table 9

Treatment of a normally washed churn with saturated sodium chloride solutions

Date	Hours after treatment with normal procedure	Counts after treatment with normal procedure: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Hours after treatment with salt solution	Counts after treatment with salt solution: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.
3/26/31	6	57	0	.08	6	41	.04	.03
3/28/31	4	34	.05	.04	48	30	.08	.22
3/30/31	4	32	0	.14	16	37	0	.08
3/31/31	4	19	0	.02	16	33	0	.19
4/4/31	6	14	.04	.04	48	11	.03	.22
4/9/31	4	27	0	0	16	20	.03	.28
4/10/31	4	14	.05	.07	16	18	.05	.11
	Average	28.14	.02	.06		27.14	.03	.16

that the discs prepared after treatment included more types than the discs prepared before treatment. This suggests that the salt solution, which was by no means sterile, probably carried into the churn a number of salt tolerant types. The apparent increase in yeast and mold counts after treatment was probably due to air contamination since there was ample opportunity for such contamination while the churn was allowed to stand after treatment. It is of interest to note that in the two trials in which the counts were taken 48 hours after the churn had been treated with salt solution there was an apparent decrease in the bacterial counts.

3. Treatment of highly contaminated churns

The results of the agar disc counts on normally washed churns indicated that treatment with hot water was effective in maintaining a churn in a satisfactory sanitary condition and the results of the experiments with chlorine solutions showed that when the initial count was low the count after treatment was commonly low while when the initial count was high the count after treatment was usually high. Since the churns used in these previous experiments were never highly contaminated investigations were made on the treatment of highly contaminated churns with chlorine compouhds and hot water.

a. Use of chlorine compounds on highly contaminated churns

Two chlorine compounds, sodium hypochlorite and a commercial chloramine preparation, were employed in the studies on the use of chlorine compounds in the treatment of highly contaminated churns. A stock solution of sodium hypochlorite was prepared as follows: One hundred grams of powdered calcium hypochlorite labeled as containing over 65 per cent available chlorine were dissolved in two liters of water and 70 grams of sodium carbonate added and thoroughly mixed with the solution. The precipitate which formed was filtered off and the resultant solution of sodium hypochlorite contained over 2.5 per cent available chlorine. The chloramine compound used was a washing and sterilizing powder labeled as containing over four per cent available chlorine.

The efficiency of the chlorine solutions was determined by making counts on the churns by both the agar disc and the rinse methods before and after treatment. Both methods were used because with the agar disc method on highly contaminated churns the colonies are frequently too numerous to be counted. In the rinse method 10 gallons of water were used to rinse the churn. When temperatures higher than that of tap water were to be used the water was warmed with steam so that after exposure it would have the approximate temperature desired for the chlorine treatment but in no case was the temperature before exposure more than 125°F. After revolving for 10 minutes a sample of the rinse water for plating was taken with a sterile 5 ml. pipette. The water was left in the churn and, if necessary, more water was added to give the desired fullness; the rinse water was left in the churn in order to eliminate the mechanical removal of micro-organisms by it. The calculated amount of chlorine solution or compound was then added and, if necessary, the solution was heated with steam to the desired temperature. The churn was revolved for the desired period, and then the temperature and a sample of the chlorine rinse for the determination of the available chlorine after treatment were taken. Also, a one ml. sample for plating was taken with a sterile pipette and mixed with 9 ml. of sterile litmus milk. The churn was then drained and rinsed with 10 gallons of tap water for the determination of the count by the rinse method. It was then drained and dried and an agar disc count made on it. The available chlorine of the solution in the churn before exposure was approximated by adding to 10 gallons of water an amount of sodium hypochlorite or chloramine compound calculated to give a dilution equal to that in the churn and determining the available chlorine content. Sterile litmus milk was used in making the dilutions in plating the samples of waters used to rinse the churn before and after treatment in order to eliminate any residual chlorine in the water exposed to the churn after treatment.

Two highly contaminated churns were used in these experiments. Churn C was a small experimental churn of 70 pounds capacity, which had been in use about two years. It was in very good mechanical condition and the wood was also in good condition but was slightly rough in places. Since this churn was not in regular use during the course of the experiments it was allowed to become excessively contaminated between the chlorine treatments by washing carelessly after agitating about a gallon of buttermilk in it for several minutes. This process was repeated two or three times between trials so that the churn was very highly contaminated when it was treated with chlorine. Churn F was a 300 pound dual type which had been in service for about 12 years. The wood was in rather poor condition in that it was somewhat spongy and slightly rough. It had not been used for a year or two but had been washed with the normal procedure about a month previous to its use in these studies. Incomplete drainage had resulted in enough moisture being left in the churn to promote mold growth to the extent that areas of profuse growth were visible on the interior surface.

1. Sodium hypochlorite

The results obtained by treating highly contaminated churns with sodium hypochlorite solutions are shown in table 10. The results of two trials with a normally washed churn (churn B. See normal procedure) are also recorded in this table for comparison with the results obtained on highly contaminated churns. (Churns C and F. Just described). In the first trial with a normally washed churn a solution containing 96 ppm. available chlorine at a temperature of 102°F. was exposed to

Trial	Date	Churn	Fullness of churn	Chlorine Solution					
					Before Exposure		After Exposure		
				Period of exposure min.	Temp. °F.	Avail. chlorine ppm.	Temp. °F.	Avail. chlorine ppm.	Bact per afte posu chur
1	12/9/32	B	1/20	10	102	96	76	10	
2	12/11/32	B	1/20	15	100	125	78	5	
3	1/8/32	C	1/3	10	70	93	72	45	55
4	1/14/32	C	1/3	10	110	104	106	50	26
5	1/22/32	C	1/3	10	113	112	109	50	2
6	1/28/32	C	1/3	30	122	141	112	19	6
7	2/5/32	C	1/3	30	125	133	115	26	4
8	2/11/32	C	1/3	30	117	105	98	16	12
9	2/18/32	C	1/3	30	121	130	110	39	6
10	3/18/32	C	3/4	60	142	75	133	18	8
11	3/14/32	F	1/3	30	128	126	113	32	
		Average of 8 trials with churn C							14

Table 10

Treatment of highly contaminated churns with sodium hy

...olution: ...r Exposure: Avail. chlorine (ppm.)	...olution: Bacteria per ml. after exposure to churn	Rinse water before chlorine treatment: Period of exposure (min.)	Rinse water before chlorine treatment: Plate Counts: Water from tap: Bacteria per ml.	Rinse water before chlorine treatment: Plate Counts: Water after exposure to churn: Bacteria per ml.	Rinse water before chlorine treatment: Plate Counts: Water after exposure to churn: Yeasts per ml.	Rinse water before chlorine treatment: Plate Counts: Water after exposure to churn: Molds per ml.	Rinse water aft...: Period of exposure (min.)	Rinse water aft...: Water from tap: Bacteria per ml.
10		5	40	4,700	2	5	5	240
5		5	8	2,700	0	0	5	
45	550	10	11	6,200,000	94	10	10	18
50	260	10	30	1,030,000	77	30	10	10
50	20	10	0	14,600,000	180	10	10	3
19	60	10	2	5,700,000	550	70	10	24
26	40	10	10	2,540,000	430	160	10	10
16	120	10	3	8,500,000	470	1,020	10	22
39	60	10	1	1,360,000	255	125	10	16
18	80	10	2	3,300,000	570	55	10	10
32	2	10	14	3,700,000	20,000	13,000	10	17
	149		7.4	5,404,000	328	185		14.1

.0

rns with sodium hypochlorite

Period of exposure min.	Rinse water after chlorine treat.: Water from tap: Bacteria per ml.	Plate Water to: Bacteria per ml.	Counts after exposure churn: Yeasts per ml.	Molds per ml.	Agar disc counts before chlorine treatment: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Agar disc after chlorine treatment: Bacteria per sq. cm.	Yeas[ts] per sq. c[m.]
5	240	1,870	2	0	1.1	.01	.26	.16	0
5					1.7	0	.01	.75	0
10	18	850,000	9	45	>2,000	43	.64	500	
10	10	1,600	1	14	643	.05	.19	20	0
10	3	4,900	1	1	>2,000	4.2	.17	86	0
10	24	175,000	67	10	>2,000	6.1	.61	13	
10	10	35,000	51	19	1,700	6.9	.29	2.3	0
10	22	119,000	146	60	1,500	5.3	1.4	4.7	0
10	16	64,000	0	0	1,500	.3	.32	9.4	
10	10	12,000	0	0	>2,000	0	.24	7.7	0
10	17	20,000	0	0	>2,000			144	0
	14.1	158,000	34	19		8.2	.48	80	

chlorine treat. Counts after exposure churn: Yeasts per ml.	Molds per ml.	Agar disc counts before chlorine treatment: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Agar disc counts after chlorine treatment: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.
2	0	1.1	.01	.26	.16	0	.1
		1.7	0	.01	.75	0	.24
9	45	>2,000	43	.64	500	.2	.03
1	14	643	.05	.19	20	0	0
1	1	>2,000	4.2	.17	86	0	0
67	10	>2,000	6.1	.61	13	.06	.02
51	19	1,700	6.9	.29	2.3	0	.05
146	60	1,500	5.3	1.4	4.7	0	.08
0	0	1,500	.3	.32	9.4	.01	.07
0	0	>2,000	0	.24	7.7	0	.03
0	0	>2,000			144	0	.05
34	19		8.2	.48	80	.03	.04

the churn for 10 minutes. After exposure the concentration of available chlorine was 10 ppm. and the temperature 76°F. The water used to rinse the churn before the chlorine treatment had a plate count of 4,700 bacteria, 2 yeasts and 5 molds per ml. while the water exposed to the churn after the treatment showed 1,870 bacteria, 2 yeasts and 0 molds. The agar disc counts before treatment were 1.1 bacteria, .01 yeasts and .26 molds per sq. cm. while the counts after treatment were .16 bacteria, 0 yeasts and .1 mold. In the second trial with a normally washed churn a solution containing 125 ppm. available chlorine, at a temperature of 100°F. was exposed to the churn for 15 minutes. After exposure the concentration of available chlorine was 5 ppm. and the temperature 78°F. The count by the rinse method before treatment showed 2,700 bacteria, 0 yeasts and 0 molds per ml. Counts were not secured by the rinse method after the chlorine treatment. The agar disc counts before treatment showed 1.7 bacteria, 0 yeasts and .01 molds per sq. cm. while after treatment the counts were .75 bacteria, 0 yeasts and .24 molds.

Eight trials were run on churn C which was very highly contaminated in every case. The concentrations of available chlorine of the solutions used ranged from 75 to 141 ppm., the temperatures from 70° to 142°F. and the periods of exposure from 10 to 60 minutes. The churn was filled three-fourths full in one trial and one-third full in the other trials. After exposure the available chlorine in the solutions ranged from 16 to 50 ppm. and the temperatures from 72° to 133°F. The bacterial counts on the chlorine solutions after exposure to the churn varied from 2 to 550 per ml. and averaged 149. The bacterial counts by the rinse method before treatment ranged from 1,030,000 to 14,600,000 per ml. and averaged 5,404,000 while after treatment they ranged from 1,600 to 850,000 per ml. and averaged 158,000. The yeast counts before treatment ranged from 77 to 570 per ml. and averaged 328 while after treatment they ranged from 0 to 146 per ml. and averaged 34. The mold counts before treatment ranged from 10 to 1,020 per ml. and averaged 185 while after treatment they ranged from 0 to 60 per ml. and averaged 19.

The agar discs prepared from the churn before treatment in the eight trials with churn C were usually so heavily seeded that the numbers of bacteria per square centimeter had to be estimated. In one trial the count was 643 per sq. cm. while in the other trials the estimates ranged from 1,500 to more than 2,000 per sq. cm.; after treatment the bacterial counts ranged from 2.3 to 500 per sq. cm. and averaged 80. The yeast counts before treatment ranged from 0 to 43 per sq. cm. and averaged 8.2 while after treatment the counts were 0 in five trials and in the other three they were .2, .06, and .01 per sq. cm.

Before treatment the mold counts ranged from .17 to 1.4 per sq. cm. and averaged .48 while after treatment they ranged from 0 to .08 and averaged .04.

In the one trial with churn F a solution containing 126 ppm. available chlorine at a temperature of 128°F. was exposed to the churn for 30 minutes. After exposure the concentration of available chlorine was 32 ppm. and the temperature was 113°F. The plate count on the chlorine solution after exposure showed only 2 bacteria per ml. and no yeasts or molds. The counts by the rinse method before treatment showed 3,700,000 bacteria, 20,000 yeasts and 13,000 molds per ml., while after treatment the counts were 20,000 bacteria, and 0 yeasts and 0 molds per ml. The agar discs prepared before treatment were completely overgrown with molds in two days but at the end of one day the bacteria were estimated at more than 2,000 per sq. cm. The agar disc counts after treatment showed 144 bacteria, 0 yeasts and .05 molds per sq. cm.

The results of treating highly contaminated churns with sodium hypochlorite solutions show that there was regularly a significant reduction in the numbers of microorganisms in churns when they were treated with solutions containing 75 to 141 ppm. available chlorine. In comparing the results obtained in the trials with normally washed churns with those obtained in the trials with highly contaminated churns it can be seen that there is a correlation between the counts before and after treatment; this agrees with the observations in the previous experiments with chlorine solutions on normally washed churns. The results obtained with churn F are especially significant since the very high contamination of yeasts and molds was apparently completely eliminated by the chlorine solution. Air contamination probably accounted for the very few molds which appeared on the agar discs prepared after treatment of the churns.

The results obtained in the eight trials with churn C permit a comparison of the effects of variations in concentration of available chlorine and the temperature and time of exposure on the efficiencies of the chlorine solutions. The highest counts after treatment by both the agar disc and rinse methods were obtained after the churn had been treated for 10 minutes with a solution containing 93 ppm. available chlorine at a temperature of 70°F. This was the lowest temperature and the shortest period of exposure used in any of the trials. The lowest count by the rinse method was obtained after the churn had been treated with approximately the same concentration of chlorine for the same period but at a temperature of 110°F. The lowest agar disc count was obtained on a churn which had been treated with a solution containing 133 ppm. available chlorine at a temperature of 125°F. for 30 minutes.

It is reasonable to assume that the flora was not uniform in all the trials and accordingly the results may be variable but, in general, high concentrations of available chlorine, high temperatures and long exposures resulted in comparatively high efficiences. The temperature of the solutions seemed to be a more important factor in determining the efficiencies than the available chlorine concentrations and the periods of exposure. The decrease in available chlorine was greatest with the high temperatures and long exposures but in every trial there was considerable residual chlorine in the solutions after exposure.

The microflora from the highly contaminated churns resembled the microflora of high count churns encountered in the study of churns in commercial plants. Many types of organisms were usually represented and the yellow micrococci were often predominant. After the chlorine treatments there were usually very few types represented and these were chiefly members of the genus Bacillus.

It is significant that the chlorine solutions after exposure to the churn contained comparatively few bacteria and no yeasts or molds while the waters exposed to the churn after the chlorine treatments always contained much larger numbers of bacteria and often significant numbers of yeasts and molds. This suggests that there are certain infection foci in the churn which do not have sufficient contact with the sterilizing medium and which are the principal sources of contamination of the water used to rinse the churn after the chlorine treatments. That organisms are harbored in these more or less protected places is also shown by the fact that churn F soon again became highly contaminated with molds after it had stood for a few days.

2. Chloramine preparation

The results obtained in the attempts to reduce the contamination in churns with hot water and with chlorine compounds suggested that a combination of the two might be even more successful than either alone. Since hypochlorite solutions lose their available chlorine rather rapidly at high temperatures a chloramine preparation was used in trials along this line.

The results of five trials in which a highly contaminated churn (churn C) was treated with chloramine solutions are shown in table 11. The churn was filled one-third full in every trial. In the first three trials the concentrations of available chlorine and the temperatures of exposure were approximately the same while the periods of exposure varied. Before exposure the concentrations of available chlorine were 113, 101 and 93 ppm. and the temperatures 192°, 190° and 188°F., respectively. After exposure the available chlorine concentrations were 91, 88 and 84 ppm. and the temperatures 176°, 165° and 158°F., respectively. In the first trial where the period of exposure was 20 minutes the chlorine solution after exposure contained 9,200 bacteria per ml. The counts by the rinse method before treatment showed 7,300,000 bacteria, 400 yeasts and 95 molds per ml., Treatment of a highly contamin

Trial	Date	Chlorine Solution: Period of exposure min.	Before Exposure: Temp. °F.	Before Exposure: Avail. chlorine ppm.	After Exposure: Temp. °F.	After Exposure: Avail chlorine ppm.	Bacteria per ml. after exposure to churn	Rinse w: Water from tap Bacteria per ml.
1	4/7/32	20	192	113	176	91	9,200	8
2	4/14/32	60	190	101	165	88		
3	4/22/32	80	188	93	158	84	9,800	0
4	4/29/32	30	135	102	128	95	7,300	1
5	5/3/32	60	190	28	168	18	15,300	80
				Average			10,400	22

Table 11

.ghly contaminated churn with a commercial chloramine preparation

	Rinse water before chlorine treatment				Rinse water after chlorine treatment				Aga
ia	Plate Counts				Plate Counts				before
.. ex- to	Water from tap: Bacteria per ml.	Water after exposure to churn for 10 min.: Bacteria per ml.	Water after exposure to churn for 10 min.: Yeasts per ml.	Water after exposure to churn for 10 min.: Molds per ml.	Water from tap: Bacteria per ml.	Water after exposure to churn for 10 min.: Bacteria per ml.	Water after exposure to churn for 10 min.: Yeasts per ml.	Water after exposure to churn for 10 min.: Molds per ml.	Bacteri per sq. cm.
)	8	7,300,000	400	95	1	29,000	2	2	>2,000
									125
)	0	2,170,000	770	120	5	8,000	0	5	>2,000
)	1	700,000	2,190	55	16	8,200	21	10	186
)	80	274,000	490	130	6	10,000	3	3	41
)	22	2,810,000	983	100	7	13,800	7	5	

on

reatment — exposure r 10 min. — ts : Molds ml.: per ml.	Agar disc counts before chlorine treatment — Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Agar disc counts after chlorine treatment — Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.
2	>2,000	.78	.07	103	0	.02
	125	1.1	.74	18	0	0
5	>2,000	1.8	1.7	32	.05	2.7
10	186	.2	1.1	55	.08	.1
3	41	0	.48	27	.02	.06
5		.78	.82	47	.03	.58

while the counts after treatment showed 29,000 bacteria, 2 yeasts and 2 molds per ml. The agar disc counts before treatment were >2,000 bacteria, .78 yeasts and .07 molds per sq. cm., while the counts after treatment were 103 bacteria, 0 yeasts and .02 molds per sq. cm.

In trial 2 the period of exposure was 60 minutes. The agar disc counts before treatment were 125 bacteria, 1.1 yeasts and .74 molds per sq. cm. and the counts after treatment were 18 bacteria and 0 yeasts and 0 molds per sq. cm. In the third trial the chlorine solution was exposed to the churn for 80 minutes and had 9,800 bacteria per ml. at the end of the exposure period. The counts by the rinse method before treatment were 2,170,000 bacteria, 770 yeasts and 120 molds per ml., while after treatment the counts were 8,000 bacteria, 0 yeasts and 5 molds per ml. The agar disc counts were >2,000 bacteria, 1.8 yeasts and 1.7 molds per sq. cm. before treatment and 32 bacteria, .05 yeasts and 2.7 molds per sq. cm. after treatment.

In the fourth trial a solution containing 102 ppm. available chlorine and at a temperature of 135°F. was exposed to the churn for 30 minutes. After exposure the available chlorine was 95 ppm., and the temperature was 128°F. and the plate count showed 7,300 bacteria per ml. of the solution. The counts by the rinse method before treatment showed 700,000 bacteria, 2,190 yeasts and 55 molds per ml., while the counts after treatment were 8,200 bacteria, 21 yeasts and 10 molds per ml. The agar disc counts before treatment were 186 bacteria, .2 yeasts and 1.1 molds per sq. cm. while the counts after treatment were 55 bacteria, .08 yeasts and .1 molds per sq. cm.

In the fifth trial a solution containing 28 ppm. available chlorine and at a temperature of 190°F. was exposed to the churn for 60 minutes. After exposure the concentration of available chlorine was 18 ppm., the temperature 168°F. and the bacterial count on the chlorine rinse 15,300 per ml. The counts by the rinse method before treatment were 274,000 bacteria, 490 yeasts and 130 molds per ml., while the counts after treatment were 10,000 bacteria, 3 yeasts and 3 molds per ml. The agar disc counts before treatment were 41 bacteria, 0 yeasts and .48 molds per sq. cm., while the counts after treatment were 27 bacteria, .02 yeasts and .06 molds.

For the five trials the average bacterial count on the chlorine rinse after exposure was 10,400 per ml. The average counts on the water used to rinse the churn before treatment were 2,810,000 bacteria, 983 yeasts and 100 molds per ml., while the average counts on the water used to rinse the churn after treatment were 13,800 bacteria, 7 yeasts and 5 molds per ml. The averages for the agar disc counts taken before treatment were .78 yeasts and .82 molds per sq. cm., while after treatment the average counts were 47 bacteria, .03 yeasts and .58

molds per sq. cm. Many of the bacterial counts before treatment were estimates and so the average would be valueless.

The results show that the treatment of a highly contaminated churn with chloramine solutions resulted in significant reductions in numbers of bacteria, yeasts and molds but that in every trial the churn still contained considerable numbers of organisms. The higher concentrations of available chlorine and the higher temperatures and longer periods of exposure were apparently more efficient than the lower concentrations of available chlorine and lower temperatures and shorter periods of exposure.

By referring to the experiment where hot water was used to treat churns (see following experiment) it can be seen that water alone gave results comparable to the results secured in the treatments with chloramine solutions using nearly the same temperatures and periods of exposure; it is apparent that the destruction of the organisms by the chloramine solutions was probably largely due to the action of heat rather than to the action of the available chlorine. The results secured in trial four, in which the solution contained 102 ppm. available chlorine and had a temperature of 135°F. and was exposed for 30 minutes, show that, by comparing the results with those secured with sodium hypochlorite solutions under similar conditions, the chloramine solutions are less effective than the sodium hypochlorite solutions, especially in the destruction of yeasts and molds. It is also significant that the bacterial counts on the chloramine solutions after exposure to the churn were all considerably higher than the counts on the hypochlorite solutions, and that appreciable numbers of yeasts and molds were still present in the churn after treatment.

Even at the very high temperatures used the chloramine solutions lost much less available chlorine than did any of the other chlorine solutions which were all used at much lower temperatures. This indicates that chloramines are much more stable than hypochlorites when in contact with the wood of churns.

b. <u>Use of hot water on highly contaminated churns</u>

The method used for determining the efficiencies of hot water treatments of highly contaminated churns was as follows:

Agar disc counts were run on the churn. Samples for counts by the rinse method were then secured by adding 10 gallons of tap water to the churn and revolving in high gear for 10 minutes. The rinse water was left in the churn, hot water was added to the desired fullness and the total quantity was heated with steam to the desired temperature. When the period of exposure was less than 30 minutes the churn was revolved in high gear for the entire period but when the period of exposure was more than 30 minutes the churn was revolved in high gear for 5 or 10 minutes and then revolved in low gear with the rollers working for the remainder of the period. After the exposure the temperature of the water in the churn was taken and a sample for plating was obtained. The churn was drained and then rinsed with 10 gallons of water for 10 minutes for the determination of the count by the rinse method. After the churn had been drained and dried thoroughly agar disc counts were run on it again, usually within four hours after treatment, but in some trials the churn was allowed to stand over night before the counts were made.

Churns C and F (see preceding experiments) were used. Churn C was contaminated between trials (See: Use of chlorine compounds on highly contaminated churns) while churn F had stood idle for over a month after it had been treated with a sodium hypochlorite solution and showed extensive mold growth in various places on the interior surface.

The results of seven trials on the treatment of highly contaminated churns with hot water are shown in table 12. The churns were filled from one-half full to full with water at temperatures ranging from 180° to 208°F. The periods of exposure ranged from 10 to 70 minutes and the temperatures after exposure from 168° to 196°F. The bacterial counts on the hot rinse water after exposure ranged from 5,000 to 23,000 per ml. and averaged 11,443. No yeasts or molds were ever detected in this water. The bacterial counts by the rinse method before treatment ranged from 1,000,000 to 13,300,000 per ml. and averaged 3,624,000, while after treatment they ranged from 2,800 to 30,000 per ml.

Treatm

Trial	Date	Churn	Fullness of Churn	Period of exposure min.	Temp. before exposure °F.	Temp. after exposure °F.	Bacteria per ml. after exposure	Plate cou ho Water from tap: Bacteria per ml.	B
			Hot rinse water						
1	2/26/32	C	2/3	10	199	190	5,000	11	13
2	3/3/32	C	2/3	20	204	192	7,500	151	5
3	3/11/32	C	2/3	30	208	196	7,800	38	2
4	3/24/32	C	full	40	204	194	10,800	3	1
5	3/31/32	C	full	60	207	191	13,800	18	1
6	4/22/32	F	1/2	70	208	196	23,000	0	1
7	5/3/32	F	1/2	60	180	168	12,200	82	1
			Average				11,443	43	3

Table 12

Treatment of highly contaminated churns with hot water

	Plate counts on rinse water before hot water treatment				Plate counts on rinse water after hot water treatment			
la , re	Water from tap: Bacteria per ml.	Water after exposure to churn for 10 min. Bacteria per ml.	Yeasts per ml.	Molds per ml.	Water from tap: Bacteria per ml.	Water after exposure to churn for 10 min. Bacteria per ml.	Yeasts per ml.	Molds per ml.
0	11	13,300,000	300	1,450	33	16,000	42	76
0	151	5,250,000	45	150	43	11,200	2	16
0	38	2,300,000	60	35	71	2,800	0	1
0	3	1,100,000	52	23	2	5,300	1	1
0	18	1,100,000	950	290	40	3,550	0	1
0	0	1,000,000	50	830,000	5	18,500	0	8
0	82	1,320,000	6	150	6	30,000	1	2
3	43	3,624,000	209	118,857	29	12,478	7	15

...ater after ...ent, exposure 10 min.: ...ts per ml.	Molds per ml.	Agar disc counts before hot water treatment: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Agar disc counts after hot water treatment: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.
2	76	> 2,000	27	2	106	.07	.2
2	16	>1,500	.4	.2	165	.01	.1
0	1	>1,000	.3	.4	54	.04	.1
1	1	400 (Est.)	.2	.1	18	0	0
0	1	600 (Est.)	.1	.3	16	0	.02
0	8	800 (Est.)	Covered with molds.		12	.02	1.1
1	2	82	.01	.74	16	0	.01
7	15		4.5	.62	55	.02	.22

and averaged 12,478. The yeast counts before treatment ranged from 6 to 950 per ml. and averaged 209 while after treatment they ranged from 0 to 42 per ml. and averaged 7. The mold counts before treatment ranged from 23 to 830,000 per ml. and averaged 118,857 while after treatment they ranged from 1 to 76 per ml. and averaged 15.

With the agar disc method, the bacterial counts before treatment ranged from 82 to >2,000 per sq. cm.; since most of the counts were estimated the average would be of no significance. After treatment the bacterial counts ranged from 12 to 165 per sq. cm. and averaged 55. In one trial (trial 6. Churn F) no yeast or mold counts were obtained before treatment because the whey agar discs were completely overgrown with molds in two days. In the other six trials the yeast counts before treatment ranged from .01 to 27 per sq. cm. and averaged 4.5 while after treatment they ranged from 0 to .07 per sq. cm. and averaged .02. In these six trials the molds counts before treatment ranged from .1 to 2 per sq. cm. and averaged .62, while after treatment they (six trials) ranged from 0 to .2 per sq. cm. and averaged .07.

These results indicate that the microbiologic content of highly contaminated churns can be reduced to a very low figure by treating the churns with water at 180°F. or above for 30 minutes or more. However, even after the most severe treatment used there was still a considerable number of microorganisms present in the churn. Since the hot rinse after exposure to the churn always contained a considerable number of bacteria but never any yeasts or molds, it is apparent that at least a part of the organisms found in the churns after treatment were able to resist the temperatures used and were not derived from protected infection foci.

The counts by the rinse method indicate that when the periods of exposure were short (trials 1 and 2) significant numbers of yeasts and molds survived the treatment; it is also significant that in these two trials and in the one trial in which a temperature of 180°F. was employed (trial 7) the counts on the waters used to rinse the churns after treatment were higher than the counts on the hot rinse waters, while in the trials in which the temperatures were 200°F. or higher and the periods of exposure were 30 minutes or longer the counts by the rinse method after treatment were always lower than the counts on the hot rinse waters. These observations indicate that, due to their being harbored in more or less protected places in the churn, yeasts, molds and non-spore forming bacteria may survive hot water treatments; however, when temperatures of 200°F. or over and periods of exposure of 30 minutes or longer were used only the spore-forming bacteria were able to survive, due presumably to the heat penetrating the wood in the churn to such an extent that the non-resistant organisms were killed.

C. Effects of organisms isolated from churns on the keeping quality of butter

From the investigation on the extent of contamination of churns in commercial use it was found that the microflora of carefully treated churns included very few types, chiefly members of the genus Bacillus, while the microflora of carelessly treated churns usually included many types representing several genera. In order to determine the effect of the different types of microorganisms found in churns on the keeping quality of butter, several series of churnings were made on a laboratory scale, using pure cultures of organisms from churns to inoculate the cream just before churning.

The pure cultures used were isolated from the agar discs prepared in the studies on churn contamination. The inocula were prepared, as follows:

A series of blank plates, corresponding to the number of cultures to be studied, was prepared by pouring about 10 ml. of beef infusion agar into each plate. After the agar had solidified each plate was inoculated by transferring a perceptible amount of the material from a culture of the organism to be used and distributing this over the whole surface of the agar in the plate with a sterile glass rod. The plates were incubated two days at 86^{o}F. and suspensions of the organisms then prepared by flooding each plate with about 10 ml. of sterile water and distributing the mass of growth throughout this with a sterile needle. In a few cases mixtures of organisms were used; the agar plates were streaked with small amounts of material secured from each of several types of colonies appearing on agar discs and the plates were then handled the same as for the pure cultures.

The cream used was prepared as follows: High quality raw cream was dispensed into sterile one-quart glass-top fruit jars, filling each jar about one-half full. The jars, with the lids on loose, were then placed in a water bath with the water deep enough to come up above the level of the cream. The cream was heated to about 180^{o}F., held for 20 minutes and then cooled slowly, with running water, to about 50^{o}F. During the heating and cooling the jars were gently shaken frequently so as to insure fairly uniform heating.

The inocula were then added and the cream churned, one uninoculated portion being churned in each series to serve as a check. The churn used was one especially built for churning cream in quart jars. It had six compartments, in each of which a quart jar could be placed. The compartments rotated on a shaft at such a speed that in the jars tumbling end over end pronounced agitation occurred. The butter was washed with sterile water and worked in sterile pans with sterile paddles.

The unsalted butter was packed in small sterile jars, each holding about one-third of a pound. The jars were shaped much like a butter tub and were closed with metal screw-tops. A piece of parchment was placed under each cap to avoid any contact of the butter with the metal.

The jars of butter were stored in an incubator at 59°F. and were scored from time to time. Because the samples were small and because of the pronounced heated flavor only the development of flavor defects was noted and no attempt was made to place a numerical score on the butter. Plate counts were run on the samples, usually after about three days storage, in order to get an idea of the numbers of organisms present and to determine whether or not the types of organisms used to inoculate the cream were highly predominant.

Sixty-one pure cultures were used in studying the effects of the organisms isolated from churns on the keeping quality of butter. The general characters of these organisms, all of which grew well at ordinary temperatures under aerabic conditions, are given in key 1. The influence of the various organisms on butter is shown in table 13; the data are arranged on the basis of the general types of the organisms in an attempt to show any correlation between the types and the defects produced.

The organisms in group 1 were Gram positive, spore forming

Key 1

Key to organisms used in inoculation of cream

A. Cells rod shaped

B. Form spores

C. Gram positive

D. Litmus milk rapidly changed

E. Slight acidity formed

F. Rennet coagulation
Reduced

G. Slowly proteolyzed

X1
X4
X5
Y4

GG. Not proteolyzed

X2
X3
X7
X8
X9
X10
Y6
Z18

FF. Not coagulated
Not reduced. Slightly acid.

C8

EE. No acid formed

F. Proteolyzed

A1
B4
C2
D1
D2
D5
F2
J2

X6
Y1

FF. Not proteolyzed.
Alkaline reaction

C3
D6
W1
Z1
Z4

DD. Litmus milk not rapidly changed
Slow reduction. Rennet coagulation.
Slight proteolysis

Y2
Y3
Y5

CC. Gram negative
Alkaline reaction in litmus milk

Z14

BB. Do not form spores

C. Gram positive

D. Litmus milk proteolyzed

B6
BH2
H3

DD. Litmus milk not proteolyzed
Alkaline reaction

C5
D14
J4

CC. Gram negative

D. Litmus milk definitely changed

E. Proteolyzed

BH4
BH5
C4
E2

EE. Not proteolyzed
Acid reaction. Not coagulated.

Z3
Z9
Z10

DD. Litmus milk not definitely changed

C7
K2
Z6
Z31

AA. Cells spherical

B. Cells in irregular masses

C. Pigment formed

D. Pigment yellow

E. Gram positive

F. Litmus milk definitely changed. Slightly acid, rennet coagulated, proteolyzed

D11
F1

FF. Litmus milk not definitely changed

BH1

EE. Gram negative
No change in litmus milk

C1

DD. Pigment orange

E. Gram positive

F. Litmus milk strong alkaline

Q1

FF. Litmus milk not alkaline. Slightly acid, partially coagulated, partially reduced.

B3

EE. Gram negative
Litmus milk acid, coagulated, partially reduced. G2

CC. Pigment not formed

D. Gram positive
Litmus milk slightly acid D3

DD. Gram negative

E. Gelatin liquefied
Litmus milk acid, coagulated, reduced D7

EE. Gelatin not liquefied

F. Litmus milk slightly alkaline Z19

FF. Litmus milk strongly alkaline Z15

BB. Cells in packets or cubes.
Gram positive, yellow pigment formed, gelatin liquefied. No reaction in litmus milk B1

Table 13

Effects of pure cultures of organisms isolated from churns on the keeping quality of butter stored at 59°F.

Organisms	Age of butter when plated	Bacteria per ml. Plate Count	Changes produced in butter during holding
Group 1	Gram positive spore forming rods. Litmus milk: acid, rennet coagulation, reduction, slow proteolysis.		
X1	3	2,850,000	25 days, slightly nutty; 58 days, slightly rancid.
X4	3	3,650,000	25 days, malty; 58 days, pronounced malty.
X5	3	3,550,000	10 days, slightly malty; 25 days, malty; 58 days, very malty.
Y4	3	3,700,000	18 days, slightly unclean, suggested rancidity; 45 days, not much change.
Group 2	Gram positive spore forming rods. Litmus milk: acid, rennet coagulation, no proteolysis.		
X2	3	1,300,000	25 days, slightly nutty; 58 days, not much change.
X3	3	2,650,000	25 days, slightly nutty; 58 days, not much change.
X7	3	1,100,000	10 days, unclean; 58 days, slightly cheesy.
X8	3	3,250,000	25 days, slightly rancid; 36 days, distinctly rancid.
X9	3	1,650,000	58 days, very little change.
X10	3	2,200,000	10 days, slightly off; 58 days, slightly cheesy.

Table 13 (continued)

Organisms	Age of butter when plated	Bacteria per ml. Plate Count	Changes produced in butter during holding
Group 2 (continued)			
Y6	3	1,250,000	45 days, little change.
Z18	3	3,500,000	41 days, slightly nutty.
Group 3			Gram positive spore forming rod. Litmus milk: slightly acid, not reduced, rennet coagulated.
C8	3	608,000	39 days, nutty, slightly rancid.
Group 4			Gram positive spore forming rods. Litmus milk: rapid proteolysis. Neutral or alkaline reaction.
A1	10	72,000	20 days, unclean; 41 days, unclean but not highly objectionable.
B4	3	9,200,000	4 days, slight English walnut flavor; 10 days, distinct English walnut flavor.
C2	10	3,350,000	11 days, slightly rancid; 41 days, very rancid.
D1	10	8,850,000	41 days, little change, slightly nutty.
D2	10	2,650,000	11 days, slightly off; 41 days, cheesy.
D5	6	2,100,000	49 days, slightly unclean.
F2	10	3,100,000	20 days, unpleasant and unclean; 41 days, unclean, rancid, cheesy.

Table 13 (continued)

Organisms	Age of butter when plated	Bacteria per ml. Plate Count	Changes produced in butter during holding
Group 4 (continued)			
J2	6	5,950,000	14 days, slight English walnut flavor; 36 days, distinct English walnut.
X6	3	2,950,000	25 days, slightly unclean, suggestion of rancidity; 58 days, not much change.
Y1	3	1,700,000	18 days, unclean; 45 days, not much worse.
Group 5	Gram positive spore forming rods. Litmus milk: Alkaline reaction. No coagulation, reduction or proteolysis.		
O3	3	30,500,000	10 days, unclean; 18 days, rancid: rancidity suggested higher volatile acids.
D6	4	980,000	31 days, slightly cheesy.
W1	3	1,750,000	18 days, slightly unclean; 50 days, not much worse.
Z1	3	434,000	50 days, slightly rancid.
Z4	6	8,300,000	14 days, slight old cream flavor; 25 days, unclean.
Group 6	Gram positive spore forming rods. Litmus milk: slow reduction, rennet coagulation, slight proteolysis.		
Y2	3	15,800,000	29 days, nutty, slightly objectionable; 45 days, not much worse.

Table 13 (continued)

Organisms	Age of butter when plated	Bacteria per ml. Plate Count	Changes produced in butter during holding
Group 6 (continued)			
Y3	3	1,400,000	45 days, slightly off.
Y5	3	15,500,000	7 days, slight surface taint; 18 days, distinct surface taint. (Butter underchurned).
Group 7 Gram negative spore forming rod. Litmus milk: alkaline.			
Z14	3	2,580,000	10 days, slightly unclean; 28 days, rancid.
Group 8 Gram positive, non-spore forming rods. Litmus milk: proteolysis.			
B6	6	200,000	49 days, slightly unclean.
BH2	3	1,850,000	45 days, slightly off.
H3	10	83,000	41 days, slightly unclean.
Group 9 Gram positive, non-spore forming rods. Litmus milk: alkaline.			
C5	10	11,200,000	41 days, little change; slightly nutty.
D14	4	400,000	31 days, slightly strong and bitter; 41 days, unclean, sour, slightly rancid.
J4	10	95,000	20 days, slightly off; 41 days, unclean, almost like surface taint.

Table 13 (continued)

Organisms	Age of butter when plated	Bacteria per ml. Plate Count	Changes produced in butter during holding
Group 10	Gram negative, non-spore forming rods. Litmus milk: proteolysis.		
BH4	3	11,850,000	45 days, slightly bitter; decided off flavor.
BH5	3	4,950,000	7 days, slight ester flavor; 45 days, fruity, cheesy and bitter.
C4	4	980,000	17 days, unclean and sour; 31 days, very unclean.
E2	10	25,800,000	41 days, unclean, bitter; almost like surface taint.
Group 11	Gram negative, non-spore forming rods. Litmus milk: acid reaction. Not coagulated.		
Z3	3	6,800,000	18 days, unclean and rancid; 39 days, very rancid.
Z9	3	28,800,000	18 days, unclean; 28 days, unclean and sour.
Z10	10	41,300,000	20 days, unclean and sour flavor like that produced by Escherichia-Aerobacter organisms.
Group 12	Gram negative, non-spore forming rods. Litmus milk: no reaction.		
C7	3	27,900,000	18 days, slightly unclean; 30 days, little change.
K2	6	625,000	14 days, unclean; 36 days, unclean; like limburger or brick cheese.

Table 13 (continued)

Organisms	Age of butter when plated	Bacteria per ml. Plate Count	Changes produced in butter during holding
Group 12 (continued)			
Z6	6	25,600,000	10 days, typical old cream flavor; 36 days, unclean.
Z31	3	9,800,000	10 days, slightly off; 58 days, unclean; suggested cheesiness.
Group 13 Cocci types.			
D11	4	13,200,000	17 days, slightly rancid; 41 days, very rancid.
F1	10	37,600,000	41 days, unclean and sour.
BH1	3	3,700,000	45 days, little change.
C1	4	1,800,000	41 days, slightly unclean.
Q1	6	13,100,000	49 days, slightly off.
B3	4	76,800,000	23 days, unclean, suggested slight rancidity; 41 days, rancid and tallowy.
G2	6	10,500,000	14 days, slightly sour and unclean; 36 days, rancid and unclean.
D3	3	31,600,000	18 days, sour and unclean; 50 days, rancid and cheesy.
D7	4	2,600,000	31 days, slightly unclean; 41 days, rancid.

Table 13 (continued)

Organisms	Age of butter when plated	Bacteria per ml. Plate Counts	Changes produced in butter during holding
Group 13 (continued)			
Z19	10	10,600,000	41 days, little change; nutty.
Z15	6	10,800,000	25 days, unclean and sour; 36 days, unclean, sour and rancid.
B1	4	4,600,000	17 days, slightly rancid; 41 days, unclean and very rancid.

rods which developed an acid reaction in litmus milk followed by rennet coagulation, reduction of the litmus and slow proteolysis. Of the four organisms of this type, two (X4 and X5) produced a malty flavor in butter and the other two (X1 and Y4) produced a slight rancidity.

Group 2 included eight organisms which differed from those in the first group by not showing any proteolysis in litmus milk. Four of the organisms (X2, X3, X9 and Y6) produced only a slight change in the butter; three of these produced a slightly nutty flavor. Two organisms (X7 and X10) caused a slight cheesy flavor while the remaining two (Z8 and Z18) caused rancidity.

The organism (C8) in group 3 differed from those in group 1 in that the only change in litmus milk was an acid reaction. It produced a nutty and slightly rancid flavor in butter.

Group 4 included the Gram positive, spore forming rods which proteolyzed litmus milk without the production of an acid reaction. With most of these organisms the proteolysis was rapid and the final product was a clear amber or wine colored liquid. Of the 10 organisms in the group, five (A1, D1, D5, X6 and Y1) produced little change in butter except for a slight unclean or slight nutty flavor; two (B4 and J2) produced a pronounced English walnut flavor, one (C2) caused rancidity, one, (D2) produced a rather cheesy flavor and one (F2) produced a dirty, rancid and cheesy flavor.

Group 5 included five organisms which differed from those in the preceding group in that they developed an alkaline reaction with no proteolysis in litmus milk. In general, these organisms caused very pronounced defects in butter. Two (C3 and Z1) caused rancidity, one (D6) caused slight cheesiness, one (Z4) caused a distinct old cream flavor while the other (W1) produced little change.

The three organisms in group 6 were Gram positive spore forming rods which caused a slow reduction of litmus milk followed by rennet coagulation and slight proteolysis. Two of them (Y2 and Y3) produced little change in butter while the third (Y5) caused a distinct surface taint flavor; however, the development of the surface taint is not significant because the butter was under churned and consequently its curd content was very high.

The organism (Z14) in group 7 was a Gram negative, spore forming rod which developed an acid reaction in litmus milk. The butter inoculated with it developed an unclean flavor and then became rancid.

In general, the changes produced by the aerobic spore forming rods (genus Bacillus) developed slowly and were not extensive. Nutty, slight unclean and slight cheesy flavors were produced by the members of this group and a rancid flavor was common in most of the samples that showed pronounced defects. The organisms which proteolyzed litmus milk rapidly were apparently more detrimental to the keeping quality of butter than were the other types belonging to the general group.

The organisms in group 8 were Gram negative, non-spore forming rods which proteolyzed litmus milk. The changes produced in butter by the three organisms in this group were not marked; two (B6 and H3) produced a slight unclean flavor and the other (BH3) produced a slight, indefinite off flavor.

The three organisms in group 9 differed from those in the previous group by producing an alkaline reaction and no proteolysis in litmus milk. One (C5) produced a slight nutty flavor, another (D14) caused an unclean, sour and slightly rancid flavor while the third (J4) produced an unclean flavor almost like surface taint.

The four organisms in group 10 were Gram negative, non-spore forming rods which proteolyzed litmus milk. All four caused the development of pronounced defects in butter. One (BH4) produced a bitter flavor, another (E2) produced a bitter, unclean flavor almost like surface taint, another (BH5) produced an ester-like flavor which became fruity, bitter and cheesy while the other (C4) produced a dirty, sour flavor which became very unclean.

The three organisms in group 11 differed from those in group 10 by developing only an acid reaction in litmus milk and no coagulation or proteolysis. The defects in butter caused by the organisms were pronounced: two (Z9 and Z10) caused an unclean, sour flavor like that produced by organisms of the Escherichia-Aerobacter group and the other (Z3) produced an unclean and rancid flavor.

The four organisms in group 12 differed from those in groups 10 and 11 in that they produced no changes in litmus milk. All produced marked defects in butter, an unclean flavor being included in the defects produced by each. With one organism (K2) the flavor eventually became like brick or limburger cheese and with another (Z31) the flavor suggested cheesiness after 58 days of storage, while with the third (Z6) a typical old cream flavor was produced within 10 days.

In general, the development of defects by the aerobic non-spore forming rods was more rapid and more pronounced than the development of defects by the aerobic spore forming rods. Also, the defects produced by the former group were more varied and often more objectionable than those produced by the latter group.

Group 13 included all the 12 coccus types studied. Presumably, 11 of these types belonged to the genus Micrococcus and one (B1) to the genus Sarcina. Four of the organisms (BH1, C1, Q1 and Z19) produced little change in butter. Four

(D11, B3, D7, and B1) produced pronounced rancidity and with the remaining four (F1, G2, D3 and Z15) an unclean and sour flavor was a common defect; further changes were produced by three of these latter organisms, two (G2 and Z15) causing a rancid and unclean flavor and the other (D3) a rancid and cheesy flavor.

In general, the changes produced by the coccus types were quite rapid and the defects were pronounced and rather objectionable. Rancidity was the most common defect produced and an unclean and sour flavor was common to several.

Effects on the keeping quality of butter of mixtures of the organisms derived from churns are shown in table 14. Each mixed culture contained organisms secured from 10 to 16 colonies representative of the flora of a churn. Since the organisms were all derived from reasonably clean churns they were chiefly members of the genus Bacillus. Each of the five mixed cultures produced a different change in butter: Number 1 produced a very rancid putrid and cheesy flavor; number 2 produced a distinctly off flavor which later developed into a slightly malty flavor; number 3 produced a very musty flavor and odor; number 4 produced a rapid development of a surface taint flavor; and number 5 developed an old, sour cream flavor.

The development of defects was very rapid in all the samples of butter inoculated with mixed cultures, a pronounced

Table 14

Effects of mixed cultures of organisms isolated from churns on the keeping quality of butter stored at 59°F.

Mixed Culture Number	Age of butter when plated	Bacteria per ml. Plate Count	Changes produced in butter during holding
1	10	1,400,000	7 days, rancid and slightly putrid; 41 days, very rancid, putrid and cheesy.
2	3	4,200,000	7 days, distinctly off; 29 days, slightly malty; 45 days, not much worse.
3	3	28,700,000	7 days, oily; suggested kerosene; 18 days, musty.
4	3	7,100,000	7 days, pronounced surface taint flavor.
5	3	700,000	7 days, unclean, slightly malty; 18 days, old sour cream flavor.

defect being evident after seven days storage; with all but one of the mixtures (number 2) the flavors developed were very objectionable.

In general, the mixed cultures produced more rapid and more undesirable changes in butter than did the pure cultures.

The results show that all of the 61 pure cultures of organisms isolated from churns produced some changes in butter although the changes produced by many of them were not serious. It is interesting to note that, in general, the organisms common to clean churns (Bacillus types) were apparently not as detrimental to the keeping quality of the butter as some of the other organisms, particularly non-spore forming rods. It is also significant that, in general, the mixed cultures brought about more rapid and more extensive changes than did the pure cultures; this suggests that a clean churn has several advantages over a contaminated churn: (1) it contains few organisms, (2) the flora includes few types, and (3) the types found in a clean churn are not particularly detrimental to the keeping quality of the butter.

D. Influence of contaminated churns on the keeping quality of butter

The studies on the effects of organisms isolated from churns on the keeping quality of unsalted butter revealed that, while many organisms had little effect, others caused pronounced defects. Although the organisms used were commonly representative of the flora of a churn it seemed desirable to expand the churning experiments to a more practical basis and allow the butter to be contaminated from the churn itself. Accordingly, experiments were run in which the keeping qualities of samples of butter made in a contaminated churn were compared with the keeping qualities of samples of butter made in the same churn after it had been carefully cleaned.

1. Methods

The general method for studying the effect of a contaminated churn on the keeping quality of the butter made in it was as follows: Counts were made on the contaminated churn by the rinse and agar disc methods and one-half of a batch of pasteurized cream was churned. The churn was then cleaned as thoroughly as possible, counts were made by the rinse method and the other half of the batch of cream was then churned. Counts were made on the butter by both the plate and direct microscopic methods and samples of the two churnings were held at various temperatures for comparison of their keeping qualities.

The churns used were small experimental churns of 70 pounds capacity. Churn C proved unsatisfactory for working the butter and its use was discontinued after two trials and churn D was used instead. The churns were washed carelessly in the interval between trials so that they would build up a flora common to churns receiving such treatment. The general method for this careless treatment involved rinsing out the fat with warm water, filling the churn about 1/3 full of hot water, revolving for about five minutes and then draining and drying. When the churn was not used regularly, it was washed carelessly after simulating churning conditions by agitating a small amount of buttermilk in the churn for a short period.

In most cases the cream used was drawn from a vat of selected cream pasteurized at 145°F. for 30 minutes for the regular plant churning. Seventy-five pounds of cream were placed in each of two ten gallon cans which had been thoroughly steamed. When no butter culture was to be used, the cream was drawn immediately after pasteurizing and cooling and stored over night in a cooler at about 40°F. When butter culture was to be used seven per cent was mixed with the cream, the mixture held cold over night and the portions of cream for the experimental churnings drawn in the morning.

In the trials where high pasteurization temperatures were used, 150 pounds of selected raw cream were pasteurized at 155°F. for 30 minutes and cooled down to about 36°F. in a small vat. The cream was then drawn into 10 gallon cans and placed in a cooler over night. In every case the first batch of cream was warmed to from 48° to 52°F. before churning while the second batch was warmed to from 38° to 42°F.; a low churning temperature was used for the second batch in order to prevent too rapid churning due to the warm condition of the churn.

Ten gallons of tap water were revolved in the churn for 10 minutes for the counts by the rinse method; for the counts on the clean churn water at about 33°F. was used in order to cool the churn. If further cooling was necessary, the churn was filled about one-half full of tap water (at about 54°F.) and revolved for 5 or 10 minutes.

The method for cleaning the churn after churning the first batch of cream was as follows: The butterfat was rinsed out with a little warm water, the churn filled one-half full of hot water (180°F. or over), one pound of soda ash added, and the churn then revolved in high gear for 15 minutes, drained and dried. The churn was then filled nearly full of water at 200°F. or more, revolved in high gear for 30 minutes and drained.

The butter was washed thoroughly with tap water (at about 54°F.), worked into a homogeneous mass and a sample taken with a sterile paddle and placed in a sterile pan covered with sterile paper. After incorporating 2.5 per cent of salt in the remainder of the butter, a sample of the salted product was taken and the two samples, one salted and one unsalted, were then dispensed in sterile, glass, metal capped jars; these jars held about one-third of a pound each and were shaped much like a butter tub. A pair of the samples, one salted and one unsalted, was placed in a butter storage room at about 32°F. and another pair was placed in a cooler at about 45°F. The latter samples were scored weekly and the samples stored at 32°F. were scored at irregular intervals. Portions of the fresh butter, salted and unsalted, were also placed in sterile, two ounce, glass stoppered bottles and stored at room temperature (about 70°F.).

A sample of the cream was taken just before churning with a sterile 5 ml. pipette and placed in a sterile test tube. This, along with the samples of tap water and rinse waters taken for the counts by the rinse method, was held in ice water until plated. These samples and samples of unsalted butter from the contaminated and clean churns were all plated on beef infusion agar for the determination of the bacterial content and on acidulated malt agar (pH 3.5) for the determination of the yeasts and mold content. The plates were incubated for four days at room temperature (about 70°F.) and then counted with the aid of a hand lens. Direct microscopic counts, as outlined by Hammer and Nelson (5), were run on the samples of fresh unsalted butter and again after seven days on the samples held at room temperature.

2. Results

a. Counts on churns, cream and butter

Seventeen trials were run in which a portion of a lot of cream was churned in a contaminated churn and another portion in the same churn after it had been cleaned thoroughly. Table 15 gives the counts on the contaminated and on the clean churns. With the agar disc method the bacterial counts on the contaminated churns ranged from 12 to >2,000 per sq. cm.; since many of the counts were estimated, no average was computed. The yeast counts on the contaminated churns ranged from 0 to .8 per sq. cm. and averaged .13 while the mold counts ranged from .01 to .7 per sq. cm. and averaged .17. Agar disc counts could not be run on the clean churns because they were always too warm and the surfaces too moist for the preparation of satisfactory agar discs.

With the rinse method the bacterial counts on the contaminated churns ranged from 21,000 to 6,500,000 per ml. and averaged 1,496,000 while with the clean churns they ranged from 1,100 to 17,300 per ml. and averaged 4,380. The yeast counts on the contaminated churns ranged from 0 to 70 per ml. and averaged 20 while with the clean churns they ranged from 0 to 23 per ml. and averaged 4.2. The mold counts on the contaminated churns ranged from 0 to 25 per ml. and averaged 5.8 while with the clean churns they ranged from 0 to 7 per ml. and averaged 1.6.

The counts by the rinse method were much greater on the contaminated churns than on the clean churns. The counts on the contaminated churns varied considerably and the microflora represented a variety of types while the counts on the clean

Table 15

Counts on contaminated and clean churns prior t

Trial	Date	Churn	Agar disc counts on contaminated churns: Bacteria per sq. cm.	Yeasts per sq. cm.	Molds per sq. cm.	Water from tap: Bacteria per ml.	Counts on churns by the — Contaminated Churns — Organisms per ml. after exposure to: Bacteria	Yeasts
1	12/18/31	C	>2,000	.8	.7	160	2,300,000	45
2	12/21/31	C	>2,000	.08	.32	433	6,000,000	3
3	12/22/31	D	593	.05	.10	80	141,000	26
4	1/12/32	D	121	.10	.33	72	32,000	1
5	1/19/32	D	681	.23	.27	33	70,000	4
6	2/2/32	D	12	.01	.05	36	42,000	4
7	2/16/32	D	40	.04	.09	22	41,000	0
8	2/23/32	D	850	.27	.17	10	1,830,000	10
9	3 /1/32	D	>2,000	.39	.20	16	1,790,000	30
10	3/8/32	D	460	.01	.06	128	21,000	0
11	3/15/32	D	75	0	.03	28	295,000	70
12	3/22/32	D	>1,000	.1	.36	22	240,000	25
13	3/31/32	D	800	.16	.14	40	5,500,000	49
14	4/5/32	D	416	.01	.01	21	370,000	19
15	4/12/32	D	26	0	.02	59	177,000	13
16	4/19/32	D	31	0	.01	10	82,000	11
17	4/26/32	D	369	.01	.08	54	6,500,000	8
			Average	.13	.17	72	1,496,000	20

Table 15

ıinated and clean churns prior to churning

Counts on churns by the rinse method. Water exposed for 10 min.							
Contaminated Churns				Clean Churns			
Water from tap: Bacteria per ml.	Organisms per ml. of water after exposure to churn: Bacteria	Yeasts	Molds	Water from tap: Bacteria per ml.	Organisms per ml. of water after exposure to churn: Bacteria	Yeasts	Molds
160	2,300,000	45	25	162	1,750	0	7
433	6,000,000	3	20	162	2,900	0	6
80	141,000	26	18	72	4,950	4	4
72	32,000	1	0	43	1,960	0	0
33	70,000	4	1	22	1,270	1	0
36	42,000	4	1	20	1,630	2	0
22	41,000	0	1	15	1,100	2	0
10	1,830,000	10	1	36	2,100	3	0
16	1,790,000	30	0	44	4,200	23	0
128	21,000	0	2	19	2,700	0	3
28	295,000	70	4	47	3,150	3	1
22	240,000	28	0	28	6,100	9	0
40	5,500,000	49	1	42	12,800	2	0
21	370,000	19	0	20	4,000	2	1
59	177,000	13	14	48	17,300	12	1
10	82,000	11	9	63	5,450	6	2
54	6,500,000	8	1	43	1,100	2	3
72	1,496,000	20	5.8	52	4,380	4.2	1.6

churns were uniformly low and the microflora included few types, chiefly members of the genus Bacillus.

Table 16 gives the plate counts on the cream used in each trial and the various counts on the samples of butter held under different conditions. The bacterial counts on the cream varied from 3,100 to 42,400,000 per ml. and averaged 5,333,000, the mold counts varied from 0 to 59 per ml. and averaged 5.4 while the yeast counts varied from 0 to 10 per ml. and averaged 1.5. With the plate counts on the fresh unsalted butter from the contaminated churns, the bacteria ranged from 8,000 to 1,730,000 per ml. and averaged 319,260, the yeasts ranged from 0 to 29 per ml. and averaged 8.2, and the molds ranged from 0 to 4 per ml. and averaged 1.4. With the plate counts on the fresh unsalted butter from the clean churns, the bacteria ranged from 2,800 to 890,000 per ml. and averaged 127,300, the yeasts ranged from 0 to 7 per ml. and averaged 1.5 and the molds ranged from 0 to 2 per ml. and averaged .53.

With the plate counts on the unsalted butter after storage at 45°F. for periods varying from 21 to 63 days the bacteria in the butter from the contaminated churns varied from 1,500,000 to 126,000,000 per ml. and averaged 47,418,000 while the bacteria in the butter from the clean churns varied from 210,000 to 378,000,000 per ml. and averaged 58,218,000.

The microscopic counts on the fresh unsalted butter from the contaminated churns ranged from 471,000 to 72,700,000 per ml.

Counts on cr

Trial	Plate Counts. Organisms per ml.									
				Counts on fresh unsalted butter from						
	Cream			Contaminated Churn			Clean Churn			
	Bacteria	Yeasts	Molds	Bacteria	Yeasts	Molds	Bacteria	Yeasts	Mo	
1	271,000	0	4	1,730,000	14	2	53,000	1		
2	47,000	0	0	610,000	0	0	12,000	0		
3	15,000,000	0	1	800,000	10	0	890,000	0		
4	42,400,000	22	4	380,000	3	2	320,000	0		
5	1,900,000	5	1	74,000	3	2	120,000	2		
6	125,000	59	4	36,000	9	3	12,600	3		
7	67,500	2	0	10,400	2	0	2,900	2		
8	80,000	2	1	370,000	3	1	11,800	2		
9	69,000	0	10	145,000	3	0	14,400	1		
11	30,200,000	0	0	360,000	11	4	650,000	7		
10	132,000	1	0	57,000	2	0	14,250	2		
12	40,000	1	0	341,000	29	0	8,000	1		
13	204,000	0	0	400,000	24	0	27,500	4		
14	62,000	0	0	35,000	13	0	5,700	0		
15	3,100	0	0	8,000	4	2	2,800	1		
16	4,700	0	0	22,000	8	4	3,550	0		
17	48,000	0	1	49,000	1	4	15,800	0		
Average	5,330,000	5.4	1.5	319,260	8.2	1.4	127,300	1.5		

Table 16

Counts on cream and on various samples of butter

ml.								Miscrosco
utter from			Bacterial counts after storage at 45°F. Unsalted butter from			Counts on fresh unsalted butter from		
ean Churn				Contaminated	Clean	Contaminated	Clean	
ia	Yeasts	Molds	Days	Churn	Churn	Churn	Churn	Sa
,000	1	2	63	28,500,000	13,500,000	4,600,000	893,000	2,
,000	0	0	60	85,000,000	30,000,000	12,400,000	9,300,000	27,
,000	0	0	59	27,000,000	119,000,000	41,600,000	46,000,000	12
,000	0	0	44	1,500,000	1,500,000	72,700,000	60,100,000	33
,000	2	0	37	11,300,000	2,700,000	5,900,000	4,970,000	3
,600	3	1	38	24,000,000	28,000,000	471,000	893,000	
,900	2	0	42	10,800,000	4,000,000	524,000	453,000	
,800	2	1	53	92,000,000	6,800,000	3,700,000	2,200,000	1
,400	1	1	46	72,000,000	70,000,000	14,200,000	9,600,000	6
,000	7	1	50	98,000,000	210,000	2,500,000	1,500,000	1
,250	2	0	57	42,000,000	126,000,000	43,000,000	37,400,000	7
,000	1	0	43	34,000,000	58,000,000	664,000	197,000	8
,500	4	0	49	33,000,000	20,000,000	1,700,000	768,000	1
,700	0	0	42	20,000,000	21,000,000	11,600,000	12,600,000	48
,800	1	1	35	126,000,000	96,000,000	13,000,000	14,000,000	47
,550	0	0	28	65,000,000	378,000,000	10,000,000	5,900,000	37
,800	0	2	21	36,000,000	15,000,000	6,600,000	4,600,000	5
,300	1.5	.53		47,418,000	58,218,000	14,421,000	12,434,000	14

Miscroscopic Counts. Bacteria per ml.					
...nts on fresh ...alted butter from		Counts after storage for seven days at 70°F. Butter from			
		Contaminated Churn		Clean Churn	
...nated ...n	Clean Churn	Salted	Unsalted	Salted	Unsalted
,000	893,000	2,900,000	183,000,000	217,000	75,000,000
,000	9,300,000	27,000,000	176,000,000	1,800,000	113,000,000
,000	46,000,000	12,300,000	28,000,000	9,200,000	42,000,000
,000	60,100,000	33,000,000	64,000,000	41,000,000	90,000,000
,000	4,970,000	3,400,000	28,000,000	1,900,000	19,000,000
,000	893,000	672,000	26,000,000	1,300,000	20,000,000
,000	453,000	249,000	28,000,000	258,000	8,500,000
,000	2,200,000	1,600,000	71,000,000	1,400,000	25,000,000
,000	9,600,000	6,300,000	91,000,000	1,400,000	55,000,000
,000	1,500,000	1,700,000	140,000,000	635,000	33,000,000
,000	37,400,000	7,400,000	12,000,000	4,900,000	37,000,000
,000	197,000	8,600,000	124,000,000	141,000	13,000,000
,000	768,000	1,600,000	135,000,000	1,100,000	89,000,000
,000	12,600,000	48,000,000	93,000,000	16,000,000	52,000,000
,000	14,000,000	47,000,000	278,000,000	56,000,000	292,000,000
,000	5,900,000	37,000,000	88,000,000	10,000,000	160,000,000
,000	4,600,000	5,600,000	70,000,000	6,700,000	47,000,000
,000	12,434,000	14,372,000	102,059,000	9,056,000	68,853,000

and averaged 14,421,000, while the counts on the fresh unsalted butter from the clean churns ranged from 197,000 to 60,100,000 per ml. and averaged 12,434,000. After storage for seven days at room temperature (about 70°F.), the microscopic counts on the salted butter from the contaminated churns ranged from 249,000 to 48,000,000 per ml. and averaged 14,372,000, while the counts on the salted butter from the clean churns ranged from 141,000 to 56,000,000 per ml. and averaged 9,056,000. After storage for seven days at room temperature (about 70°F.) the microscopic counts on the unsalted butter from the contaminated churns ranged from 12,000,000 to 278,000,000 per ml. and averaged 102,059,000, while the counts on the unsalted butter from the clean churns ranged from 8,500,000 to 292,000,000 per ml. and averaged 68,853,000.

In trials 3, 4 and 11 ripened cream was used. In the first 11 trials the cream was pasteurized at 145°F. for 30 minutes while in the last 6 trials (trials 12 to 17 inclusive) it was pasteurized at 155°F. for 30 minutes. Excluding the three trials in which the cream was ripened, the average count on the cream pasteurized at 145°F. (8 trials) was 336,438 per ml., while the average count on the cream pasteurized at 155°F. (6 trials) was only 56,966 per ml.; it is also significant that the cream pasteurized at 145°F. often contained appreciable numbers of yeasts and molds while the yeasts and molds were practically eliminated in the cream pasteurized at 155°F. These results indicate that the high pasteurization temperature was the more efficient.

The results of the plate counts on the fresh butter show that in only 3 trials (trials 3, 5 and 11) of the 17 were the bacterial counts higher on the butter from the clean churns than on the butter from the contaminated churns. In these three cases the differences were very small and probably due to experimental error; in many of the other trials the differences were often very large. The microflora of the butter from the contaminated churns usually included many types while the microflora of the butter from the clean churns usually included very few types, chiefly yellow coccus and Bacillus types which were apparently derived principally from the pasteurized cream. The average yeast and mold counts on the butter from the contaminated churns were higher than those on the butter from the clean churns although the differences were not as great as with the bacterial counts; this indicates that the contaminated churns contributed yeasts and molds as well as bacteria to the butter made in them.

After storage at 45°F. for periods varying from 21 to 63 days the average number of bacteria (plate count) in the unsalted butter from the clean churns was somewhat higher than in the unsalted butter from the contaminated churns but an examination of the individual counts shows that the difference is of no significance because in 9 of the 17 trials the counts on the butter from the contaminated churns were higher than the counts on the butter from the clean churns. In every trial the bacterial content of the butter from the contaminated churns increased during storage at 45°F. while with the butter from the clean churns the bacterial content increased in every trial but one; it is interesting to note that in this trial the initial count on the butter from the clean churn was higher than the initial count on the butter from the contaminated churn. Since ripened cream was used in this trial, it is apparent that the microflora of the butter from the clean churn was made up largely of butter culture organisms which gradually died off, while the microflora of the butter from the contaminated churn included certain types which were able to develop in the butter and raise the count to a very high figure.

In trial 15, in which the count on the cream and the counts on the fresh unsalted butter from the contaminated and clean churns were the lowest of all the trials, the counts on the various samples of butter after storage were practically the highest of all the trials. This indicates that there were present in the butter from both the contaminated and clean churns certain types of organisms which were able to grow extensively in all the various samples.

The initial microscopic counts were much higher than the initial plate counts as would be expected in view of the fact that pasteurized cream was used. The average initial microscopic count on the butter from the contaminated churns was greater than that of the butter from the clean churns, although the difference was not great. However, after holding for seven days at room temperature (about 70°F.) the differences in counts were very significant. With the salted butter, the average microscopic count on the butter from the contaminated churns was about the same as the initial count while the average count on the butter from the clean churns showed a significant decrease.

With the unsalted butter, the average microscopic count after storage for seven days at about 70°F. was much higher than the average initial microscopic count with both the butter from the contaminated and from the clean churns but the increase in average count was much greater with the butter from the contaminated churns. These results indicate that the contaminated churns added to the butter certain organisms which were able to develop extensively in both the salted and unsalted products.

A comparison of the microscopic counts on the salted and unsalted butter after storage for seven days at room temperature shows that the salt had a very definite restraining effect on the organisms in the butter. Since pasteurized cream was used, autolysis of some of the cells killed by the pasteurization would tend to decrease the microscopic counts during storage.

b. Scores on butter from contaminated and clean churns

The scores on the samples of fresh butter and on the samples after storage under different conditions are shown in table 17. The table includes criticisms on the unsalted butter

Table

Scores on butter from clean

	45°F.							
	Salted butter from		Unsalted butter from					
	Clean Churn	Contaminated Churn	Clean Churn		Contaminated Churn			
Days	Score	Score	Score	Criticism	Score	Criticism	Days	
							Trial	
2	92	92	92	sl. woody	92	woody	2	
16	91.5	91	91	sl. tallowy	90	rancid	22	
38	90.5	90.5	90	old	88	unclean rancid	70	
63	90.5	90	88	fruity; dirty	88	unclean rancid	109	
							132	
							Trial	
2	92	91.5	92		92		2	
13	91.5	90.5	90	sl. old	89.5	sl. rancid	19	
35	90.5	90.5	88	sl. fruity	86	unclean cheesy	67	
60	90	90	89.5		88		106	
							129	
							Trial	
1	92.5	91.5	91	sl. unclean	91		1	
12	92.5	91.5	90	sl. rancid	90.5		18	
34	91	91	89	fruity	88.5	fruity unclean	63	
59	90	90	88	fruity	86.5	rancid	105	
							128	
							Trial	
2	93	93	93		93	*	2	
9	92	92	90	coarse; oily	92		45	

Table 17

utter from clean and contaminated churns

		32°F.					
		Salted butter from		Unsalted butter from			
ted		Clean Churn	Contaminated Churn	Clean Churn		Contaminated Churn	
icism	Days	Score	Score	Score	Criticism	Score	Criticism
	Trial 1						
	2	92	92	92		92	
.d	22	92	91.5	92		91	unclean
ean .d	70	92	91	90	shows age	88	cheesy
ean .d	109	90	90	89	stale	86	very cheesy
	132	89	89	88.5	stale	87	very cheesy
	Trial 2						
	2	92	91.5	92		92	
rancid	19	91.5	92	90.5		91	
ean sy	67	91.5	91.5	91		88	cheesy
	106			89	stale	87	unclean very cheesy
	129			88	stale	85	unclean very cheesy
	Trial 3						
	1	92.5	91.5	91		91	
	18	92.5	91	91		90	
ty ean	66	92	91.5	90	sl. cheesy	90	sl. cheesy
ld	105	90.5	90.5	90	cheesy	89	cheesy
	128	89	89	87	cheesy	87	cheesy
	Trial 4						
	2	93	93	93		93	*
	45	92.	92.5	92.5		93	

59	90	90	88	fruity	86.5	rancid	105	9
							128	8
								Trial
2	93	93	93		93	*	2	9
9	92	92	90	coarse; oily	92		45	9
23	92	91.5	88.5	fruity	90		84	9
37	91.5	91	88.5		89	old; unclean	107	8
58	91	90.5	88.5	fruity sl. cheesy	88	cheesy rancid		
								Trial 5
2	93	92	92.5		93		2	9
9	93	92.5	90	fruity	92		38	9
16	91.5	91	87.5	cheesy	89	sl. rancid	77	9
30	91	90.5	87	very cheesy	88	unclean rancid	100	9
44	90.5	90.5	87		87	cheesy rancid	128	8
								Trial
2	92	91.75	92		92		2	9
16	92	91.5	91.5		89	unclean rancid	24	9
30	91	91.5	89	unclean	88	unclean rancid	63	9
65	91	91	88.5	sl. cheesy	86.5	cheesy rancid	86	9
72	90.5	90.5	88	cheesy	86	cheesy rancid	112	8
								Trial
2	92.5	92.5	92.5		92.5		2	9
9	92.5	92.5	92	sl. off	91.5	unclean sl. rancid dirty	10	9
23	91.5	91.5	88.5	sl. fruity sl. cheesy	88	unclean sl. rancid	49	9
51	91	91	89.5	old	88	unclean rancid	72	9
58	90.5	90.5	89	old; stale	87	unclean	100	8

	105	90.5	90.5	90	cheesy	89	cheesy
	128	89	89	87	cheesy	87	cheesy
Trial 4							
	2	93	93	93		93	*
	45	92+	92.5	92.5		93	
	84	91.5	91.5	90.5		91	
uclean	107	89.5	89.5	88	old; stale	89	old
Trial 5							
	2	93	92	92.5		93	
	38	92.5	92	86	cheesy	88	sl. cheesy sl. rancid
ncid	77	91.5	91.5	89.5	sl. cheesy	88	sl. cheesy sl. rancid
n	100	90	90	88	cheesy	88	cheesy rancid
	128	89	89	87	rancid	87	rancid
Trial 6							
	2	92	91.75	92		92	
n	24	93.5	93	93		92.75	
n	63	92	92	91.5	sl. fruity	90	unclean fruity sl. rancid
	86	90	90	90	tallowy	88	putrid unclean rancid
	112	89	89	88	stale	86	very rancid
Trial 7							
	2	92.5	92.5	92.5		92.5	
n ncid	10	93	93	93		93	
n ncid	49	92	92	91.5		91	sl. rancid
n l	72	91	90	88	putrid sl. rancid	89	putrid
n	100	89	88	86	cheesy	87	cheesy

9	92	92	90	coarse; oily	92		45	92.
23	92	91.5	88.5	fruity	90		84	91.
37	91.5	91	88.5		89	old; unclean	107	89.
58	91	90.5	88.5	fruity sl. cheesy	88	cheesy rancid		
							Trial 5	
2	93	92	92.5		93		2	93
9	93	92.5	90	fruity	92		38	92
16	91.5	91	87.5	cheesy	89	sl. rancid	77	91
30	91	90.5	87	very cheesy	88	unclean rancid	100	90
44	90.5	90.5	87		87	cheesy rancid	128	89
							Trial 6	
2	92	91.75	92		92		2	92
16	92	91.5	91.5		89	unclean rancid	24	93
30	91	91.5	89	unclean	88	unclean rancid	63	92
65	91	91	88.5	sl. cheesy	86.5	cheesy rancid	86	90
72	90.5	90.5	88	cheesy	86	cheesy rancid	112	89
							Trial 7	
2	92.5	92.5	92.5		92.5		2	92
9	92.5	92.5	92	sl. off	91.5	unclean sl. rancid dirty	10	93
23	91.5	91.5	88.5	sl. fruity sl. cheesy	88	unclean sl. rancid	49	92
51	91	91	89.5	old	88	unclean rancid	72	91
58	90.5	90.5	89	old; stale	87	unclean rancid	100	89

	45	92+	92.5	92.5		93	
	84	91.5	91.5	90.5		91	
nclean	107	89.5	89.5	88	old; stale	89	old
Trial 5							
	2	93	92	92.5		93	
	38	92.5	92	86	cheesy	88	sl. cheesy sl. rancid
ncid	77	91.5	91.5	89.5	sl. cheesy	88	sl. cheesy sl. rancid
n	100	90	90	88	cheesy	88	cheesy rancid
	128	89	89	87	rancid	87	rancid
Trial 6							
	2	92	91.75	92		92	
ın	24	93.5	93	93		92.75	
ın	63	92	92	91.5	sl. fruity	90	unclean fruity sl. rancid
r l	86	90	90	90	tallowy	88	putrid unclean rancid
r l	112	89	89	88	stale	86	very rancid
Trial 7							
	2	92.5	92.5	92.5		92.5	
an ancid	10	93	93	93		93	
an ancid	49	92	92	91.5		91	sl. rancid
an d	72	91	90	88	putrid sl. rancid	89	putrid
an d	100	89	88	86	cheesy sl. rancid	87	cheesy

Table 17 (cont

	45°F.							
	Salted butter from		Unsalted butter from					Sal
	Clean Churn	Contaminated Churn	Clean Churn		Contaminated Churn			Clea Ch
Days	Score	Score	Score	Criticism	Score	Criticism	Days	Sco
							Trial 8	
2	92	92	92		92		2	92
9	92	92	92		90	unclean suggestion of fruity	42	92
37	91.5	91.5	91.5		89	fruity unclean	65	9
51	90	89.5	89	old; sl. rancid	87.5	sl. bitter fruity rancid		
65	90	90	89	old; sl. rancid	86	cheesy rancid	93	9
							Trial 9	
2	93	93	93		93		2	9
23	91.5	91.5	87	quite cheesy	88	unclean sl. cheesy sl. rancid	35	9
37	90.5	90.5	86	sl. rancid very cheesy	87	rancid	58	9
51	91	90.5	86	very cheesy	86	cheesy rancid	86	9
							Trial 1	
2	93	93	93		93		2	9
16	92.5	92.5	92		91.5	sl. unclean	28	9
23	92	92	92	sl. old	89	rancid	51	9
30	92	92	90.5	sl. old	86	very rancid	79	9
44	91.5	91.5	90	old; sl. off	87	fruity rancid		
							Trial	
2	93.5	93.5	93		93		2	
16	92.5	92.5	92		90	unclean	21	

Table 17 (continued)

		32°F.					
		Salted butter from		Unsalted butter from			
ed		Clean Churn	Contaminated Churn	Clean Churn		Contaminated Churn	
ism	Days	Score	Score	Score	Criticism	Score	Criticism
	Trial 8						
	2	92	92	92		92	
an ation fruity	42	92	92	92		90	fruity
r an	65	90	90	90		89.5	fruity sl. rancid
itter y l							
y l	93	90	90	90	old	87	surface taint sl. rancid
	Trial 9						
	2	93	93	93		93	
an heesy ancid	35	92	91.5	90.5		91.5	
l	58	91	91	90	sl. putrid	90.5	unclean
y l	86	90	90	88.5	cheesy	89	sl. cheesy
	Trial 10						
	2	93	93	93		93	
nclean	28	92.5	92.5	92		91.75	
d	51	91.5	91.5	90.5		90.5	
rancid	79	91	91	90	stale	90	stale
y d							
	Trial 11						
	2	93.5	93.5	93		93	
n	21	93	92.5	93		93	

30	92	92	90.5	sl. old	86	very rancid	79	91
44	91.5	91.5	90	old; sl. off	87	fruity rancid		
							Trial 11	
2	93.5	93.5	93		93		2	93
16	92.5	92.5	92		90	unclean	21	93
23	91.5	91	89.5	sl stale	88	sl. fruity	44	91
37	90.5	90.5	89	stale	86	fruity rancid	72	91
51	90.5	89.5	89	old; stale	87	sl. rancid very unclean		
							Trial 1	
2	92.5	92.5	92.5		92.5		2	9
9	92.5	92.5	92.5		89	fruity	14	9
16	92	92	91.5		87	rancid fruity	37	9
51	91	90.5	90		86	very rancid fruity		
65	90.5	90	89.5		86	very rancid	65	9
							Trial 1	
2	92.5	92.5	92.5		92.5		2	9
9	92.5	92.5	92.5		89	unclean sl. rancid sl. cheesy	30	9
23	92	91.5	91	sl. old	86.5	fruity cheesy rancid	58	9
58	91	90.5	90	old	86	cheesy rancid		
							Trial	
2	92.5	92.5	92.5		92.5		2	
16	92.5	92.5	92		88	fruity	23	
37	91.5	91.5	90.5	old	86	unclean cheesy rancid	51	
51	91	91	90.5		86	cheesy rancid		

ncid	79	91	91	90	stale	90	stale
	Trial 11						
	2	93.5	93.5	93		93	
	21	93	92.5	93		93	
ty	44	91.5	91.5	91.5		88	putrid
	72	91	91	91		86	rancid cheesy
id lean							
	Trial 12						
	2	92.5	92.5	92.5		92.5	
	14	93	93	92.5		92.5	
	37	91.5	91.5	91		88	sl. fruity sl. rancid putrid
ncid							
ncid	65	91	91	90	sl. stale	86	rancid cheesy
	Trial 13						
	2	92.5	92.5	92.5		92.5	
cid esy	30	91	91	92.5		90	sl. fruity sl. putrid
	58	91	91	91		87	cheesy
	Trial 14						
	2	92.5	92.5	92.5		92.5	
	23	92	92	92		90	sl. putrid
	51	91.5	91.5	91.5		89	surface taint

Table 17 (co

	45°F.							
	Salted butter from		Unsalted butter from					S
	Clean Churn	Contaminated Churn	Clean Churn		Contaminated Churn			Cl
Days	Score	Score	Score	Criticism	Score	Criticism	Days	S
							Trial	
2	92.5	92.5	92.5		92.5		2	
16	92	92	91.5		88.5	sl. cheesy	16	
30	92	92	91		87	unclean cheesy	44	
44	91	91	90	stale	86.5	very cheesy limburger		
							Trial	
2	92.5	92.5	92.5		92.5		2	
9	92.5	92.5	92		91.5	sl. fruity	9	
30	91.5	91.5	88	cheesy	87	unclean sl. rancid	37	
37	91.5	91	87	cheesy	86	rancid		
							Trial	
2	92.5	92.5	92.5		92.5		2	
9	92.5	92.5	92.5		91	sl. fruity	30	
23	92	92	91.5		90	sl. rancid		
30	92	92	91		88.5	sl rancid fruity		

*Small amount of salt added by mistake.

Table 17 (continued)

om inated rn Criticism	Days	32°F. Salted butter from Clean Churn: Score	Salted butter from Contaminated Churn Score	Unsalted butter from Clean Churn Score	Unsalted butter from Clean Churn Criticism	Unsalted butter from Contaminated Churn Score	Unsalted butter from Contaminated Churn Criticism
		Trial 15					
	2	92.5	92.5	92.5		92.5	
.. cheesy	16	92.5	92.5	92.5		92.5	
ıclean ıeesy	44	92	92	92		91.5	sl. off
ıry cheesy .mburger							
		Trial 16					
	2	92.5	92.5	92.5		92.5	
l. fruity	9	92.5	92	92.5		92.5	
ıclean l. rancid	37	92	92	92		90	sl. putrid
ancid							
		Trial 17					
	2	92.5	92.5	92.5		92.5	
l. fruity	30	92	92	91		88	sl. surface taint
l. rancid							
l rancid ruity							

but the criticisms on the unsalted butter are not included because no serious defects developed in any of the samples.

1. Butter stored at 45°F.

(a) Salted

The scores, on the salted butter stored at 45°F. indicate that there was no significant difference in the keeping qualities of the butter made in clean churns and of that made in contaminated churns. The changes that took place in the salted butter were gradual and not extensive; none of the samples showed any marked defects even after extended holding. In a few trials the butter from the clean churns tended to show better keeping qualities than that from the contaminated churns but the differences were too small to be of much significance. A comparison of the scores on the salted butter with those on the unsalted butter shows that the salt had a decided restraining action on the organisms in the butter.

(b) Unsalted

With the unsalted butter stored at 45°F. the changes during storage were much more rapid and more extensive than with the salted butter. The butter from the contaminated churns generally deteriorated more rapidly than the butter from the clean churns but in the 17 trials there were 3 exceptions (trials 4, 5 and 9). In one of these (trial 4) a small amount of salt was added through error to what was intended to be the sample of unsalted butter from the contaminated churn; the restraining action of this salt could easily account for the differences in scores. In another trial (trial 5) the high count on the pasteurized cream was probably largely responsible for the rapid deterioration of the butter from both the contaminated and clean churns. Since the contaminated churn had a comparatively low count in this trial, the numbers of organisms added by it to the butter would be small compared to the numbers derived from the cream. Differences in curd content could easily account for the differences in rate of deterioration. No logical reason can be given for the unexpected differences in scores in the third trial (trial 9).

In 5 trials (trials 1, 2, 3, 7 and 16) the unsalted butter from clean churns showed slightly better keeping qualities than the butter from the contaminated churns, while in 9 trials (trials 6, 8, 10, 11, 12, 13, 14, 15 and 17) the butter from the clean churns showed distinctly superior keeping qualities. The development of defects was generally much more rapid and more extensive in the butter from the contaminated churns than in that from the clean churns, the differences in score often being 4 or 5 points. Notable examples of large differences in scores are found in five trials (trials 10, 12, 13, 14 and 15); it is significant that four of these trials (trials 12, 13, 14 and 15) were among the six trials in which a high temperature (155°F. for 30 minutes) was used to pasteurize the cream.

The most common defects which developed in the unsalted butter stored at 45°F. were rancid, cheesy, fruity and unclean flavors. Rancidity was a very common defect in the butter from contaminated churns while when extensive deterioration took place in the butter from clean churns, a cheesy flavor was most common. Fruity flavors were common to both the butter from clean and from contaminated churns. It is significant that in the trials in which the cream was pasteurized at a high temperature (155°F.) only one of the samples of unsalted butter from the clean churns (trial 16) showed any serious defect even after extended holding.

2. Butter stored at 32°F.

(a) Salted

The salted butter stored at 32°F. kept well in every trial and in no case did a serious defect develop even after extended holding. In many cases the butter from the clean churns scored higher than the butter from the contaminated churns but the differences in score were too small to be of much significance.

(b) Unsalted

The unsalted butter stored at 32°F. showed much more rapid deterioration than the salted butters and the changes were much more extensive. The butter from the contaminated churns usually showed more rapid and more extensive deterioration than did the butter from the clean churns; in four trials (trials 11, 12, 13 and 17) the differences in scores were comparatively great, in eight trials (trials 1, 2, 3, 6, 8, 14, 15 and 16) the differences were not great but very definite, in three trials (trials 5, 7 and 10) there were practically no differences and in two trials (trials 4 and 9) the butter from the contaminated churns scored higher than the butter from the clean churns. In general, the scores on the samples of butter stored at 32°F. followed the same trend as the scores on the samples stored at 45°F. but the changes were not as rapid nor as extensive as those brought about in the butter held at 45°F.

The most common defects which developed in the unsalted butters stored 32°F. were cheesy, rancid, putrid, surface taint, and stale flavors. The butter from the contaminated churns commonly became cheesy and rancid, with putrid and surface taint flavors not uncommon, while when extensive deterioration occurred in the butter from the clean churns, the most common defect was a cheesy flavor. Rancidity was not as common a defect in the butter stored at 32°F. as in the butter held at 45°F.

E. <u>Contamination of churns from the air</u>

In making agar disc counts on churns it was observed that the discs prepared from the surfaces more or less exposed to the creamery air showed greater numbers of yeasts and molds than protected surfaces. Since an environment in which yeasts and molds are present ordinarily also contains bacteria in larger numbers it was thought that the creamery air might be an important source of contamination of churns. While the numbers of microorganisms falling through the open door of a churn would not be expected to seriously contaminate a churn, the numbers carried in by the strong convection currents developed in a churn just washed might be of significance.

In order to approximate the extent of air contamination of churns, the numbers of organisms falling on a given area in a given time were determined by exposing petri plates to the creamery air and to the air within churns.

Beef infusion agar was used for the bacterial counts and acidulated malt agar (pH 3.5) was used for the yeast and mold counts. The blank plates were prepared by pouring about 10 ml. portions of the melted media into sterile petri plates and allowing them to solidify. Two plates, one infusion agar and one malt agar, were exposed to the creamery air by placing them on top of a switch box (about four feet above the floor), near one of the churns and removing the covers. A similar set of plates was exposed on the roller of churn A, about half way between the middle and one of the ends and another set on the front shelf of churn B, about half way between the center and one of the ends, so that the plates would not be directly inside the door opening. In every case the churns were turned so that the door was half way up on the side. The plates were generally exposed to the creamery air for 30 minutes while inside the churns they were generally exposed two hours. After exposure the covers were replaced and the plates incubated for four days at room temperature. The results are expressed as the number of organisms falling per hour on a 90 mm. petri plate.

A number of trials were run in which the door opening of one churn was covered with a piece of muslin tacked on a frame which fit into this opening while the other churn was left unprotected. It was presumed that covering the opening in this way would tend to reduce the numbers of organisms getting into the churn by filtering out the dust particles and by eliminating strong convection currents.

The results of exposing petri plates to the creamery air and to the air within churns are shown in table 18. In addition to the counts secured this table includes the data on the length of time that the churn had stood since washing and whether or not the churn was protected with a muslin door covering. Fifty-seven bacterial and 60 yeast and mold counts were obtained on the plates exposed to the creamery air. The bacterial counts

Table 18

Bacteria, yeasts and molds following

Table 18

Bacteria, yeasts and molds falling per hour on 90 mm

		Creamery Air			Inside Churn A			
Date	Time	Bacteria	Yeasts	Molds	Bacteria	Yeasts	Molds	Remarks
9/28/31	10 A.M.	255	6	18				
9/30/31	10 A.M.	58	2	52	5	2	11	Stood 1 day
10/1/31	10 A.M.	14	1	35		3	6	Stood 2 days
10/3/31	3 P.M.					9	201	Just washed
10/5/31	3 P.M.	142	54	328				
10/8/31	7 P.M.	18	6	28	35	1	4	Just washed
10/9/31	7 P.M.	16	2	40	9	1	15	Just washed
10/10/31	7 P.M.	54	2	50	27	2	62	Just washed
10/12/31	7 P.M.	14	2	22	62	6	30	Just washed
10/13/31	7 P.M.	26	14	30	36	6	15	Just washed
10/14/31	7 P.M.	28	2	24	76	4	32	Just washed
10/15/31	7 P.M.	14	2	36	21	0	9	Just washed
10/16/31	7 P.M.	16	0	76	21	2	40	Just washed
10/19/31	7 P.M.	30	0	32	51	2	47	Just washed
10/20/31	7 P.M.	30	2	38	26	1	6	Just washed
10/21/31	7 P.M.		20	64	6	1	9	Just washed
10/26/31	7 P.M.	26	2	58	27	4	31	Just washed
10/27/31	7 P.M.	48	12	76	25	5	31	Just washed
10/30/31	7 P.M.	22	5	13	5	1	6	Just washed
11/2/31	7 P.M.	18	2	54	39	4	13	Just washed

Table 18

s and molds following

Table 18

s and molds falling per hour on 90 mm. petri plates

Inside Churn A				Inside Churn B			
Bacteria	Yeasts	Molds	Remarks	Bacteria	Yeasts	Molds	Remarks
				49	2	14	Stood 1 day
5	2	11	Stood 1 day	14	1	11	Stood 1 day
	3	6	Stood 2 days	2	1	19	Stood 1 day
	9	201	Just washed		7	214	Just washed
				43	6	52	Just washed
35	1	4	Just washed	11	1	12	Just washed
9	1	15	Just washed	9	2	22	Stood 1 day
27	2	62	Just washed	13	1	12	Just washed
62	6	30	Just washed	46	5	27	Just washed
36	6	15	Just washed	13	2	6	Stood 1 day
76	4	32	Just washed	19	0	16	Just washed
21	0	9	Just washed	10	2	18	Stood 1 day
21	2	40	Just washed	24	2	28	Stood 2 days
51	2	47	Just washed	10	2	10	Stood 1 day
26	1	6	Just washed	30	0	8	Just washed
6	1	9	Just washed	5	0	15	Stood 1 day
27	4	31	Just washed	17	4	39	Just washed
25	5	31	Just washed	10	4	29	Just washed
5	1	6	Just washed	10	1	5	Just washed
39	4	13	Just washed	17	2	3	Stood 2 days
[illegible]	2	[illegible]	Just washed	[illegible]	[illegible]	[illegible]	[illegible]

10/19/31	7 P.M.	30	0	32	51	2	47	Just washed
10/20/31	7 P.M.	30	2	38	26	1	6	Just washed
10/21/31	7 P.M.		20	64	6	1	9	Just washed
10/26/31	7 P.M.	26	2	58	27	4	31	Just washed
10/27/31	7 P.M.	48	12	76	25	5	31	Just washed
10/30/31	7 P.M.	22	5	13	5	1	6	Just washed
11/2/31	7 P.M.	18	2	54	39	4	13	Just washed
11/3/31	7 P.M.	34	8	98		2	29	Just washed
11/4/31	7 P.M.	24	70	104	1	2	34	Just washed
11/5/31	7 P.M.	54	8	56	1	5	24	Just washed
11/11/31	7 P.M.	24	6	18	1	3	4	Stood 1 day
11/12/31	7 P.M.	4	8	28	4	1	9	Just washed
11/13/31	7 P.M.	8	8	34	4	3	29	Just washed
11/16/31	7 P.M.	4	4	36	14	1	18	Just washed
11/18/31	7 P.M.	12	2	8	3	1	6	Just washed
11/20/31	7 P.M.				1	0	8	Stood 1 day
11/23/31	7 P.M.		38	20		2	5	Just washed
11/30/31	7 P.M.		0	4		1	15	Just washed
12/2/31	7 P.M.	19	2	10	5	0	5	Stood 1 day
12/4/31	2 P.M.	30	0	10	3	0	2	Stood 1 day
12/7/31	2 P.M.	24	0	18	15	1	8	Just washed
12/8/31	2 P.M.	11	5	13	4	1	7	Just washed
12/10/31	2 P.M.	24	1	15	26	1	2	Just washed
12/14/31	1 P.M.				34	2	8	Just washed
12/15/31	2 P.M.	22	0	6	2	1	6	Just washed*
12/17/31	3 P.M.	460	3	12	14	1	2	Just washed*
1/7/32	3 P.M.	579	0	2	3	0	0	Just washed*
1/9/32	1 P.M.	410	1	2				
1/11/32	3 P.M.	265	2	4	95	1	5	Just washed
1/13/32	2 P.M.	52	8	6				

51	2	47	Just washed	::	10	2	10	Stood 1 day
26	1	6	Just washed	::	30	0	8	Just washed
6	1	9	Just washed	::	5	0	15	Stood 1 day
27	4	31	Just washed	::	17	4	39	Just washed
25	5	31	Just washed	::	10	4	29	Just washed
5	1	6	Just washed	::	10	1	5	Just washed
39	4	13	Just washed	::	17	2	3	Stood 2 days
	2	29	Just washed	::	8	0	32	Just washed
1	2	34	Just washed	::	5	1	27	Stood 2 days
1	5	24	Just washed	::				
1	3	4	Stood 1 day	::	6	3	13	Just washed
4	1	9	Just washed	::	1	1	8	Just washed
4	3	29	Just washed	::	5	3	16	Just washed
14	1	18	Just washed	::	1	3	3	Stood 2 days
3	1	6	Just washed	::	4	0	4	Stood 1 day
1	0	8	Stood 1 day	::	1	0	3	Stood 1 day
	2	5	Just washed	::		0	2	Stood 2 days
	1	15	Just washed	::		3	6	Just washed
5	0	5	Stood 1 day	::	10	1	8	Just washed
3	0	2	Stood 1 day	::	4	0	9	Stood 1 day
15	1	8	Just washed	::	21	3	9	Just washed
4	1	7	Just washed	::	3	0	9	Stood 1 day
26	1	2	Just washed	::	24	0	1	Stood 1 day
34	2	8	Just washed	::				
2	1	6	Just washed*	::	2	0	1	Stood 1 day*
14	1	2	Just washed*	::	8	0	1	Stood 2 days*
3	0	0	Just washed*	::	4	0	0	Stood 1 day*
95	1	5	Just washed	::	181	1	5	Just washed
				::	3	0	2	Stood 2 days*

Table 18 (continued)

Date	Time	Creamery Air			Inside Churn A			
		Bacteria	Yeasts	Molds	Bacteria	Yeasts	Molds	Remarks
1/15/32	2 P.M.	274	1	5		0	4	Just washed
1/21/32	1 P.M.	103	1	2	10	0	6	Just washed
1/27/32	1 P.M.				64	0	0	Just washed
1/28/32	2 P.M.	465	34	12	14	0	1	Just washed
2/1/32	2 P.M.	112	1	9	73	0	6	Just washed
2/3/32	3 P.M.	110	3	5				
2/6/32	2 P.M.	264	1	6	33	0	2	Just washed
2/15/32	2 P.M.	443	3	2	83	1	2	Stood 2 day
2/18/32	2 P.M.	188	2	4	22	0	3	Stood 1 day
2/24/32	3 P.M.	271	28	3	5	0	1	Just washed
2/26/32	2 P.M.	195	19	5	45	2	5	Just washed
2/27/32	2 P.M.	541	4	15	427	1	8	Just washe
3/3/32	3 P.M.	259	2	3	86	0	2	Stood 1 day
3/7/32	2 P.M.	659	10	17				
3/11/32	2 P.M.	428	20	15				
3/14/32	2 P.M.	200	1	5	112	0	0	Just washed
3/18/32	2 P.M.	608	3	8	63	1	3	Just washed
3/24/32	2 P.M.	343	26	14				
3/28/32	3 P.M.	478	13	15	234	1	2	Just washed
4/1/32	3 P.M.	754	4	10		0	5	Just washed
4/4/32	2 P.M.	67	0	10				
4/8/32	3 P.M.				29	1	1	Just washed
Average		169	7.9	29	41	1.6	15	

*Door covered with muslin.

Table 18 (continued)

Inside Churn A				Inside Churn B			
Bacteria	Yeasts	Molds	Remarks	Bacteria	Yeasts	Molds	Remarks
	0	4	Just washed	1	1	0	Stood 1 day
10	0	6	Just washed	93	1	5	Stood 1 day
64	0	0	Just washed				
14	0	1	Just washed*	88	29	6	Stood 1 day
73	0	6	Just washed	3	0	1	Just washed*
				2	0	3	Stood 2 days*
33	0	2	Just washed*				
83	1	2	Stood 2 days	6	0	1	Stood 2 days*
22	0	3	Stood 1 day	22	0	1	Just washed
5	0	1	Just washed*				
45	2	5	Just washed	13	0	2	Just washed*
427	1	8	Just washed	6	0	2	Just washed*
86	0	2	Stood 1 day	153	1	4	Just washed
				144	2	5	Just washed
				83	1	6	Just washed
112	0	0	Just washed	6	0	0	Just washed*
63	1	3	Just washed				
				24	1	4	Just washed
234	1	2	Just washed	217	1	6	Just washed
	0	5	Just washed	226	2	7	Stood 1 day
				14	0	1	Stood 2 days
29	1	1	Just washed*	292	0	3	Just washed
41	1.6	15		39	1.8	13	

ranged from 4 to 754 and averaged 169, the yeast counts ranged from 0 to 70 and averaged 7.9 and the mold counts ranged from 2 to 328 and averaged 29.

Forty-nine bacterial and 56 yeast and mold counts were obtained on the plates exposed inside churn A. The bacterial counts ranged from 1 to 427 and averaged 41; the yeast counts ranged from 0 to 9 and averaged 1.6 and the mold counts ranged from 0 to 201 and averaged 15.

Fifty-five bacterial and 58 yeast and mold counts were obtained on churn B. The bacterial counts varied from 1 to 292 and averaged 39, the yeast counts varied from 0 to 29 and averaged 1.8 and the mold counts varied from 0 to 214 and averaged 13.

The organisms falling per hour per plate inside churns protected with a muslin door covering are shown in table 19. In the seven trials reported with churn A the bacterial counts ranged 2 to 33 and averaged 17, and the molds ranged from 0 to 6 and averaged 2.2. No yeasts were detected on the plates in four of the trials and in the other three trials there was only one colony per plate. The churn had just been washed before each trial. In 10 trials with churn B the bacterial counts ranged from 2 to 13 and averaged 5.3 while the mold counts ranged from 0 to 3 and averaged 1.3. No yeast colonies were detected on any of the plates in the 10 trials. In four of the trials the churn had justbeen washed and in the other six it

Table 19

Bacteria, yeasts and molds falling per hour on 90 mm. petri plates exposed inside protected churns.

Churn A					Churn B				
Date	Bacteria	Yeasts	Molds	Remarks	Date	Bacteria	Yeasts	Molds	Remarks
12/15/31	2	1	6	Just washed	12/15/31	2	0	1	Stood 1 day
12/17/31	14	1	2	Just washed	12/17/31	8	0	1	Stood 2 days
1/7/32	3	0	0	Just washed	1/7/32	4	0	0	Stood 1 day
1/28/32	14	0	1	Just washed	1/13/32	3	0	2	Stood 2 days
2/6/32	33	0	2	Just washed	2/1/32	3	0	1	Just washed
2/24/32	5	0	1	Just washed	2/3/32	2	0	3	Stood 2 days
4/8/32	29	1	1	Just washed	2/15/32	6	0	1	Stood 2 days
					2/26/32	13	0	2	Just washed
					2/29/32	6	0	2	Just washed
					3/14/32	6	0	0	Just washed
Average	17	.5	2.2			5.3	0	1.3	

had stood for one or two days after washing.

The results show that large numbers of organisms are deposited upon plates exposed to the creamery air and to the air inside churns. On the plates exposed to the creamery air the average number of bacteria falling was over five times as large as the number of molds and over 21 times as large as the number of yeasts. This same general relationship between the numbers of the various groups of organisms occurred with the plates exposed inside the churns.

The counts on the plates exposed to the creamery air were considerably greater than, and roughly proportional to, the counts on the plates exposed inside the churns; the bacterial and yeast counts of the former averaged over four times as high as the counts of the latter, and the mold counts averaged about twice as high. It is apparent from the data that there were many more organisms deposited on the plates in a freshly washed churn than on the plates exposed in churns which had stood for a day or more after washing; the strong convection currents set up in the warm churns was most likely responsible for this difference.

A comparison of tables 18 and 19 shows that the numbers of organisms falling on plates exposed inside churns protected with muslin door coverings were less than the numbers falling on plates exposed inside unprotected churns; elimination of strong convection currents by the door covering was probably largely responsible for the difference in counts.

The mold counts on the plates exposed to the creamery air, and also on the plates exposed inside the churns, were very high during the first two months of the investigation (September and October) but they were appreciably lower during the following months, while the bacterial counts seemed to be highest during the latter months of the investigation (February, March and April).

The counts inside the churns were obtained by exposing the plates in more or less protected placed and, consequently, are probably much lower than they would have been if the plates had been exposed directly inside the door openings. It is obvious that if the churns were turned so that the door openings would be up instead of on the side more organisms would fall into them.

CONCLUSIONS

1. Studies carried out on 27 churns in 24 Iowa creameries showed that the sanitary condition of the churns varied greatly and that few of them were in a satisfactory sanitary condition.

2. The microflora of the churns with low bacterial counts usually included few types, chiefly members of the genus Bacillus, while the microflora of the churns with high bacterial counts generally included many types, chiefly micrococci.

3. The yeast and mold counts on the churns were much lower than the bacterial counts and were roughly proportional to them.

4. The general sanitary condition of a plant was usually a better index to the cleanliness of the churn than the churn washing procedure reported by the plant manager.

5. Uniformly low counts were secured on churns treated with the normal procedure used in the Iowa State College creamery. This consists of rinsing out the fat, filling the churn one-third to one-half full of water at 180°F. or higher, adding washing powder, revolving for about 15 minutes and draining. The churn is then filled one-half full of water at about 200°F. and revolved for about 20 minutes, drained and dried.

6. The microflora of the churns washed with the normal procedure included very few types, chiefly members of the genus Bacillus.

7. The yeast and mold counts on churns just washed with the normal procedure were very low; the counts were commonly higher

on churns that had stood for a day or two after washing.

8. The use of solutions of sodium hypochlorite, chlorinated lime or calcium hypochlorite on churns washed with the normal procedure resulted in significant reductions in the numbers of organisms in the churns.

9. The bacterial counts on the churns treated with the chlorine solutions were all very low and the variations very small.

10. With the chlorine treatments of churns washed with the normal procedure there was a closer correlation between the counts before and after treatment than there was between the concentration of available chlorine, the temperature, or the period of exposure and the count after treatment.

11. The decreases in available chlorine in the solutions during exposure to the churns were generally greatest with high temperatures or long periods of exposure.

12. There was apparently no difference in the efficiencies of sodium hypochlorite, chlorinated lime and calcium hypochlorite in the treatment of churns washed with the normal procedure.

13. The use of a saturated sodium chloride solution on a churn washed with the normal procedure did not significantly reduce the numbers of organisms contained in the churn; there was evidence of certain salt tolerant types being carried into the churn by the sodium chloride solutions.

14. The treatment of highly contaminated churns with sodium hypochlorite solutions effected significant reductions in the numbers of organisms in the churns.

15. In general, high concentrations of available chlorine, high temperatures and long periods of exposure resulted in the greatest efficiencies in treating highly contaminated churns with sodium hypochlorite solutions.

16. The temperatures of the chlorine solutions were apparently a more important factor in determining the efficiencies than were the available chlorine concentrations or periods of exposure.

17. The microflora of highly contaminated churns before treatment with chlorine solutions generally included many types of microorganisms, while after treatment it usually included few types, chiefly members of the genus Bacillus.

18. The chlorine solutions after exposure to contaminated churns never contained yeasts or molds while the water used to rinse the churn after the chlorine treatment often showed significant numbers of these organisms; this suggests the presence in the churns of certain infection foci which do not have sufficient contact with the sterilizing medium.

19. On a highly contaminated churn a commercial chloramine preparation was not as efficient, especially in the destruction of yeasts and molds, as was sodium hypochlorite.

20. The solutions of the chloramine preparation were most effective at high temperatures.

21. The loss of available chlorine during exposure was much less with the solutions of the chloramine preparation than with the hypochlorite solutions.

22. The treatment of churns with hot water was effective in reducing the numbers of organisms in them to very low figures when the temperature of the water was 180°F. or higher and the period of exposure 30 minutes or longer, but spore forming bacteria were able to survive.

23. In the treatment of highly contaminated churns with hot water, various microorganisms, including yeasts and molds, survived when the periods of exposure were short; this suggests that they were harbored in more or less protected places to which the heat did not penetrate sufficiently.

24. The 61 pure cultures of organisms isolated from churns, and used to inoculate cream just before churning, all caused some change in unsalted butter stored at 59°F. although with many the changes were not great.

25. In general, organisms from clean churns (genus Bacillus types) were apparently not as detrimental to the keeping quality of butter as some of the types commonly found in highly contaminated churns.

26. In general, mixed cultures of organisms, isolated from churns brought about more rapid and extensive changes in butter

than did the pure cultures.

27. The fresh butter churned in contaminated churns had a considerably higher average plate count and a significantly higher microscopic count than the butter churned in the same churn after cleaning.

28. The unsalted butter from the clean churns usually had a lower plate count after storage at 45°F. for from 21 to 63 days than did the butter from the contaminated churns.

29. After storage for seven days at room temperature (about 70°F.) the average microscopic counts on the salted and unsalted butter from the contaminated churns were higher than those on the butter from the clean churns.

30. There was no significant differences either at 32°F. or at 45°F. in the keeping qualities of salted butter from clean and from contaminated churns.

31. The unsalted butter deteriorated much more rapidly than the salted butter, both at 32°F. and at 45°F., and the deterioration was more rapid at the higher than at the lower temperature.

32. Unsalted butter from the contaminated churns deteriorated much more rapidly and more extensively than that from the clean churns, both at 32°F. and at 45°F.

33. Rancidity was the most common defect produced in butter from contaminated churns and cheesiness was the most common defect in butter from the clean churns.

34. The creamery air may be a source of contamination of churns because it was shown that considerable numbers of organisms fell upon petri plates exposed to it and to the air within churns; the numbers of bacteria which fell on the plates were far greater than the numbers of yeasts and molds.

35. Covering the door openings of churns with muslin markedly decreased the numbers of organisms falling into the churns.

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ECONOMICS OF FEED UTILIZATION

WITH SPECIAL EMPHASIS ON RISK AND UNCERTAINTY

by

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INTRODUCTION

The problem of feed utilization has come to the forefront in recent years in connection with the increased emphasis on soil conservation and the recognition that grasses and legumes play an important part in farm cropping systems as one means of conserving soil. Grasses and legumes in a cropping system may contribute to farm income by increasing or maintaining the yields of other crops through their beneficial effects on soil productivity and, more directly, by providing a product which can be used in livestock production. Thus the profitability of increasing forage acreage is dependent partially on its conservation value but to a large extent on its value in livestock feeding.

The United States Conservation Service has from its birth encouraged a shift in crop acreage from grain to forage crops. Other public agencies, numerous private organizations and individual conservation enthusiasts have in the past decade been pleading for increased attention to soil conservation, and especially through shifting land now in grain crops to hay and pasture production. More recently the United States Department of Agriculture and The Association of Land Grant Colleges have drawn up a joint resolution calling for increased efforts in promoting "grassland farming" (50).

These recommendations for increased forage imply the assumptions that a shift to more grass and legume acreage will be (a) profitable for the individual farmer and (b) beneficial to society. These assumptions are not arrived at altogether intuitively. Numerous testimonials and many rotation experiments support the view that increased forage production is profitable. That more forage in the rotation would retard the rate of soil loss and thus leave society less impoverished with respect to soil resources in the future has been adequately demonstrated for most soil situations. Yet, there is not adequate evidence that individual farmers will profit from increased forage acreage. Nor can we say definitely that society is made better off by substituting forage for grain production.

The assumption that society stands to benefit from an increase in forage acreage seems to rest largely on the proposition that society looks favorably on any sacrifice of current consumption which contributes to the amount of goods available for posterity. Such an assumption is not entirely unrealistic; we do through state and federal legislation express a high regard for providing for future generations. On the other hand, the individuals who make up society also express their preferences through the market mechanism. In a society such as ours, where free consumer choice is permitted, prices are normally free to reflect the aggregative preferences of society. If the market is taken as an expression of society's interest in future vs. current agricultural production there is some doubt that a shift to forage crops is beneficial to society. Thus society has at least two ways of indicating its desires with regard to inter-temporal substitution of agricultural production, and these two indices may be contradictory. The exact nature of society's indifference map for consumption in different time periods defies measurement[a]. But to say that society is made better off by postponement of consumption of agricultural resources implies considerable knowledge about such an indifference map. If only a relatively short period of time is taken into account, however, prices established in the market may be taken as society's criterion for allocating resources between soil conserving and soil depleting agricultural products. If so, it can be said that in a competitive economy the optimum position for an individual farmer is consistent with society's optimum position.

The assumption that it is profitable for farmers to increase forage acreage may have the following bases:

(a) The present average ratio of forage acreage to grain crops is low; when the ratio of forage to grain in a cropping system is low the response of yields to small increases in the ratio is generally large and, with so low a ratio, forage and grain production may even be complementary -- i.e. an increase in the proportion of forage in the rotation may increase total grain output. Recommendations to increase forage acreage may then be rationalized on the basis that compliance would bring the aggregate ratio of forage to grain acreage nearer the level at which the value of added returns from forage just offsets the loss in returns from grain. One fallacy of the argument is that some individuals may already be operating beyond this level of forage intensity; compliance by them may place them in a position even farther from equilibrium.

(b) Total production of feed units is increased as forage is

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[a]For a discussion of inter-temporal welfare criteria see Heady (17, p. 399).

substituted for grain in the rotation and therefore the quantity of livestock product which can be produced from a given land area is increased by a shift to forage. This argument fails to take into account the differences in bulkiness and other features of feeds which cause them to substitute at diminishing rather than fixed rates in livestock production. Further, it does not take into account the inability of individual farmers to reorganize their resources to market a new combination of feeds. Grain crops may be sold directly, but forage crops must ordinarily be processed through livestock in order to provide a return. Inability to handle additional livestock (due to capital or labor limitations, for example) may preclude obtaining any returns from the feeds.

(c) Static analyses of costs and returns may indicate that many farmers can increase their forage acreage profitably. These analyses fail to take into account the effect of time in the production process. Livestock production processes take considerable time; consequently, the prices, costs and other factors which determine the net returns cannot be known with certainty at the time many of the decisions affecting production are made. The optimum position indicated by the static analysis may be entirely inappropriate for the situation involving uncertainty.

Despite the efforts being made in urging farmers to devote more of their land to forage production the percentage of land in grasses and legumes has actually declined in some of the major farm areas. In Iowa, for example, the percentage of all land in farms used for hay and pasture production averaged about forty per cent over the period 1930 to 1939.

The percentage increased to about forty-five per cent in 1940 under the impetus of the Soil Conservation payments. Since then it has declined until in 1950 only thirty-eight per cent of all farm land was used for hay and pasture production. The failure of farmers to accept recommendations for increasing forage production is not due to a failure to recognize the importance of forage crops in building and maintaining soil productivity. These benefits are generally conceded. But the profitability of increasing forage acreage may also depend on making efficient use of the added forage. The problem of forage utilization thus becomes an important obstacle to the increase of forage acreage on many farms (9, pp. 109-110).

A tremendous amount of research funds and scientific effort has been directed toward research in livestock feeding problems since the establishment of the land grant colleges and agricultural experiment stations. That this research has contributed greatly to more efficient livestock production is not questioned; but, in spite of the great amount of information concerning animal feeding now assembled, there still remains considerable doubt, confusion, and conflicting advice with respect to the profitability of alternative ways of utilizing feeds in livestock production.

Unambiguous recommendations concerning the profitability of increased forage production requires an understanding of the technical relationships between crops in crop production and between these crops as feeds in livestock production. In addition, insight is needed into the economic forces affecting returns from alternative feed combinations, the risk and uncertainty surrounding alternative decisions and the effect of farmers attitudes toward uncertainty.

STATEMENT OF THE PROBLEM AND OBJECTIVES OF THE STUDY

Nature of the Problem

The discussion of the preceding section poses the problem of how much forage to produce. More specifically, answers are sought to the following questions: (a) What is the optimum forage acreage for an individual farmer to produce? (b) What is the optimum forage acreage from the standpoint of society? In this analysis an attempt is made to determine the optimum position for the individual farmer. This may or may not be the optimum forage output for society. As pointed out earlier, society may express its desires regarding the amount of forage or other product to be produced through the prices it establishes in a free market or through legislation. Farmers in pursuing their own self interests are guided by relative prices provided by consumers in the market. Allocation of resources by farmers in accordance with this joint expression of individual consumers may often be inconsistent with the longer term aims and objectives of society as expressed through various federal, state and local regulations, penalties and subsidies. However, to the extent that market price relationships truly reflect society's preferences regarding resource use, efficient allocation of resources within the individual farm firm is consistent with the goals of society.

Interrelated aspects of this problem

The most profitable forage acreage for any individual farmer is dependent on (a) the relationship of forage to grain in crop production and (b) the relationship between forage and grain in livestock feeding. The optimum forage acreage for any farmer can be determined only as these two relationships are integrated.

A recent study by Heady and Jensen (15) draws on considerable experimental work on crop rotations to demonstrate the nature of the relationship between forage and grain in crop rotations. It shows that forage and grain in a rotation may be competitive or they may be complementary. The two are competitive whenever an increase in the production of one necessitates a reduction in the output of the other. They are complementary when an increase in the production of one is accompanied by an increase in the output of the other crop. On many soils a complementary relationship between forage and grain exists for the present levels of forage production. As more and more acreage is withdrawn from grain production and put into forage production the response in grain yields becomes less and less (forage substitutes for grain at an increasing rate) until the end of the complementary relationship is reached -- grain output becomes a maximum. Beyond this point any increase in forage acreage must come at the expense of a diminution of grain output -- forage becomes competitive with grain. Obviously, the gross returns from crops would always be increased by increasing forage acreage to the limit of the complementary relationship, even if none of the forage was sold or utilized. As long as the cost per acre of producing forage did not exceed the per acre cost of producing grain net income would also be increased. According to estimates made by Heady and Jensen (15, p. 444) the production costs are no greater for forage than for grain. Since harvesting costs would be saved, the total cost involved in obtaining the maximum grain output would be less than for a smaller grain output obtained if more acres are devoted to grain production. The full response in yields to increased forage in the rotation is realized only over a number of years, of course. But for the individual who remains on a farm for a sufficient length of time that the rotation can be reflected in the yields, net income is increased by expanding forage production to the end of the complementary relationship -- the point where total grain output is a maximum.

The profitability of increasing forage acreage beyond the limit of the complementary relationship with grain depends upon the value of additional forage produced. Gross returns will be increased by any increase in forage acreage as long as the value of the forage added is worth more than the grain output sacrificed. Since forage is used almost exclusively for livestock feed, its value is determined by its productivity in terms of livestock and livestock products. Only as the forage has a value as a livestock feed is it profitable for a farmer to expand forage production (except in the special case where a ready cash market for forage exists) beyond the limit of the complementary relationship with grain. The extent to which it pays to expand forage acreage beyond that point depends on the rate at which forage replaces grain production in the crop rotation and the rate at which forage replaces grain in the livestock ration. Thus the optimum forage acreage for an individual farmer cannot be determined independently of his ability to utilize the forage in livestock production.

Scope and Objectives of the Study

The relationship of forage to grain in crop production has been dealt with in considerable detail in other recent studies (15) and will not be considered further here. The focus of this investigation will be the problems of forage utilization in livestock feeding. The specific objectives of the study are:

(a) To indicate some of the alternative possibilities for increasing forage consumption by livestock

(b) To evaluate alternative feed utilization systems with respect to potential returns and variability of returns.

(c) To suggest criteria for determining the optimum forage-grain feed combinations in feeding livestock for individual farmers in different situations with special emphasis on the basis for selection in a setting of uncertainty of expectations.

Applications to be Made of Results

Attainment of the above objectives will provide a basis for recommendations regarding efficient utilization of feeds. Used in conjunction with information regarding forage-grain relationships in crop production intelligent recommendations can be made regarding the extent to which it pays farmers in particular situations to increase forage acreage. The analysis of the effect of uncertainty of expectations on production plans should throw some light on the effectiveness of market prices in allocating resources for the most efficient production of livestock products.

The results of the study should be of particular value in formulating public policy with respect to soil conservation and pricing of agricultural products. Only as the level of conservation which is profitable and feasible for the individual farmer is determined can the need for public assistance in order to attain desired conservation goals be determined. Also, the effect of uncertainty of expectations on production plans indicates the cost of market instability in terms of less than optimum production plans being followed by farmers. The differences among individuals in their attitudes toward uncertainty and the subjective nature of uncertainty itself makes the analysis of uncertainty difficult and inconclusive. But if some knowledge is gained of the degree of uncertainty associated with alternative production plans and of the response of individuals in different circumstances to different degrees of uncertainty such information would be extremely useful in working out any program involving price ceilings or minimum prices for farm products.

THEORETICAL ANALYSIS

In the search for solutions to the problems posed in the preceding section a few technical relationships and generally accepted economic principles provide useful models. In this section these fundamental concepts are applied to obtain a theoretical solution to the problem of feed utilization.

The primary function of the theoretical analysis is to give direction to the empirical investigation of the problem to be analyzed. The theoretical models facilitate the empirical investigation by organizing and classifying the relevant data, indicating the types of data needed and their form, specifying the appropriate statistical techniques and tests to be employed and setting forth the criteria for determining the optimum position of individual producers.

The Firm in a Static Setting

Production is a dynamic process. Plans must be laid, investments made and costs incurred well in advance of any returns. Throughout the production period prices and cost change, and in ways which cannot be predicted accurately at the outset. It is therefore unrealistic to propose production plans to maximize net income which are based on perfect knowledge of production functions, costs and price relationships. Nevertheless, such assumptions are useful as a starting point. Economic concepts of the firm in a "timeless" situation provide a useful set of analytical tools. The analysis can be extended later to take account of the complexities encountered in actual farm operation.

Any livestock producer has four types of decisions to make. He must decide: (a) what product or combination of products to produce, (b) the scale of operations, (c) the level of production per unit of livestock and (d) the combination of resources to use in producing that quantity of the selected product. In a static setting, with prices, costs and production responses known with certainty, the following equilibrium conditions (19, pp. 78-88) must be met if the firm is to maximize its net returns:

(a) The marginal rate of substitution between any two products is equal to the inverse ratio of their price ratios.

(b) The marginal rate of transformation of any factor into any product equals the ratio of their prices.

(c) The marginal rate of substitution between any two factors equals their inverse price ratios.

Also, in order for these points to be optimum, the following stability conditions corresponding to each of the above equilibrium conditions must be satisfied:

(a) The marginal rate of substitution between alternative products is increasing.

(b) The marginal rate of transformation of each factor into any product is decreasing.

(c) The marginal rate of substitution between factors is decreasing.

If these equilibrium and stability conditions hold no possibility exists for improving the firm's position in respect to net income.

Combination of enterprises

Normally a livestock producer has an opportunity to produce several different kinds of livestock or combinations of livestock. Feed and labor may be used effectively with dairy cows, hogs, feeder cattle, sheep or other kinds of livestock. Similarly , more specialized resources such as buildings and equipment may often be used for any of several different kinds of livestock production. The optimum combination of enterprises is attained when the marginal rates of substitution between any two products is equal to the inverse ratio of their prices. Normally enterprise relationships are such that some combination of livestock enterprises satisfies this condition; however, in simplifying the following analysis, it is assumed (except as otherwise noted) that a single livestock product is being produced.

Scale of operation

The question arises as to how many units of livestock to produce -- that is, what scale of livestock operations to achieve. Not a great deal is known about the economies of scale in livestock production. While there are logical reasons for expecting constant returns to scale, farmers are seldom in a position to expand all services proportionately. Land area, management and often capital are limited resources which cannot be expanded at the will of the entrepreneur. Thus the problem of scale as ordinarily considered is more nearly one of variable proportions and the principles determining the optimum level of production per unit of livestock apply as well in defining the optimum size of an enterprise.

Level of production

Given a single livestock product to be produced the question arises as to what level of output per unit of livestock is most profitable. The relationships relevant to the problem are: (a) the technical relationship of resource inputs to production response, and (b) the price of the product relative to the price of the productive factors. These relationships can be expressed in terms of cost and revenue curves as in Figure 1. Normally the nature of the production relationship is such that diminishing marginal productivity causes each additional unit of output to require a greater resource input than the preceding one. Thus as output is increased beyond some point (OA in Figure 1) total costs increase at an increasing rate. Eventually a limit is reached beyond which production cannot be increased regardless of the quantity of resources applied and the total cost curve becomes vertical (at output OC).

Assuming a purely competitive market for the product, total revenue is a linear function of the output and price of the product (Curve R). The optimum level of output is OB. At this output the net income is cd, a maximum. This corresponds to the condition that the marginal rate of transformation of any factor into a product is equal to their price ratio. It is apparent that any increase in the price of the product will increase the slope of the total revenue curve, pushing the optimum

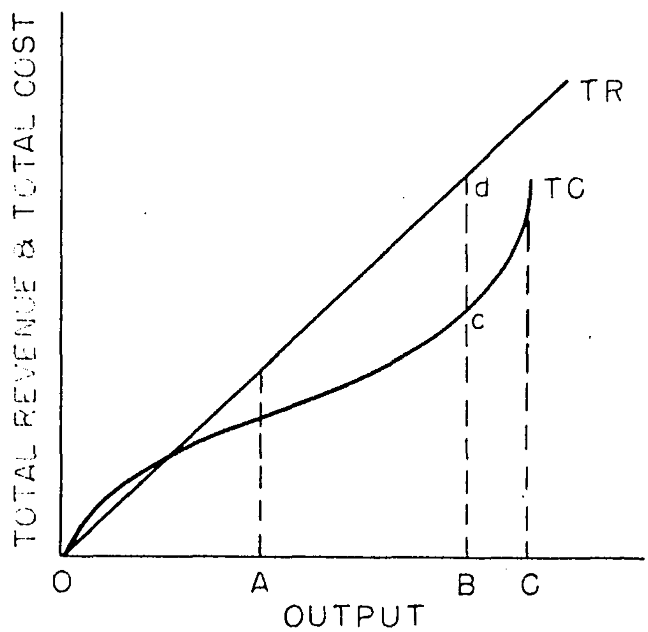

Fig. 1 Optimum level of output.

level of production (the point at which cd is a maximum) to the right. A reduction in the cost of the factors of production would lower the slope of the total cost curve and have a similar effect on the optimum level of production.

Substitution between factors

Ordinarily several alternative production plans will yield the same output. In Figure 1 a single total cost curve was considered. Actually a farmer may choose one from among many possible cost functions. Total cost is a function of labor, equipment, management, protein, grain, forage, the price of each factor, and perhaps other less important variables. These inputs need not be combined in fixed proportions. On the contrary, for most kinds of livestock considerable substitution between factors is possible. Equipment may be substituted for labor. A particular output can be achieved with any of several feed combinations. The extent to which it is profitable to substitute one factor for another depends on (a) the relative prices of the various factors and (b) the marginal rates of substitution between these factors in producing a given product.

Marginal rates of substitution. This study is concerned with the extent to which it is economical to substitute forage for grain in a livestock ration. Thus the important relationships which need to be established empirically are the marginal rates of substitution of forage for grain in livestock production and the ratio of the price of grain to the price of forage. With given technical conditions of production the output of a Product Y depends on the amounts of the variable factors X_1, X_2, ---- X_n used. The production function can be expressed as $y = f(x_1, x_2, ---- x_n)$, where y is the output of product forthcoming from quantities x_1, x_2, ---- x_n of the productive factors. Letting Y represent a particular kind of livestock product and letting X_1 and X_2 represent forage and grain respectively, the production function for livestock production may be expressed as $y = f(x_1, x_2)$, where other factors are assumed fixed or unimportant. In the present analysis continuous divisibility of factors and continuous variability of the production process are assumed. Thus the production function is a continuous function of continuous variables. The production function for grain and forage in the production of a livestock product can be represented graphically by a production surface in which OX_1 and OX_2 are horizontal axes and OY is the vertical axis, as in Figure 2. The contour of the production surface consists of a system of curves in the Plane OX_1X_2 which represent constant product contours and are defined by $f(x_1x_2)=$ Constant. Curve ab, corresponding to a given value c of the constant product, includes all points (x_1, x_2) representing amounts of the factors giving a definite Product c. These points may be extended to the corresponding Curve a'b' in the OX_1X_2 plane. The entire system of curves is continuous and non-intersecting, covering the positive quadrant of the OX_1X_2 plane in such a way that one, and only one, curve passes through each point. As the quantities of grain and forage are varied in any way the Points x_1x_2 move across the constant product contours in the Plane

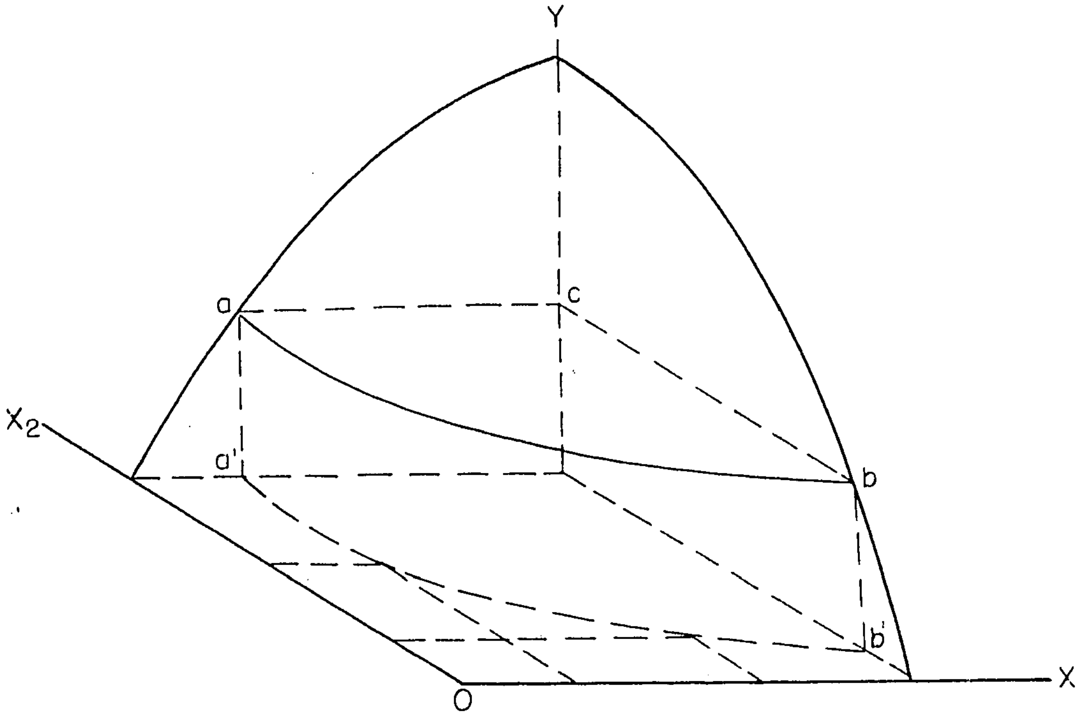

Fig. 2 Production surface involving two factors.

OX_1X_2 determining the resulting change in livestock product. Thus a system of constant product contours or iso-quants can be established and represented in a two dimensional diagram such as Figure 3. Curve y_1 in the figure represents the various input combinations of grain (x_2) and forage (x_1) which lead to output y_1. Similarly Curves y_2, y_3, and y_4 represent the various combinations of grain and forage which yield y_2, y_3, and y_4 quantities of livestock product, where y_2 is larger than y_1, y_3 is larger than y_2 and y_4 is larger than y_3.

The equation of the iso-quant (constant product contour) is obtained directly from the production function

$$y_0 = f(x_1, x_2)$$

where y_0 represents the output for each particular iso-quant. From the differential of this function is obtained

$$0 = \frac{\partial y}{\partial x_1} dx_1 + \frac{\partial y}{\partial x_2} dx_2 , \quad \text{or} \quad \frac{dx2}{dx_1} = - \frac{\partial y}{\partial x_1} \Big/ \frac{\partial y}{\partial x_2}$$

The slope of the iso-quant is given by $\frac{dx2}{dx_1}$. The partial rate of change of output with respect to factor x_1 is the marginal productivity of x_1 for a particular value of x_2 and is designated by $\frac{\partial y}{\partial x_1}$. Similarly, the marginal productivity of factor x_2 is expressed as $\frac{\partial y}{\partial x_2}$. Thus the slope of the iso-quant at a particular point is equal to minus one times the ratio of the marginal productivities of the productive factors. This ratio may be termed the marginal rate of substitution of factor x_2 (grain) for factor x_1 (forage) in producing a constant output y_0 of livestock product.

<u>Nature of the product contours</u>. The nature of the iso-quants is a part of the technical data and, as shown in the previous section, is derived directly from the production function. Several types of iso-quants are possible. In certain types of production factors must be combined in a fixed proportion, with no substitution possible between factors. Thus the relevant portion of each iso-quant is a single point representing that required factor combination. A second possibility is that the two factors are perfect substitutes for each other. In this case a given output is obtainable from a series of combinations of the two factors and, further, a unit change in one of the factors requires a constant opposite change in the other factor to maintain that output. Since substitution is perfect the relationship between marginal productivities of the factors does not change as the factor combination changes. The marginal rate of substitution, and consequently the slope, of each iso-quant is constant. In other words, the iso-quants are straight lines parallel to each other.

Usually in production factor combinations are not technically fixed, nor are they often perfectly substitutable. In livestock production one would expect the factors grain and forage to be imperfect substitutes for each other. Logically the iso-quants will be downward sloping and convex to the origin at all points. As forage is substituted for grain each additional unit increase in forage would be expected to replace less and less grain in producing a particular output of livestock product --

i.e. diminishing marginal rates of substitution are expected. Curve y_0 of Figure 4 describes the general nature of the hypothetical iso-quant for various combinations of grain and forage in production of a livestock product.

The iso-cost curve and optimum combination

By combining into curves all factor combinations that have the same cost a system of iso-cost curves is obtained. In livestock production involving only two variable productive services (forage and grain) whose prices are fixed (in the sense that the prices are independent of the quantity used by the firm) the iso-cost curves are expressed by the equation

$$p_1x_1 + p_2x_2 = \text{Constant},$$

where the p's and x's stand for the prices and quantities of grain and forage. Differentiation of this equation gives the tangent to the iso-cost curve,

$$\frac{dx_2}{dx_1} = -\frac{p_1}{p_2} .$$

The iso-cost curves are in this case straight lines with a downward slope equal to the (inverse) ratio of their prices.

If the grain and forage combination for a particular output are varied along the given iso-quant, the minimum cost combination is reached where the iso-quant is tangent to the lowest possible iso-cost curve. In

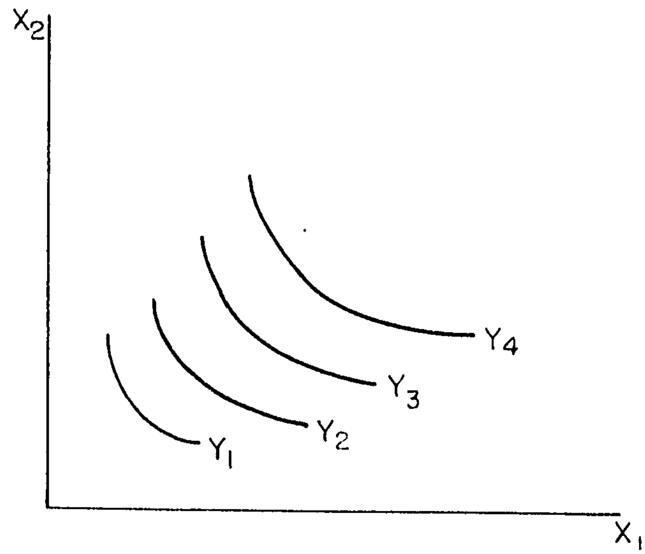

Fig. 3 Constant product contours.

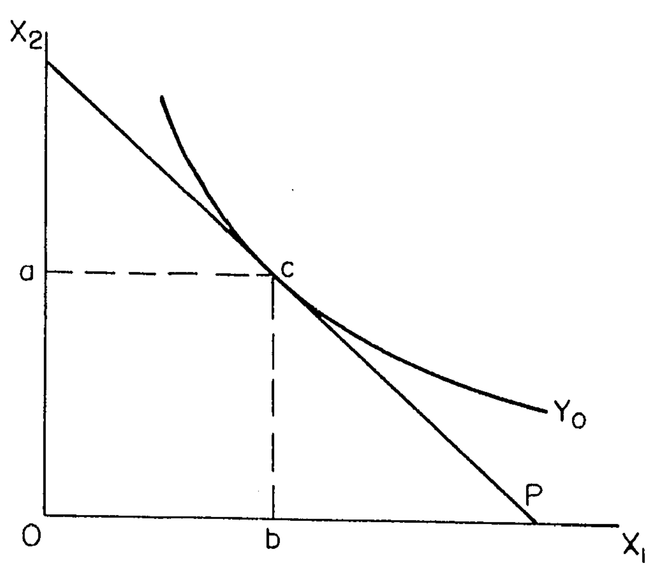

Fig. 4 Optimum factor combination.

this case, where the prices of the factors are fixed and the iso-cost curves straight and parallel lines, the iso-quant will be tangent to only one such iso-cost curve. Moving from the point of tangency along the given iso-quant must lead to a higher iso-cost curve. The iso-cost curve which is tangent to the constant product contour y_0 is given in Figure 4 by the Line P. The two curves are tangent at Point c. It is here that the marginal rate of substitution of forage for grain in producing output y_0 of livestock product is equal to the inverse ratio of the prices of forage and grain. The feed combination which minimizes the feed cost of producing y_0 quantity of livestock product is evidently Oa units of grain and Ob units of forage.

Dynamic Concepts

The preceding analysis was based on the assumption of a static, or "timeless", situation. The actual situation in livestock production is more complex. The production process is spread over time. With the passage of time prices, costs, and the technical production relationships are subject to change. Production plans cannot be made on the basis of given costs, prices, and production responses but on the basis of expectations of what these will be. Thus before production plans are made expectation of future events must be formulated.

Subjective certainty

While in actual practice it is not possible to estimate exactly which of the numerous possibilities with respect to prices, costs and production relationships will come about in any future time period, in order to keep the analysis manageable it is assumed for the present that the farmer thinks he knows exactly what will happen under each business plan he contemplates. Thus plans are made in a setting of subjective certainty. The business plan can now be viewed as a stream of investments or expenditures and a stream of returns through time. The optimum plan will be the one which maximizes the present value of the net receipts over time. The present value of receipts and expenditures anticipated in the future is determined by the expected interest rate. The present value of the stream of costs is given by the equation

$$C = \sum_{t=0}^{n} c_t(1 + i_t)^{-t}$$

where C is the present value of the stream of expenditures, c_t is the cost in each time period (t = 0, 1, 2, ---- n), and i_t is the expected interest rate in each time period. The present value of the receipts stream is given by the equation

$$R = \sum_{t=0}^{n} r_t(1 + i_t)^{-t}$$

where R is the present value of the stream of receipts and r_t is the receipts in each time period (t = 0, 1, 2, ---- n), and i_t is the interest rate in each period. The present value of the stream of net returns, NR, is given by the equation

NR = R - C.[a]

The optimum production plan for producing a particular livestock product, the plan which maximizes the capitalized value of net receipts, must meet these conditions: (a) the marginal rate of substitution between the products of any two time periods must equal the ratio of their discounted prices; (b) the marginal rate of transformation of any factor into a product must equal the ratio of their discounted prices; and (c) the marginal rate of substitution between any two inputs must equal the inverse ratio of their discounted prices. Condition (a) is analogous to the condition in the static situation for the optimum combination of products; here products of different points in time are treated as different products. The effect of condition (b) is to lower the optimum level of production from what it would be with the same prices and costs but without the time consideration. This is especially true in the case of livestock production, where much of the cost is incurred well in advance of production, since

$$\frac{\text{discounted price of product}}{\text{discounted price of factor}} < \frac{\text{price of product}}{\text{price of factor}} .$$

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[a]Lutz and Lutz (32, pp. 16-48) show that maximization of R - C is only one of four logical criteria. Alternative criteria are R/C, the "internal rate of return" on the total capital invested, and the rate of return on his own capital. They show further that the four criteria coincide when the rate of interest equals the maximized average rate of return, which in turn equals the marginal internal rate of return. These conditions are not always met; when they are not met the four criteria may not lead to the same answers. They conclude that R - C is the appropriate criteria to use. However, Hildreth (20, pp. 156-164) has suggested certain situations in which it is rational to maximize the internal rate of return rather than R - C.

If costs for the substitutable factors, grain and forage, are incurred simultaneously the optimum combination of grain and forage in the ration is not affected by the discounting process --

$$\frac{\text{discounted price of grain}}{\text{discounted price of forage}} = \frac{\text{price of grain}}{\text{price of forage}} .$$

In that case, in a setting of subjective certainty, production plans for minimizing the feed cost of a particular output of livestock product are identical with plans in a static framework.

The analysis is made more complex if in substituting forage for grain the length of the production period is extended (or reduced). If, for example, the price of beef is different at different points in time it is not realistic to consider beef at different dates as identical products. The concept of an iso-product contour connecting forage-grain combinations which yield a given weight of beef, but at different dates, is then not a very useful one. We are then no longer interested only in minimizing the feed cost of a given livestock output, but also in finding the optimum feed investment period.

Uncertainty and production planning

The assumption of subjective certainty underlying the analysis of the previous section, while useful in examining the effect of the passage of time in the production process on the optimum production plan, is at variance with the facts. Farmers seldom have a single valued expectation about prices, costs, or yields. They recognize that their estimates are subject to error; for any particular plan they set out to follow they realize that a whole set of outcomes is possible.

Anticipations about future events which are not known with certainty involve either risk or uncertainty.[a] Knight (29) makes essentially this distinction between the two terms: in the former case the parameters of the probability distribution of probable outcomes are known a priori; whereas in the situation involving uncertainty the parameters of the probability distribution are not known -- that is, we are faced with a probability distribution of probability distributions. Tintner (42) has introduced the term "subjective risk" to apply to the situation where the individual thinks he knows the parameters of the probability distribution of probable outcomes and uses the term "subjective uncertainty" to describe the situation where the individual views the probable outcomes in terms of a set of probability distributions corresponding to a set of uncertain contingencies.

Hicks (19, pp. 125-129) and Lange (31, pp. 29-34) use a device in handling uncertainty (in the sense in which Tintner uses the term subjective risk) which permits use of the same analysis as outlined above

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[a]As Hart (12, p. 51) points out "The event viewed in isolation is always uncertain. But viewed as a member of a group of events so related that their joint outcome is more certain than the individual events in the group, it is a risk." Within a firm risk in this sense is encountered only where the firm carries on a large number of comparable operations whose results are independent, thus giving an "actuarial" basis for assigning probabilities. In the agricultural problem of feed combination with which this study is concerned the situation is more generally one of uncertainty.

for a situation of subjective certainty. Their procedure is essentially the following: An entrepreneur faced with various possible prices (or costs or transformation coefficients) may consider one of these the most probable, or perhaps the mean, outcome. But individuals are not likely to react in the same way to an uncertain as to a certain expectation of a given magnitude. Rather, they will want to make some allowance for the fact that the future event is uncertain. The allowance made will be different for different individuals, depending not only on the degree of uncertainty each attaches to the event but also on the aversion each has to risk bearing.

It is assumed that each probability distribution (whether its parameters are known with certainty or judged subjectively) of probable outcomes has a corresponding unique outcome expectation -- the "representative expectation" -- for each individual. That is, the individual reacts in the same manner to the probability distribution as he would to the representative expectation. Thus formally the analysis in a situation of uncertainty involves only single valued expectations just as in planning under subjective certainty.[a]

Shackle (37, pp. 109-127) has been critical of the orthodox idea of frequency-ratio probability in treating uncertainty and argues strongly for his concept of "potential surprise". Briefly, Shackle's theory may be sketched as follows: An entrepreneur looking out from the present point in time (his "viewpoint") at the date when returns are expected to

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[a]Stiendl (38, pp. 47-48) suggests that instead of adjusting the expected prices downward to compensate for the uncertainty individuals may adjust the interest rate used in discounting future incomes upward -- thus decreasing the present value.

be forthcoming (his "image date") is uncertain as to the outcome. But he visualizes a series of hypotheses regarding possible outcomes (yields, for example) and assesses the surprise which the fulfillment of each of these hypotheses would afford him. The "potential surprise function" is defined by the degrees of surprise he considers each of the different outcomes would present. While surprise may not be capable of numerical measurement, the alternative hypotheses can be arranged in order of the surprise the individual believes each would produce should it be fulfilled. Thus the hypotheses may be arranged in order from "zero surprise" to some maximum surprise (Shackle's $\bar{y}$) which would be associated with an outcome considered impossible.

The enjoyment or distress obtained from anticipating a hypothesis depends on (a) the profit or loss which it involves and (b) the potential surprise associated with it. If an event is considered "perfectly possible" the enjoyment afforded by its contemplation is derived entirely from the outcome. If, on the other hand, some potential surprise is associated with an event, the enjoyment is related to the outcome but is reduced according to the amount of surprise the individual attaches to its occurrence.

An individual, according to Shackle, relates his enjoyment (or distress) to the alternative outcomes and their degrees of surprise by means of a "stimulation function". Enjoyment and distress are ordered and represented numerically on a scale whose zero represents complete absence of stimulus. Any of the possible outcomes whose contemplation affords any enjoyment or distress possesses some stimulus.

The various hypotheses visualized by the entrepreneur are mutually exclusive. The stimuli to which they give rise are not, therefore, additive but are entirely independent rivals. Shackle (36, p. 70) considers this a "central strand" of his theory, for it provides a measure of acceptance of a hypothesis which is independent of the degrees of acceptance attached at the same time to rival hypotheses. Since the degrees of potential surprise (or of stimulation) do not need to add to any number they need not be affected by the discovery of a new possible outcome or a change in the surprise attached to an alternative hypothesis.

The entrepreneur fixes his attention on only two of the hypotheses, according to Shackle, -- the one offering the greatest enjoyment and the one stimulating the most distress by anticipation. These are the "primary focus-outcomes". In making comparisons, these are replaced by "standardized focus-outcomes" -- outcomes which give the same stimuli but involve zero potential surprise. If on one of a pair of cartesian axes we measure focus-gains and on the other we measure focus-losses, any point on the plane will represent a plan involving the combination of a particular standardized focus-gain and a particular standardized focus-loss. All of the opportunities open to an individual may be represented by a series of points on this plane. Some of these points will be equally attractive to an individual. It is likely that all these points representing equally attractive opportunities will fall on a smooth and continuous curve sloping upward to the right. These curves are the "gambler indifference curves". The curves forming the gambler indifference map will, of course, be different for different individuals --

making inter-personal comparisons impossible. For each individual, however, the gambler indifferences map will consist of a non-intersecting family of curves, one through each point on the map. In deciding between two alternative plans an individual will prefer the plan represented by a point on the highest gambler indifference curve (the indifference curve in a position nearest the focus-gain axis).

Shackle's objections to the use of frequency-ratio probability may be summarized as follows:

1. For many important kinds of decisions it is impossible to find a sufficient number of past instances which occurred under the same conditions; that is, no "well founded" figures of probability of different outcomes can be established from experience.

2. Even if a probability is established, many kinds of decisions are virtually unique for each individual, in the sense that failure may prevent the entrepreneur from remaining in business.

3. The entrepreneur cannot, therefore, look upon the possible outcomes of a particular course of action as being related and occurring with given relative frequencies over time. Rather, they must be regarded as independent and mutually exclusive alternatives arising out of a single set of actions.

Shackle's objection that it is impossible to carry out a long series of decisions under identical conditions does not seem to be a serious one. A general knowledge gained from experiences involving several similar yet not identical situations may be the basis for forming a judgement of the probabilities of alternative outcomes from a given action.

The objection that many decisions facing an entrepreneur are of such a nature that he has only a single chance -- that a failure prevents him from continuing in business -- does not necessarily strike at the orthodox theory. The entrepreneur faced with such a situation might base his decision on the frequency ratio probability while limiting the size of his investment to take account of the prospect of failure.

Shackle's contention that the application of frequency-ratio probability to economic decisions is unrealistic appears well taken, however. It is unrealistic in the sense that the true probability distribution of future events contains elements completely unknown (such as whether or not there will be war or peace, or who will win the election next year). Any frequency-ratio will be based on past events; probabilities assigned to future events on the basis of these frequency ratios must be subjective. Carter (4, p. 99) cites the following paragraph from John Venn (51, p. 158), one of the chief authors of the frequency-ratio concept of probability, to support his view that the probabilities on which entrepreneural decisions are based lie outside the field of frequency-ratio theory:

> In every case in which we extend our inferences by Induction or Analogy, or depend upon the witness of others, or trust to our own memory of the past, or come to a conclusion through conflicting arguments, or even make a long and complicated deduction by mathematics or logic, we have a result of which we can scarcely feel as certain as of the premisses from which it was obtained. In all these cases then we are conscious of varying quantities of belief, but are the laws according to which the belief is produced and varied the same? If they cannot be reduced to one harmonious scheme . . . then it is in vain to endeavor to force them into one science.

Carter (4, p. 95) then argues as follows:

> We are left, in fact, with no more than a set of entirely

> subjective assessments of probability, capable of formal measurement on a numerical scale by a single individual, but not of comparison between individuals. The calculation of a mathematical expectation in such circumstances seems a formal and irrelevant exercise.
>
> But if we reduce probability to this level, how does it differ from Mr. Shackle's concept of potential surprise? Clearly there is a one to one correspondence between the two; if the essence of our knowledge of probabilities is that we can place them in order, this order of 'more or less probable' corresponds to 'less or more surprising'. To the concept 'zero probability' corresponds 'maximum potential surprise'. But the other bound of the potential surprise scale, 'perfect possibility' corresponds to the highest probability in the series under consideration, whatever that may be.

Carter's conclusion, which seems reasonable to this writer, is that Shackle's theory of potential surprise is essentially equivalent to "the only kind of probability theory valid for economic hypothesis". Professor Ingvar Svennilson (40, pp. 39-55) has explicitly assigned "marks" to the alternative hypothesis and treated them as mutually exclusive. Shackle (36, p. 73) raises no objection to the use of frequency-ratio probability in this sense. It seems, however, that this same ordering is implicit in the conventional use of the probability concept. Economist have, it seems, avoided its use for inter-personal comparisons.

As long as the limitation of the frequency-ratio probability concept pointed up by Shackle are recognized and the use of the concept confined to personal comparisons it appears that its use is a harmless convenience. The assignment of probabilities may be considered a useful way of ordering the degree of belief accorded the alternative hypothesis. We may then return to the less complex methods of Hicks and Lange in conducting the empirical analysis of uncertainty.

The conditions for equilibrium of the competitive firm producing a single livestock product in the context of uncertainty may now be stated in the following terms: (a) the representative marginal rate of substitution between products of any two points in time must be equal to the inverse ratio of their discounted representative prices, (b) the representative marginal rate of transformation of each factor into a given livestock product must equal the ratio of their discounted representative prices, and (c) the representative marginal rates of substitution between grain and forage (or any other factor inputs) must equal the discounted representative prices of grain and forage (or other input factors). Where the farmer has the opportunity of producing several different livestock products a fourth condition, which is analogous to the first, is that the representative marginal rate of substitution between products be equal to the inverse ratio of their discounted representative prices.

Three types of uncertainty are important in agricultural production: technical uncertainty, technological uncertainty and market uncertainty. Technical uncertainty exists in the sense that the physical response in output to a particular combination of resource inputs is not known with certainty a priori. That is, the physical output from a particular plan may be viewed at the time plans are made as a probability distribution of possible results. In terms of the present problem of determining the optimum feed combination, technical uncertainty may be viewed as producing a whole set of possible product contours for each level of output. If the variation in production is independent of the composition of the ration the possible product contours may take the form of essentially parallel curves. This is illustrated in Figure 5 where Curve B represents the mean contour for a given level of livestock product and Curves A and C represent the upper and lower limits of the forage-grain combinations which yield that output. The variation in feed requirements to produce a given output of livestock product may, on the other hand, be correlated (either positively or negatively) with the proportion of grain in the ration. For example, as the proportion of grain in the ration is increased dairy cows may be subjected to greater chance of udder difficulties; feeder cattle and sheep may be in greater danger of "going off feed"; or, increasing the proportion of forage in the ration may increase the chances of death loss from bloat. Where the variation in the production function is associated with the makeup of the ration the dispersal of the possible product contours for a given output may be represented by Figure 6, where Curve B is again the mean contour for a given level of output and Curves A and C represent the outer limits of the possible feed combination to give the same level of production.

Technological uncertainty is present in agricultural production in that innovations leading to new and more efficient production functions are not foreseeable. An innovation, even though it may merely result in the saving of resources for an individual firm, results in an increased output for the industry as a whole -- and consequently, a lower price per unit of output. Some innovations in livestock production may be such that an individual farmer cannot take advantage of them immediately. For example, investments in housing, equipment and breeding stock once made constitute part of the fixed costs of production for a considerable time

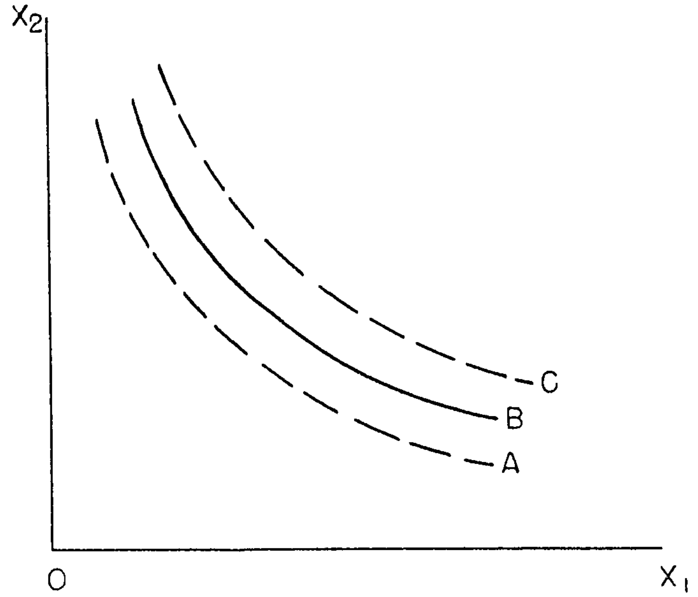

Fig. 5 Technical variation in production indenendent of factor combination.

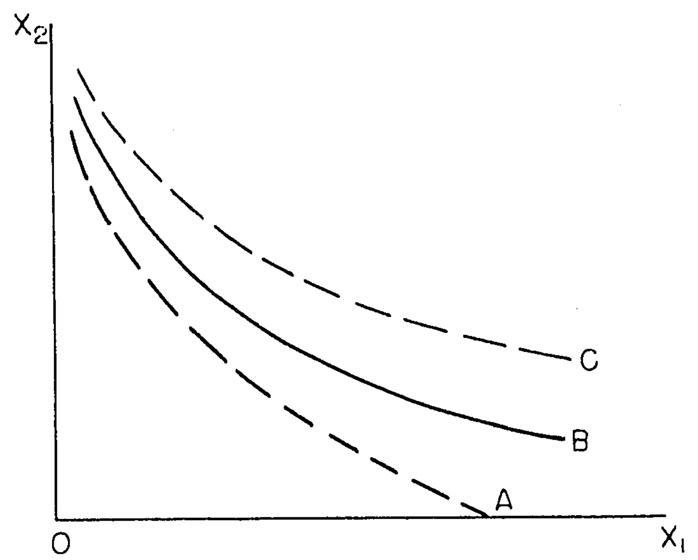

Fig. 6 Technical variation in nroduction correlated with factor combination.

into the future. Improvements in building or equipment design or in animal breeding often cannot be adopted by a farmer economically except as old buildings and equipment wear out or as present herds can be replaced. Yet, the more efficient techniques encourage production and tend to depress product prices. Thus technological advances of this nature result in a decline in net income for the farmers who are not in a position to change immediately to the improved production function. The possibility of such innovations contributes to the uncertainty involved in laying production plans of a long term nature. Other technological advances have a similar effect in reducing the factor requirements for a given output of product and yet result in a diminution of uncertainty. For example, considerable advancement has been made in controlling livestock disease; recent development of antibiotic and other nutritional discoveries have the effect of reducing the grain and forage required to produce a given amount of livestock product. Adoption of these innovations add nothing to the fixed cost of livestock production. They do add to the variable costs, and consequently to the total costs. They also increase the total production and reduce the variability of production. The effect of such an innovation is illustrated in Diagrams I and II of Figure 7, where Diagram I shows the mean and range of possible product contours for a given livestock output before the innovation and Diagram II shows the mean and range of possible product contours for the same output following adoption of the innovation. Curve B', the mean product contour following the innovation, lies nearer the origin than Curve B, the mean pre-innovation contour. Curve C', the upper limit of

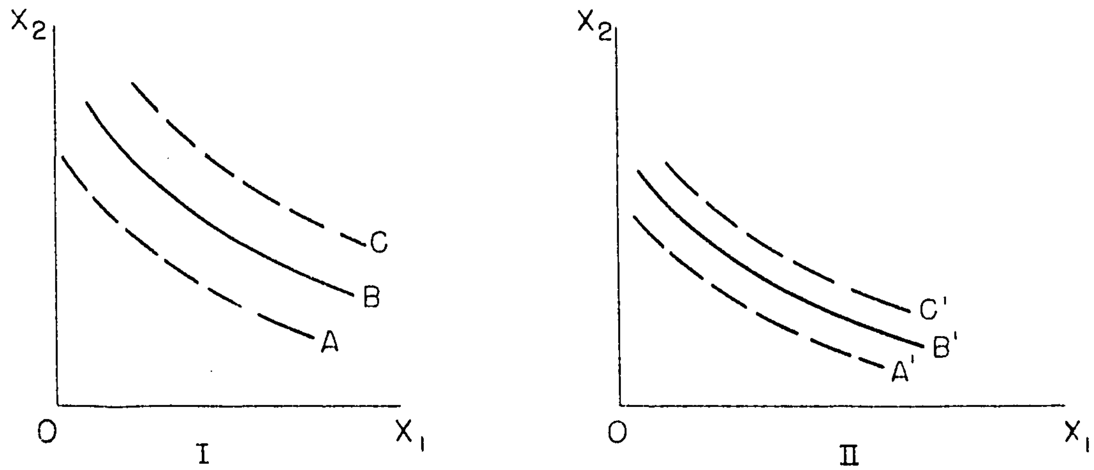

Fig. 7 Technological uncertainty and technical variability of resource requirement.

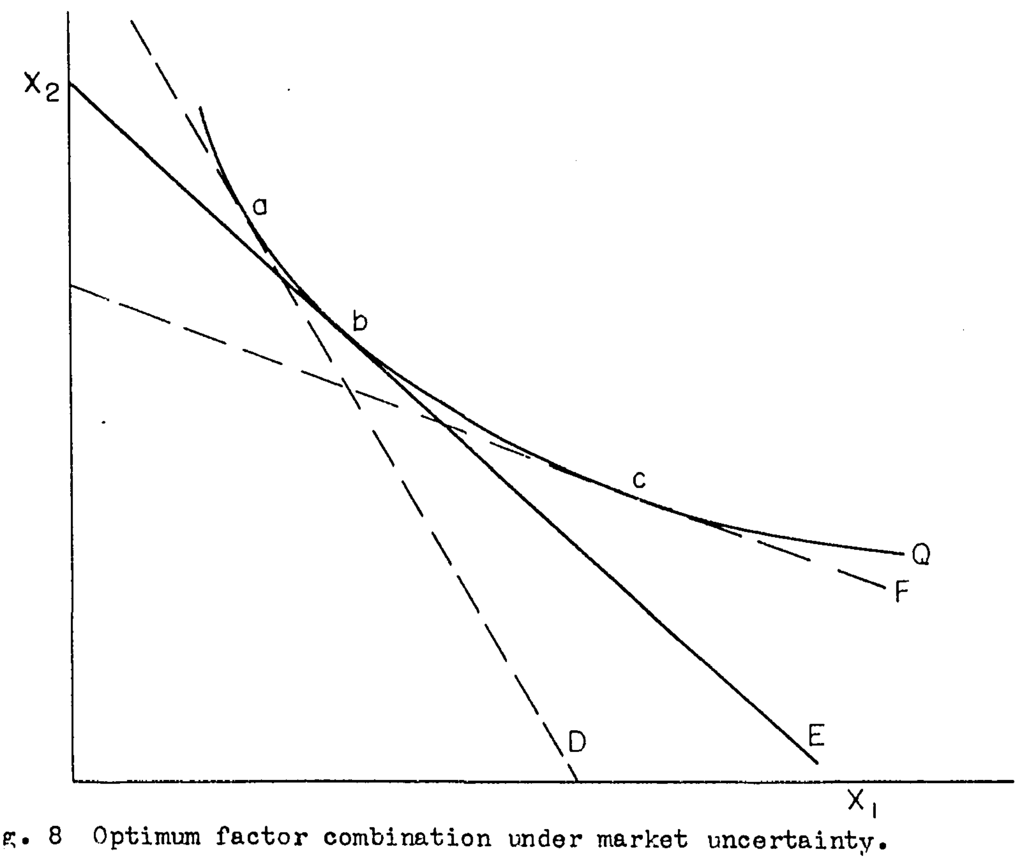

Fig. 8 Optimum factor combination under market uncertainty.

the product contour following the innovation, lies nearer the origin than Curve C; it also lies nearer the mean than does Curve C. Curve A', the lower limit of possible product contours for a given output of livestock product, will also lie nearer the mean product contour; it may or may not be nearer the origin than Curve A -- depending on the nature of the innovation. To illustrate, the innovation may be one such as vaccination of livestock. Vaccination may greatly reduce the risk of heavy death loss (and thus high feed requirements per pound of product) but even without vaccination livestock may avoid getting that disease and can make as thrifty gains as those which were vaccinated. In such cases it appears that Curves A and A' are identical. Other innovations may increase the production potential of the animal and thus cause Curve A' to lie nearer the origin than Curve A.

A third source of uncertainty in agricultural production is that involved in the purchase of factors and the sale of products. At the time plans are made the farmer does not know with certainty the prices he will have to pay for resources used throughout the production process, nor can he be certain what prices will be obtained at the time the products are sold. These uncertainties must be taken account of in deciding the combination of products to be produced, the level of production per unit of livestock, and the feed combination with which to produce that output. In each case a wide range of price ratios are possible. As pointed out in an earlier section some "representative" price ratio (different for different individuals) will determine the best decision in each case. Market uncertainty as it relates to the selection of the best feed combination in producing a given output of livestock product is illustrated in Figure 8. Line E may be considered the mean ratio of the price of forage to the price of grain. Lines D and F may be considered the extremes of possible forage-grain price ratios. Curve Q is a given product contour for a particular livestock product. The feed combination which minimizes feed costs in years when the grain forage price ratio is average is at Point b. The least cost feed combination in any year may vary from that given by Point a to that given by Point c. The proper planned combination will vary for each individual depending on his judgement of the probability of each of the possible price ratios being obtained and his attitude toward risk bearing.

Measurement of uncertainty. In the above paragraphs it was suggested that individuals faced with uncertainty view the future event as a probability distribution of possible outcomes but that they plan on the basis of a single valued "representative" outcome. That is, the individual reacts in the same way to the probability distribution as he would to the representative expectation. The important elements which determine an individual's reaction to an uncertain event -- and thus determine his representative expectation -- are (a) the degree of uncertainty associated with the event and (b) the individual's "risk" aversion.

The degree of uncertainty associated with a venture is given by the various characteristics of the probability distribution of possible results; such as the variance, range, skewness and kurtosis. In a situation of risk these characteristics are known with certainty. In a situation of true uncertainty these characteristics are not known; they can only be judged subjectively. How, then, can a notion be gained of the degree of uncertainty involved in alternative feed utilization systems? Perhaps some indication of the degree of uncertainty surrounding future prices and costs can be obtained from historical price and cost behavior. It may be assumed that certain characteristics of future prices will be a reflection of past prices. For example, the relative prices of various farm products in the future may be expected to be roughly similar to the relative prices of these products in the past (this is the assumption made in the "parity" concept); too, it may be assumed that if the prices of particular commodities exhibited a great deal of variation in the past the future prices of the commodity will also be characterized by considerable variability. Thus by measuring the distribution of price ratios of grain to forage over an historical period some notion of the variance, range, skewness, and kurtosis of the probability distribution of future grain-forage price ratios may be obtained.

Response to uncertainty. Where an event involves merely risk some individuals may be quite indifferent to the degree of risk involved in a venture. For instance, an individual in a strong financial position may be able to withstand severe losses in any one year; he may be willing to do this if he is assured that these losses will be offset in subsequent years by larger rewards. In other cases involving merely risk it is often possible to insure against the occurrence of an unfavorable outcome; thereby reducing risk to a known cost. Situations involving uncertainty are not insurable; neither are they likely to be treated with indifference. Even though an individual has sufficient resources to withstand severe losses in any one year he is not likely to care to do so if he does not know what the chances are of being able to recoup that loss in following years.

The reaction of an individual to a situation involving a particular degree of uncertainty is conditioned by his financial position, his previous training and experience, and his peculiar personality traits -- boldness, timidity, or love for adventure. In general, however, it is perhaps true that most people prefer a certain event to another less certain event of equal magnitude. Many farmers may be concerned with business survival; a severe loss in a single year may force them out of business. Such farmers may have a strong preference for safe ventures and may select business plans which promise considerably less returns over time than some other venture if the latter involves a greater degree of uncertainty.

Determination of the optimum plan

Any plan an entrepreneur may consider with respect to combinations of products to produce, scale of enterprise, level of production per unit, or combination of inputs for particular levels of output may be represented by points on an indifference map, once the pertinent parameters of the probability distribution of present value of net returns from each is known. If we can use a single measure of dispersion the indifference map of an individual may be represented by a two dimensional diagram such as

Figure 9, where the mean net returns are represented on the horizontal axis and the dispersion is shown on the vertical axis. The indifference curves connect the points (representing the various opportunities) which are equally attractive to the individual.[a] Thus, the plan represented by Point p, which involves a dispersion of OB and a mean of OD, is as attractive as the plan represented by Point q, which involves a dispersion of OA and a mean of OC. Both of these plans are just as desirable as a plan represented by the Point r, which involves a mean of Or and zero dispersion. The value Or may be thought of as the representative net returns for any of the plans falling on the risk indifference curve I_2. In choosing between alternative plans the producer will choose the one represented by the point on the highest indifference curve -- the one furthest to the right. Of the possible plans which are represented by points on the map there may be several which have the same dispersion, but only the one which has the maximum mean value is important. By connecting all of the plans which have a maximum mean value for each level of dispersion a boundary line such as S is obtained. The optimum plan is represented by the point at which the Line S is tangent to a risk indifference curve (Point s in the diagram).

The same principles would apply if more than two parameters are involved, but in that case, of course, the presentation cannot be made in terms of a two dimensional diagram.

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[a]If the producer has a preference for risk the indifference curve will fall from left to right.

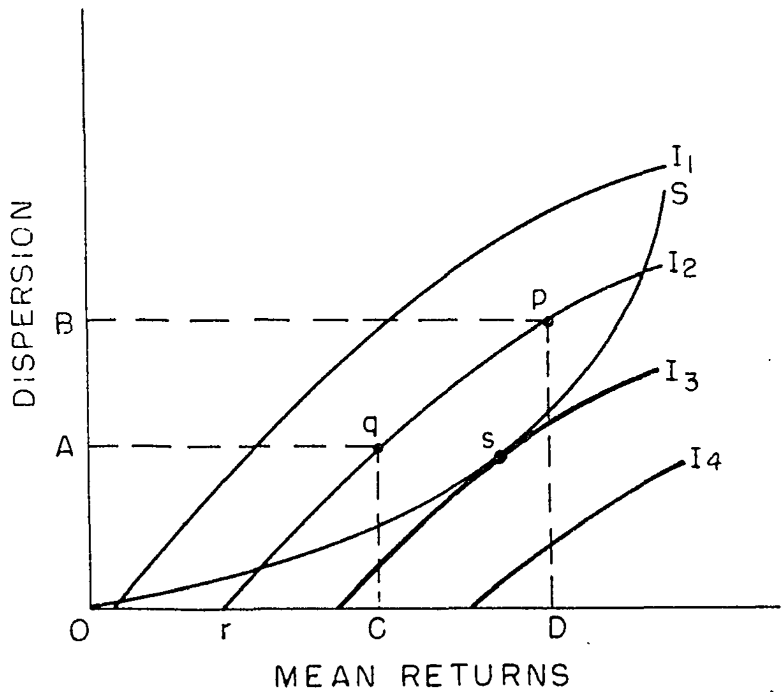

Fig. 9 A risk indifference map.

Capital Rationing

The assumption has been implicit in much of the preceding discussion that factors were available to the firm in any quantity desired. Many farmers face a situation wherein they are unable to apply capital in the amount justified on the basis of profitability. This is capital rationing. Capital rationing is a consequence of uncertainty. Investors may be uncertain about the integrity of the borrower, his ability to repay the loan, or the profitability of the contemplated venture by the borrower. Because of these uncertainties lenders have come to put more emphasis on the borrower's equity in the investment and normally give little consideration to the prospective returns from additional applications of capital by the borrower. The effect is a limitation on the amount of capital available to the firm; and this limitation bears little or no relationship to the marginal productivity of capital.

The firm faced with capital rationing is unable to secure enough capital to equate marginal cost with marginal revenue.[a] Equilibrium in this situation is achieved where the values of the marginal products of capital from each of its alternative uses are equated. These values will exceed the cost (interest rate) of capital.

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[a]The marginal cost curve may, of course, be viewed as becoming perfectly vertical at the point of discontinuity.

PRESENTATION OF RESULTS

A theoretical analysis of the feed utilization problem was presented in the preceding section. The empirical counterpart presented in this section is somewhat more limited in scope. Ideally, data would have been obtained to test all of the relationships represented in each of the models of the theoretical analysis. Unfortunately, some of the data needed for a precise calculation of the desired relationships must await further technical research. Also, inadequacy of statistical techniques limit the precision with which true relationships can be measured. Thus, while the following empirical analysis takes its direction from the theoretical analysis presented earlier, it should be clear that the data used and methods employed may not lead to the ideal solution. It is hoped, however, that the results of this study will give some insight into the problem of feed utilization and permit some inferences concerning profitable adjustments in forage-grain production and utilization.

Feed Substitution Relationships

Grain and forage make up nearly all of the feed cost (and a major part of the total cost) in producing most kinds of livestock products. The substitution relationship between forage and grain is therefore technical data which is needed for determining the feed combination which will produce a particular livestock output at a minimum cost. A recent Iowa study (16) provides estimates of substitution rates between forage and grain in feeding dairy cows, beef cattle, hogs and sheep. These estimates and their applicability are discussed below:

Forage-grain substitution in dairy production

Estimates of forage-grain substitution relationships in dairy production were based on data pertaining to heavy breeds (Holsteins and Brown Swiss) from the Jensen-Woodward study (25). Production records from only those cows which received comparable feeds (legume hay, corn silage and grain) and with an expected production capacity of 300 to 400 pounds of butterfat (when fed the standard Haeker ration) were used in arriving at these estimates. Thus the relationships estimated are applicable over only a small range of output levels and a narrow selection of feeds. The milk production function estimated was

$$Y = 3.56\, X_1^{.5035}\, X_2^{.4}$$

where Y is the pounds of 4 per cent fat corrected milk produced per cow, X_1 is the pounds of forage fed and X_2 is the pounds of grain fed. By setting Y at various levels the iso-product equation for each of those outputs is determined. Thus the iso-product equation for 8500 pounds of milk[a] is given by

$$X_2 = \left(\frac{8500}{3.56 X_1^{.5035}}\right)^{2.5}$$

[a]Observations on production per cow, on which estimates were based, ranged from nearly 8000 pounds to slightly over 10000 pounds of 4 per cent milk.

From this the marginal rate of substitution of grain for forage is obtained as the first derivative:

$$\frac{dX_2}{dX_1} = - \frac{350,640,222}{X_1^{2.25875}}$$

Forage-grain substitution in pork production

Estimates of forage-grain substitution rates in hog production were based on experiments by the United States Department of Agriculture at Beltsville, Maryland.[a] These experiments involved fall pigs fed different combinations of chopped legume hay and No. 2 yellow corn. All hogs in the experiment were raised to a weight of about 225 pounds. The data were inadequate for a determination of a significant portion of the production surface. It was therefore necessary to calculate the product contour directly as the least squares regression of grain (X_2) on forage (X_1). This procedure of arbitrarily considering pounds of grain the dependent variable is subject to some criticism. It is defended here on the grounds that a more precise estimate must await the results of additional research designed to give observations over a wider range of the production surface. The contour for one hundred pounds of pork was estimated to be

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[a]For details of this study see Ellis (7). The data used in arriving at these estimates included the initial weight of the pigs at weaning time (about 60 pounds), the final weight per pig at the end of the experiment (225 pounds) and the pounds of grain and of forage fed per pig from weaning until the end of the experiment. Thus the pounds of pork produced is about 165 pounds. The feed requirements per 100 pounds of pork produced reflect the average over the entire 165 pounds.

$$X_2 = 327.5 - .5113X_1 + .00423X_1^2$$

The marginal rate of substitution between forage and grain in producing one hundred pounds of pork is obtained as the first derivative of the above function with respect to X_1 and is

$$\frac{dX_2}{dX_1} = - .5113 + .00848X_1$$

Forage-grain substitution in beef production

Beef may be produced by any of a large number of systems. Estimates made in the Iowa study are for choice beef produced on yearling steers. The estimates were based on an experiment conducted at Page County, Iowa by the Agricultural Experiment Station (24). The experiment involved yearling steers purchased in the fall, wintered, and fed out the following fall. Four lots were fed out each year for five years (1946 to 1950). Rations for each of the four lots contained different proportions of forage and grain. In deriving the product contour, feed inputs were reduced to the basis of 100 pounds of gain. The one hundred pound beef contour equation was estimated directly as follows:

$$X_2 = 1111.15 - .4219X_1 + .0000686X_1^2$$

The equation for the marginal rates of substitution is derived as the first derivative of the above equation as follows:

$$\frac{dX_2}{dX_1} = - .4219 + .000137X_1$$

Forage-grain substitution rates in lamb feeding

Feed substitution rates for fattening lambs were also derived. These estimates were based on an Iowa experiment (5) involving lambs fed six different proportions of chopped hay and corn. All lambs were finished to prime or choice grade. Since there was considerable variation in marketing weights of the lambs the data permitted an estimate of the production function. The following functional relationship was estimated:

$$Y = -158.4345 + .7157X_1 - 2.3118X_2 - .001046X_1^2 - .0074X_2^2 - .0037X_1X_2$$

where Y is the pounds of lamb produced and, as before, X_1 is the pounds of forage fed and X_2 is the pounds of grain fed. The product contour equation is obtained by setting Y at a particular value and expressing the above relationship in terms of X_2. The contour equation for 25 pounds of lamb may then be stated as

$$X_2 = \frac{2.3118 - .0037X_1 - \left[(2.3118 - .0037X_1)^2 \; .021175X_1 - .000031X_1^2 - 5.4267\right]^{1/2}}{.014792}$$

The marginal rates of substitution are derived from the contour equation as follows:

$$\frac{dX_2}{dX_1} = -.250676 \frac{9.210359 - .078568X_1}{\left[18.42072X_1 - .078568X_1^2 - 375.5419\right]^{1/2}}$$

Least Cost Feed Combinations

The criteria for minimizing feed costs of producing a particular livestock output were set forth in an earlier section. It was shown that in a timeless situation the least cost feed combination is the one at which the marginal rate of substitution between feeds equals the inverse of their price ratios. In a non-static situation, but one involving subjective certainty, the optimum combination is attained where the marginal rate of substitution equals the inverse of the discounted prices. Where, as is generally true in livestock feeding, the forage and grain are fed simultaneously the price ratios are unaffected by the discounting process. In a setting of uncertainty, it was pointed out, the least cost feed combination is the one which equates the representative marginal rate of substitution with the inverse of the discounted representative price ratios.

The particular price ratio to equate with the marginal substitution rates determined in the preceding section depends, then, on the nature of the setting in which production decisions must be made. A setting of timelessness is inconceivable. A dynamic setting involving subjective certainty is conceivable but not realistic. In the present economic order decisions concerning the combination of feeds in feeding livestock are ordinarily made in an atmosphere of uncertainty.

Least cost feed combinations under uncertainty

This study is primarily concerned with market uncertainty; no attempt is made to take into account technical and technological variations, which also affect the decisions of producers. Market uncertainties are assumed to be independent of the physical uncertainties and may therefore be studied in isolation. In a situation involving price uncertainty (but with production coefficients known) the optimum (ex ante) feed combination is obtained where the marginal rate of substitution between feeds is equal to the inverse ratio of the discounted representative prices. The optimum feed combination for each individual producer depends on (a) his expectations regarding feed prices and (b) his aversion or affinity for risk taking. Thus no unique solution exists; at any point in time the representative prices of different individuals may be quite different.

Analysis is simplified if the following assumptions are made: first, forage and grain in the ration are fed simultaneously and thus their price ratios are not affected by the discounting process. Second, the degree of uncertainty involved in the purchase of a unit of grain is equivalent to the degree of uncertainty attached to a unit of forage and each individual makes the same proportional adjustment in his expectations for grain prices as he does for forage prices. The effect of this latter assumption is to eliminate the influence of risk aversion (or affinity) on the decision of the producer. As a consequency of the two assumptions the discounted representative price ratio is identical with the ratio of the prices considered most probable. The problem is reduced to determining the most probable outcome. Assuming a normal distribution of the anticipated price ratios we may consider, instead of the modal, the mean of the probable prices. This mathematical expectation of the distribution of anticipated price ratios we shall call the expected price ratio. The condition for an optimum forage-grain combination may now be restated as the equality of the marginal rate of substitution between feeds with the reciprocal of their expected price ratio.

Farmers expectations concerning future prices may be influenced by a variety of information. Past prices appear to play an important part. While future absolute prices may be expected to differ considerably from historical prices, past relative prices of substitutable feed crops might be expected to be similar to their future price ratios. The ratio of the average price per pound of corn in November to the average price per pound of alfalfa hay in December for each of thirty-two years (1917-1948) are presented in Table 1. During this period the price ratio ranged from as low as .61 in 1932 to a high of 3.9 in 1947. The mean price ratio over the period was 1.95, with a standard deviation of .67. On the basis of this sample we can be confident that the actual corn-hay price will deviate from the mean of 1.95 by less than .67 over 68 per cent of the time. It will deviate from the mean by less than 1.34 over 95 per cent of the time. Expressing it another way, in less than one year out of twenty would we expect the ratio of the price of corn to the price of hay to be less than .61 or more than 3.29. While the corn-hay price ratio realized may be quite different from the mean, under the assumptions made it is presumed that plans are made on the basis of the most probable outcome. The least cost combination of forage and grain in a livestock ration from the ex ante viewpoint is determined by setting the reciprocal of the mean price ratio (1/1.95, or .5128) equal to the marginal rate of substitution between forage and grain and solving. The resulting combinations are: (a) 8157 pounds of forage and 3320 pounds of grain in

Table 1. Ratios of November price of corn to December price of alfalfa hay, Iowa average, 1917-1948.

Year	Price per lb. corn/price per lb. alfalfa hay	Year	Price per lb. corn/price per lb. alfalfa hay
1917	2.62	1933	1.00
1918	2.01	1934	1.38
1919	2.01	1935	2.52
1920	1.47	1936	2.56
1921	1.05	1937	1.94
1922	1.33	1938	1.92
1923	1.81	1939	2.00
1924	2.40	1940	2.62
1925	1.43	1941	2.37
1926	1.16	1942	2.32
1927	1.85	1943	2.17
1928	1.61	1944	2.23
1929	1.94	1945	2.31
1930	1.69	1946	2.84
1931	.89	1947	3.90
1932	.61	1948	2.36

producing 8500 pounds of 4 per cent fat corrected milk, (b) 327.5 pounds of grain and no forage in the production of 100 pounds of pork, (c) no forage[a] and 1111 pounds of grain in the production of 100 pounds of choice beef on yearling steers, and (d) 50 pounds of forage and 125 pounds of grain in the production of 25 pounds of prime or choice gain on feeder lambs.

Limitations of analysis

The actual outcome of price ratios will frequently be such that the above feed combinations do not minimize the feed cost of producing a given amount of product. But the question is: could the producer have made a wiser choice on the basis of the information at hand when the decision had to be made? It does not appear so if the assumptions stated earlier are accepted. We may well examine these assumptions further, however.

In comparing corn and hay prices it is found that corn prices exhibited a great deal more sensitivity to the movement of the general level of farm prices. As a result the ratio of corn prices to hay prices increased significantly with increases in farm prices. The regression of the ratio of the price of corn per pound to the price of alfalfa hay per pound (Y) on the index of prices received by farmers (X) for the thirty-two year period (1917-1948) is estimated as

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[a]This combination is outside the range of data. Projection of the estimated product contour would give a combination involving a negative quantity of forage. Since this is impossible the contour was extended only to the X_2 (grain) intercept and that quantity of grain selected as the optimum combination.

$$Y = .91692 + .006818X$$

The correlation coefficient (r = .570) is significant at the one per cent level of probability.

The apparent correlation between the level of farm prices and the ratio of the price of corn to the price of hay weakens the assumption that expectations of future corn-hay ratios are rationally based on the historical relationships since there is little logic for thinking that the level of farm prices in the past thirty-two years are a satisfactory guide to expectation concerning the level of prices in the future. Also, if corn prices are more responsive to price level changes than hay prices, the degree of uncertainty attached to grain prices may be greater than for forage prices, resulting in disproportionate adjustments of expected prices in establishing representative prices.

One further limitation of the above analysis is more serious. It concerns the failure to take the time variable fully into account. As forage is substituted for grain the length of the production period may be extended; if so, the validity of using iso-product contours at all is open to question. Strictly speaking, given quantities of product turned out at different points in time are not identical products -- they do not command the same price. Unless time can be treated as a factor of production, coordinate with the forage and grain inputs, the solution cannot be achieved with the aid of constant product contours. It does not appear that time can ordinarily be so considered because time has the effect of changing the product (in the sense that 100 pounds of choice beef today is not the same product as 100 pounds of choice beef next month) rather than of changing the quantity of product. It may be possible to transform a given quantity of output at one point in time to its equivalent in another time period but since this involves a consideration of the prices of the product in each time period the simplicity of the product contour analysis is soon lost. An alternative procedure is to compare costs and returns which would be expected from each of several discrete feeding systems. This is the approach taken in the following sections.

Optimum Net Income Under Uncertainty

The above analysis has been in terms of minimizing feed costs in producing a given output of livestock product. This may be justified on the basis that feed costs make up the largest single element of costs in livestock production, and minimizing feed costs for a given output would usually be consistent with minimizing total costs for that output. Other costs are important too, however, and are often not independent of the forage-grain combination. Also, as was pointed out in the preceding section, different combinations of feeds may require different investment periods, and specific quantities of output at different points in time may have different values. Thus minimum feed costs for producing a given livestock output is not the only important consideration in selecting a feed combination for livestock production in a situation involving a variable feed investment period and uncertain price expectations. The following analysis provides estimates of costs, returns and income variability as the bases for choice from among a few of the possible feeding systems open to a livestock producer.

Costs and returns for each of thirty-two years (1917-1948) were estimated for (a) four different feed combinations for dairy cows; (b) one system of handling feeder calves, one system of feeding two-year old steers and three feed combinations for yearling steers; and (c) three feed combinations for hogs on pasture and three feed combinations involving forage and grain fed to hogs in dry lot. All of these systems are representative of feeding systems which are either common in the corn belt or offer possibilities for forage utilization under corn belt conditions.

Net returns were calculated for each feeding system for each of the thirty-two years. Net returns for each year reflect prices and costs for that year but assume present coefficients of production. A detailed description of the data and procedure used in arriving at the estimates of costs and returns is provided in the Appendix.

The relative frequencies of occurrence of various values of income may be expressed in a probability density function, where the probability of a particular value occurring is expressed as the number of times it occurred in the thirty-two year period divided by the total number of years it could have occurred (thirty-two). The sum of these probabilities for all values is one. These probability distributions, or certain parameters of them, may serve as guides for assigning degrees of belief to the various hypothetical outcomes visualized for the future for each feeding system considered.

It need not be assumed that the hypotheses concerning outcomes at some future date reflect precisely the same probabilities of occurrence as the distribution functions for the historical period. It is only necessary that we assume that some parameters of the historical distribution resemble the parameters of its future counterpart closely enough that the subjective ordering of degrees of belief (or assignment of probabilities) concerning the hypothetical outcomes is related to the probability distribution for the previous period. For example, while it is not inconceivable that some people have notions of a "normal" price based on an historical mean, it seems likely that most individuals would be influenced more in forming their expectations about the level of corn prices by the outlook for the general level of business activity, employment and national income. But, on the other hand, expectations regarding relative prices and relative incomes for rival plans might very well be based on their relative positions in the past. Since many of the rival products produced by farmers are substitutes for each other in consumption and compete for the same resources in production, their relative prices and costs might be expected to change only as people's tastes change or as innovations affect the costs of production of one relative to another.

Further, the relative amplitude of the variations in prices or returns for rival plans may be important in forming expectations about relative variability of returns from these alternatives in the future. Fluctuation in production, responses of consumers to changes in incomes and similar phenomena account for fluctuations in returns from farm products. All farm products do not exhibit the same stability of production from year to year; the demands for some products are more sensitive to changes in consumer incomes than are others. If we assume that such characteristics of the rival production plans do not change much over time, we may expect the relative variability of returns from the alternatives in the past to be a good indication of their relative variability in the future.

In the pages that follow characteristics of the frequency distributions of returns from fifteen different livestock feeding systems for the thirty-two year historical period are compared. These comparisons are intended to indicate (a) the relative mean net income farmers might expect from alternative opportunities in the future and (b) the relative uncertainty which will be associated with the alternatives in planning future production. Thus it is hoped that these comparisons can be used in conjunction with the gambler indifference curves of any livestock producer in determining which of the alternative feed utilization systems will provide him with the greatest satisfaction in his particular situation.

In order to place returns from different classes of livestock on a comparable basis net returns are expressed in terms of returns per $100 of costs. Returns per $100 of all costs were computed by dividing the gross returns per unit of livestock by the total cost of producing one unit (including imputed costs for interest, depreciation and family labor) and multiplying the quotient by 100. Returns per $100 of feed and labor costs were computed in a similar way except that gross returns were divided by feed and labor cost only. Returns per $100 feed costs were calculated on the basis of feed cost only.

Average returns and the variability of returns per $100 all costs for the thirty-two year period of 1917 to 1948 are shown in Table 2.

Table 2. Variability of returns per $100 all costs for various l

Returns per $100 all costs	Dairy cows High grain (a)	Dairy cows Medium-high grain (b)	Dairy cows Medium-high forage (c)	Dairy cows High forage (d)	Feeder cattle Feeder calves	Feeder cattle Yearling steers High grain (a)	Feeder cattle Yearling steers Medium grain (b)	Feeder cattle Yearling steers High forage (c)
0- 19	-	-	-	-	-	-	-	-
20- 39	-	-	-	-	1	1	1	1
40- 59	-	-	-	-	2	1	-	2
60- 79	-	1	1	1	4	6	6	3
80- 99	9	11	14	16	3	9	6	6
100-119	13	14	17	15	12	6	7	9
120-139	9	6	-	-	6	2	5	2
140-159	1	-	-	-	4	6	3	4
160-179	-	-	-	-	-	-	3	3
180-199	-	-	-	-	-	-	-	1
200-219	-	-	-	-	-	1	1	-
220-239	-	-	-	-	-	-	-	1
Average returns	111	106	102	99	106	104	112	113
Variance	219	172	133	125	883	1388	1416	1873
Standard deviation	14.80	13.10	11.50	11.20	29.70	37.50	37.80	43.20
Coef. of var.	13.3	12.3	11.4	11.2	28.0	35.9	33.5	38.2
Range	57.3	45.6	40.3	38.6	119.1	186.6	183.2	195.6
$\bar{x} - 2\sigma$	81.40	79.80	79.00	76.60	46.60	29.0	37.40	26.60
$\bar{x} + 2\sigma$	140.60	132.20	125.00	121.40	165.40	179.00	187.60	199.40
Maximum loss	18.60	20.20	21.00	23.40	53.40	71.00	62.60	73.40
Maximum gain	40.60	32.20	25.00	21.40	65.40	79.00	87.60	99.40

per $100 all costs for various livestock feeding systems, 1917-1948.

	Feeder cattle					Hogs					
		Yearling steers				Dry lot hogs			Pasture hogs		
	Feeder calves	High grain (a)	Medium grain (b)	High forage (c)	2-yr.-old steers	All grain (a)	Medium forage (b)	High forage (c)	All grain (a)	Medium forage (b)	High forage (c)
	-	-	-	-	1	-	-	-	-	-	-
	1	1	1	1	-	-	-	-	-	-	-
	2	1	-	2	2	-	-	1	1	1	1
	4	6	6	3	6	2	3	2	2	2	2
	3	9	6	6	9	4	3	3	6	4	7
	12	6	7	9	3	10	10	13	11	10	8
	6	2	5	2	3	9	10	7	7	7	8
	4	6	3	4	5	4	3	3	4	5	3
	-	-	3	3	3	2	2	2	1	-	2
	-	-	-	1	-	1	1	1	-	2	1
	-	1	1	-	-	-	-	-	-	1	-
	-	-	-	1	-	-	-	-	-	-	-
	106	104	112	113	103	122	121	118	114	122	115
	883	1388	1416	1873	1498	732	735	716	663	1074	999
	29.70	37.50	37.80	43.20	38.60	27.10	27.10	26.80	25.70	32.90	31.60
	28.0	35.9	33.5	38.2	37.4	22.2	22.3	22.6	22.5	26.9	27.4
	119.1	186.6	183.2	195.6	157.5	122.4	123.6	121.9	114.2	145.9	138.3
	46.60	29.0	37.40	26.60	25.80	67.80	66.80	64.40	62.60	56.20	51.80
	165.40	179.00	187.60	199.40	180.20	176.20	175.20	171.60	165.40	187.80	178.20
	53.40	71.00	62.60	73.40	74.20	32.20	33.20	35.60	37.40	43.80	48.20
	65.40	79.00	87.60	99.40	80.20	76.20	75.20	71.60	65.40	87.80	78.20

Variability of returns is expressed in terms of the variance, standard deviation, coefficient of variation and range. In addition, the frequency distribution, showing the number of years out of thirty-two in which returns per $100 of all costs fell in various intervals, gives an indication of the skewness and kurtosis of the distribution.

<u>Criteria for choice of feeding system</u>

Before proceeding with an interpretation of the data in Table 2 the appropriateness and limitation of the various measures used in the table will be considered. The mean is used as the measure of central tendency rather than the mode. On theoretical grounds the mode may be preferred because it is the most typical value regardless of the symmetry of the distribution; the mean, on the other hand, is distorted by extreme values within the distribution and in the case of assymmetrical distributions is an unsatisfactory measure of central tendency. The mean has the advantage, however, of being more easily determined. Also, in the case of symmetrical distributions it has the same value as the mode. The apparent symmetry of the frequency distributions shown in Table 2 justifies the use of the mean rather than the mode in these distributions.

The range is one measure of the absolute dispersion of values within a distribution. Since its value is determined by the high and low extremes within an array, it is often distorted by an unusual event at either or both extremes.

The variance, a measure of the squared deviations from the mean, gives a good indication of the dispersion of a distribution based on all the observations. The square root of the variance, the standard deviation, is a more convenient measure of the dispersion. 68.27 per cent of all randomly drawn observations from a symmetrical distribution will lie within one standard deviation above and below the mean. The mean plus and minus two standard deviations will include 95.45 per cent of all the observations. Thus the standard deviation provides an estimate of the probability of particular outcomes. If a distribution is skewed the percentages of observations falling within one or two standard deviations of the mean will be changed slightly.

Frequently it is desired to compare dispersions for different types of data where a common denominator is needed. Relative measures of variability are needed rather than absolute measures, such as the range or standard deviation. One measure which is often useful is the coefficient of variation, which is obtained by dividing the standard deviation by the mean and multiplying the quotient by 100. One difficulty with the use of the coefficient of variation is that unless it is accompanied by its mean and standard deviation it may be very misleading. It is misleading when abstracted from its mean and standard deviation because there is then no way of knowing whether differences in its value are due to differences in means or in standard deviations.[a] Since returns from

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[a]The misleading nature of the coefficient of variation is illustrated in the diagram at the right. The coefficient of variation is the ratio of the standard deviation of a distribution to the mean expressed as a percentage. The coefficient of variation for each of the alternative opportunities open to an entrepreneur may be represented by points in a plane, where the horizontal coordinate is the mean returns and standard deviations are represented on the vertical axis. Then all plans having a common coefficient of variation must fall on a straight line going

various livestock systems have already been placed on a comparable basis by stating them in terms of returns per $100 of costs there is no apparent advantage in including a comparison of the coefficients of

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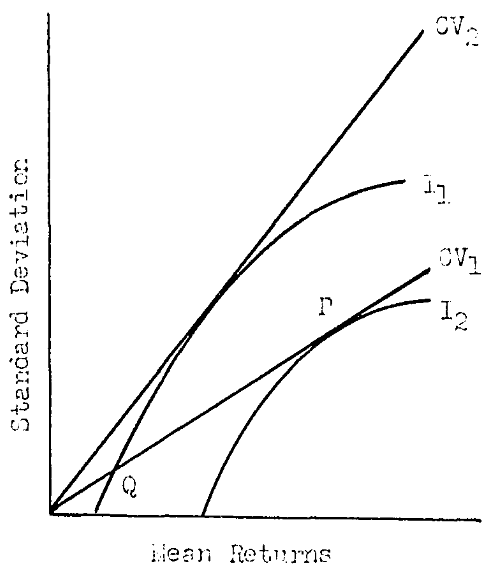
through the origin. Line CV_1 in the diagram connects all points representing plans with a ratio of standard deviations to mean returns equal to the slope of CV_1. Similarly, the ratio of standard deviations to mean returns for all distributions represented by Line CV_2 are equal to the slope of Line CV_2. If the coefficients of variation of alternative plans are considered apart from their means and standard deviations, all plans having identical coefficients of variation will be considered equally attractive. If we now consider the diagram at the right as a risk indifference map, similar to that in Figure 9, it is seen that the risk indifference curves are straight lines emanating from the origin, with the flattest such line, the horizontal axis, as the highest possible risk indifference curve. This implies a knowledge about the nature of the risk indifference maps of individuals which can hardly be verified. Moreover, it implies similar risk indifference curves for all individuals. It is easily shown that such use of the coefficient of variation is inconsistent with our earlier hypothesis of the nature of the risk indifference map. Curves I_1 and I_2 are two possible risk indifference curves for an individual. The individual is interested in finding the distribution having the combination of mean returns and standard deviation falling on the highest risk indifference curve. Of all the distributions having a coefficient of variation represented by Line CV_1, that distribution represented by Point P, and only that distribution, falls on indifference Curve I_2. Point Q, which represents a plan having the same coefficient of variation, falls on indifference Curve I_1 -- a lower indifference curve. Another individual having a stronger aversion to risk taking (a flatter indifference curve) might find Point Q on a higher indifference curve than any other point on Line CV_1. Thus the important difference between the above use of the coefficient of variation and our concept of the indifference map described earlier is that the former assumes a fixed reaction to income variation while the latter treats the attitude to variability as a subjective value, different for different individuals.



variation. The coefficients of variation are included in the table primarily to show how they compare with the other measures of dispersion.

Skewness and kurtosis are other characteristics of the distribution of possible returns with which we are concerned. Skewness, or the departure from symmetry, is important in this respect: if a distribution is skewed the most probable and the median outcomes may be quite different from the mean outcome. If a distribution is positively skewed the mean value will be larger than the median; less than 34.13 per cent of the values included in the distribution will be within one standard deviation above the mean, while more than 34.13 per cent will be within one standard deviation below the mean.

Kurtosis is characterized by the flatness or peakedness of the distribution near the mean. A positive kurtosis is characterized by an excess of values near the mean and more distant from the mean with a deficit in the intermediate areas. A negative kurtosis is characterized by a flat topped distribution -- one in which the probabilities of moderate deviations are very high.

Skewness and kurtosis may both be measured. A measure of skewness is provided by the third moment about the mean. The generally accepted measure of relative skewness is the ratio of the third moment about the mean to the cube of the standard deviation. Relative kurtosis is measured by the ratio of the fourth moment about the mean to the square of the variance.

A visual examination of the frequency distributions in Table 2 suggests that there is no marked skewness or kurtosis in any of the distributions. This observation is verified by the measurements of these characteristics; they were found to be very small in each case. Thus each of the distributions can be treated as normally distributed. The means are then satisfactory measures of central tendency and the standard deviations may be used as measures of dispersion.

In considering only the mean returns and the standard deviation of returns when comparing the attractiveness of alternative plans an important feature of an individual's attitude toward uncertainty may be overlooked. It seems that a person's aversion to uncertainty is directed primarily at the prospects of loss resulting from an unfavorable outcome. To illustrate, suppose that an individual views the prospective outcomes from a particular plan as having a distribution such as A in Figure 10, and that he views the distribution for a rival plan as that of B in the figure. Distribution B exhibits considerably more dispersion than does Distribution A. It also has a larger mean. The misgivings which an individual may have about proceeding with either plan is due, we assume here, to the distress he feels in contemplating negative deviations from the mean, or most probable, outcome and not due to the prospects of positive dispersion in the distribution of outcomes. Thus in comparing two rival plans he might ask himself this question: "What is the most unfavorable outcome I can expect from this plan as compared with the least favorable outcome expected from the rival plan?" Suppose that he considers the outcome two standard deviations below the mean as the lowest outcome which he is likely to obtain -- he is 97.725 per cent confident that no lower value will be obtained. These limits may be labeled L_{1A}

and L_{1B} for distributions A and B in Figure 10. The relative level of these limits together with the means for each distribution may be the criteria on which the choice between the alternative ventures is made.

These limits may be expressed in another way when considering returns per \$100 of costs: taking a return of \$100 as a position of zero gain and loss, the value of the Limit L_1 subtracted from \$100 defines the magnitude of loss at Position L_1. This we shall refer to as the maximum loss associated with a plan. A new risk indifference map can be constructed in which the standard deviation is replaced by the maximum loss on the vertical axis. In Diagram I of Figure 11 the two rival plans, A and B, whose distributions are shown in Figure 10, are represented on an indifference map based on the standard deviation and mean returns. In Diagram II these same plans are represented on an indifference map where the coordinates are maximum loss and mean returns. The relative positions of the points representing the two plans are changed considerably in going from Diagram I to Diagram II. Curve I in Diagram I is the indifference curve of an individual who considers Plans A and B equally attractive from the standpoint of mean returns and standard deviation of returns. Any individual possessing a stronger aversion to risk taking (i.e. a risk indifference curve having less slope) prefers Plan A, while individuals who are more indifferent to uncertainty (expressed in terms of standard deviations) prefer Plan B. When the two plans are compared in Diagram II, however, it is apparent that the only individuals who prefer Plan A are the ones having a strong affinity for suffering losses. Rational individuals would not have

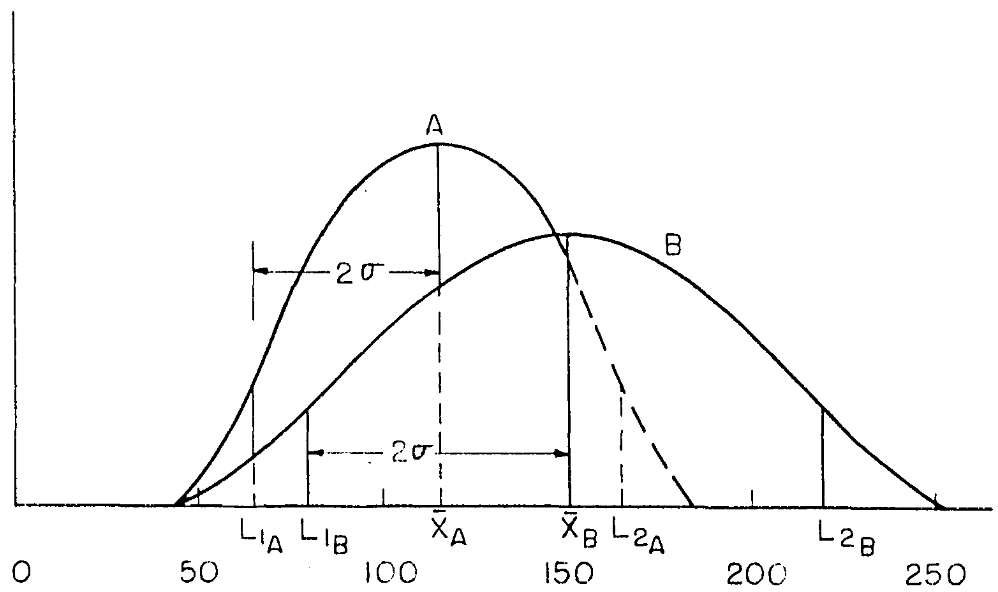


Fig. 10 Probability distribution B superimposed on distribution A.

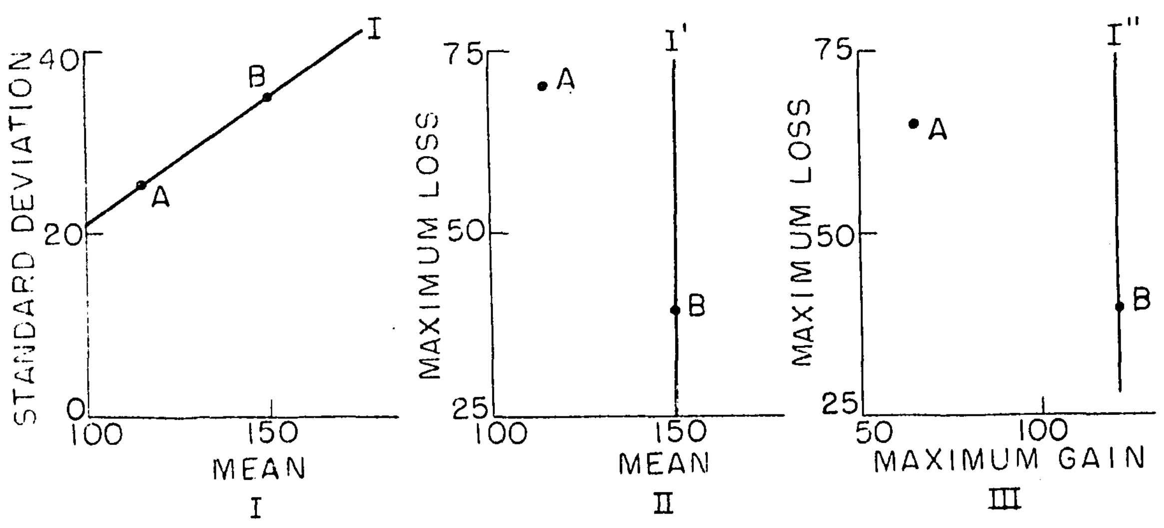


Fig. 11 Risk indifference maps involving distribution A and B.

negatively sloping risk indifference curves based on these criteria since negative curves express a preference for high maximum losses as well as for low average returns (or most probable returns).

It is possible that many individuals consider the probability of obtaining very high gains as well as the chances of heavy losses in deciding between alternative plans. They may consider returns greater than two standard deviations above the mean so unlikely that they ignore the possibility of their occurrence -- they can be 97.725 per cent confident that larger returns will not occur. Thus the mean plus two standard deviations may be considered the effective upper limit of values for a distribution. These are labeled L_{2A} and L_{2B} for distributions A and B in Figure 10. Considering returns of $100 per $100 of costs as the position of zero gain or loss, maximum gain may be defined as the difference between L_2 and $100. In Diagram III of Figure 11 the plans represented by Distributions A and B are indicated by points in a plane having as coordinates the maximum loss and maximum gain. Again risk aversion can be represented by positively sloping risk indifference curves. The vertical Curve I" in Diagram III indicates complete indifference to the possibilities of loss (i.e. maximum gain is sole basis for choice between rival plans). A negatively sloping risk indifference curve appears completely foolhardy and need not be considered.[a]

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[a]A negatively sloped risk indifference curve (when dealing with normally distributed populations, at least) means that a person prefers a situation involving the prospects of high losses or low gains to one of smaller losses and higher gains.

Diagrams I, II, and III illustrate three of the possible bases for choosing from among alternative plans. In many situations the solutions provided by each of these methods of comparison will be identical; this will ordinarily be true when dealing with normal distributions among which the differences in means are small relative to the differences in dispersion of outcomes. The possibility of contradiotory conclusions on the basis of these three comparisons are clearly demonstrated in Figure 11.

It is possible that some individuals compare rival opportunities on the basis of the mean returns and some measure of the dispersion as in Diagram I. Others may consider the mean returns in relation to the magnitude of prospective losses as in Diagram II. Still others may, as we have suggested in Diagram III, consider the magnitude of possible losses in relation to the size of gains they consider possible. While the process of selection may not consciously involve any of these criteria, it appears that all are useful in indicating the relative attractiveness of alternative plans to individuals possessing different attitudes toward uncertainty. In the comparisons of the alternative feeding systems in the pages that follow all three bases for comparison are used.

Comparison on basis of all costs

The information in Table 2 provides two interesting kinds of comparisons: First, returns from alternative rations can be compared for each type of livestock. Second, returns for different kinds of livestock may be compared. In each case comparisons can be made in respect to average returns over time and variability of returns. Differences in average returns and variability of returns per $100 of all costs for different rations fed each type of livestock are considered first.

Optimum dairy system. Average returns per $100 of all costs for the four dairy feeding systems differ considerably. The cows fed the high-grain rations returned an average of $111 for each $100 of costs over the entire period compared to only $99 returned per $100 of costs for the cows on the high-forage ration. At the same time, each of the measures of dispersion show that the variability of returns increased as the proportion of grain in the ration increased. The standard deviation of returns for the high-forage system was only 11.2 compared to 14.8 for the high-grain system. Thus in determining which is the optimum feeding system the higher mean returns for the high-grain system must be balanced against the lower variability of returns for the high-forage systems. Different individuals will balance these in different ways depending on their own attitudes toward uncertainty. In many cases where both mean returns and the variability of returns are larger for one plan than for its rival no unique "best" choice can be made. In Figure 12 each of the dairy systems are represented by points in a plane where the vertical coordinate measures the standard deviation of returns and the horizontal axis measures the mean return per $100 of all costs. Curve Ib represents an indifference curve for an individual who considers dairy system a (the high-grain system) equally as attractive as System c (the medium-forage system). Anyone possessing a more steeply sloping risk indifference curve prefers System a. An individual having a risk indifference curve such as Ia considers Systems d and c equally attractive. Anyone having a stronger aversion to risk taking (a more gently sloping indifference curve) prefers System d.[a]

Comparison of the returns from the four dairy rations, however, also shows that the mean returns for the high-grain system are sufficiently higher than for the other systems that, despite the larger variability of returns, the probability of large losses from that system is less than for the less variable systems. 97.725 per cent of the values of returns per $100 of all costs fall above the following levels for the four systems: $81.40 for System a (the high-grain system), $79.80 for System b (the medium-high grain ration), $79.00 for System c (the medium-high forage system) and $76.60 for System d (the high-forage system). Thus the maximum losses, as defined above, are $18.60, $20.20, $21.00 and $23.40 respectively.

The four dairy systems are compared on the basis of maximum losses and mean returns in Figure 13. The relative positions of the points representing the four rations are changed from what they were in Figure 12, where the comparison was on the basis of standard deviations of returns and mean returns. In Figure 13 Curve I' is the indifference curve of an individual who is completely indifferent to the magnitude of

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[a]The Lines Ia and Ib may, as an alternative, be viewed as forming a boundary line or "opportunity" curve (dca) corresponding to Curve S in Figure 9. All plans which can be represented by points in the plane to the left of and above Curve dca must be on a lower indifference curve than some alternative plan.

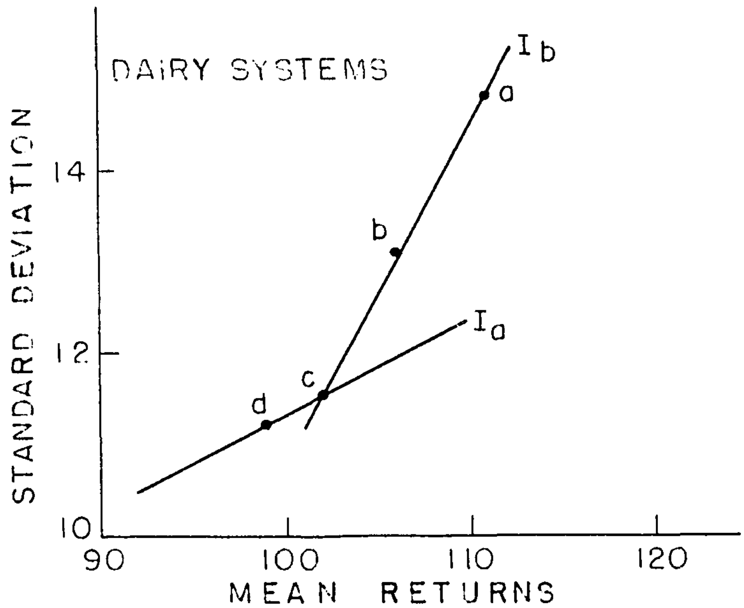

Fig. 12 Standard deviations and mean returns for alternative dairy systems.

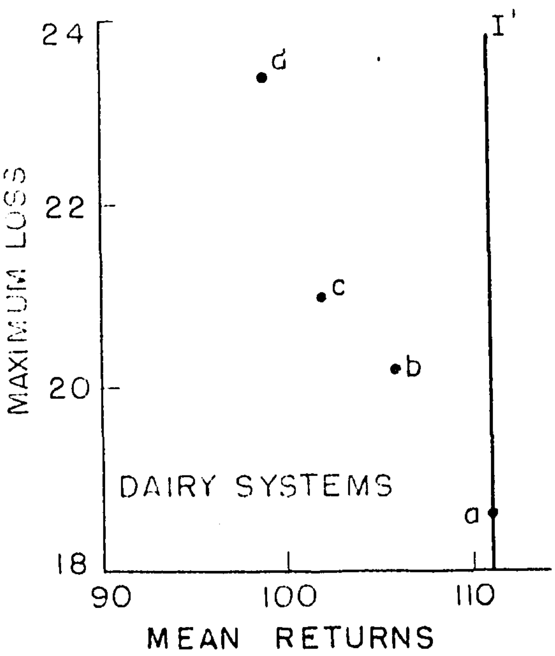

Fig. 13 Maximum loss and mean returns for alternative dairy systems.

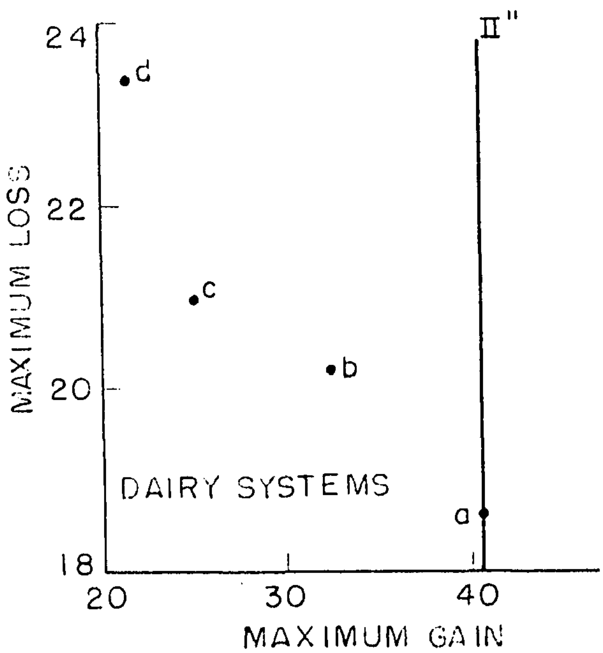

Fig. 14 Maximum loss and maximum gain for alternative dairy systems.

loss possible. Only the unusual individual who enjoys dangerous investments would prefer any of the plans represented by points to the left of Curve I', since they involve greater likelihood of loss and less possibility of gain. Thus the comparisons in Figure 13 indicate that System a is the most attractive of the four dairy systems; it lies on a higher indifference curve (further to the right) than any of the other systems. This holds true regardless of the degree of positive slope an individual's risk indifference curve may have. The only individuals for whom it would not be true are those having negatively sloped indifference curves.

Maximum losses and maximum gains are used as criteria of choice in the comparison of the four dairy systems in Figure 14. The relative positions of the points representing the different rations are quite similar to those of Figure 13. Again any positively sloping risk indifference curves passing through the points representing Systems b, c, and d will lie to the left of one passing through the point representing System a. Since a negative sloping indifference curve is inconsistent with our assumption of rationality System a may be considered the most attractive of the four dairy systems.

Optimum cattle feeding system. Similar comparisons of the five feeder cattle systems are less conclusive. Again the mean returns per $100 of all costs as well as the variability of returns differ from one system to another. But which is the most attractive? First, consider the three feed combinations fed to yearling steers. The steers fed the largest amount of grain gave a mean return of $104 per $100 of all costs compared to $112 for those fed the moderate-forage ration and $113 return for those on the high-forage ration. The standard deviations of returns from each of these systems were $37.50, $37.80 and $43.20, respectively. The intervals including the mean returns plus and minus two standard deviations (including 95.45 per cent of the values in each distribution) have the following lower limits: $29.00 for the high-grain system, $37.40 for the moderate-forage system, and $26.60 for the high-forage system. The upper limits are $179.00, 187.60 and 199.40, respectively. On the basis of the comparisons of standard deviations and mean returns in Diagram I of Figure 15 the high-grain yearling steer system is preferred over the other two yearling steer systems only by individuals having risk indifferences curves with less slope than that of dotted Line Ic. Curve Ib indicates indifference between the high-forage yearling steer system and the medium-grain yearling steer system.

According to the comparison in Diagram II of Figure 15, involving maximum losses and mean returns, and the comparison in Diagram III, where maximum losses and maximum gains are the criteria, the choice must be between the high-forage ration and medium-grain system, with Curves I'b of Diagram II and I"b of Diagram III indicating indifference between the two systems.

Comparisons of the yearling steer systems with the feeder calf and two year old steer systems are also included in Figure 15. The choice in each case is between the high-forage yearling steer system, the medium-grain yearling steer system and the feeder calf system, depending on the slope of the risk indifference curve. Regardless of the degree of positive

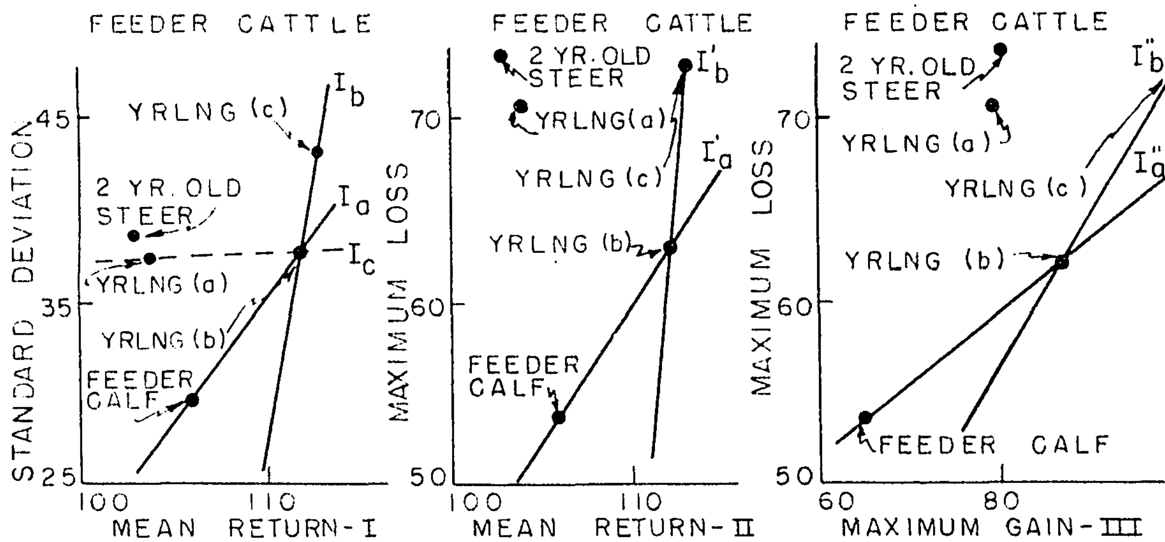

Fig. 15 Relative attractiveness of alternative cattle feeding systems.

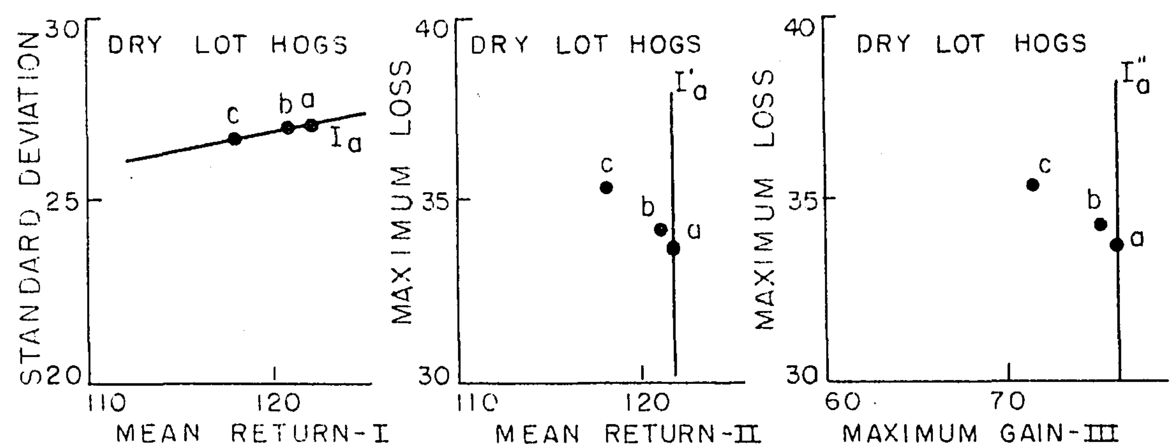

Fig. 16 Relative attractiveness of alternative dry-lot hog systems.

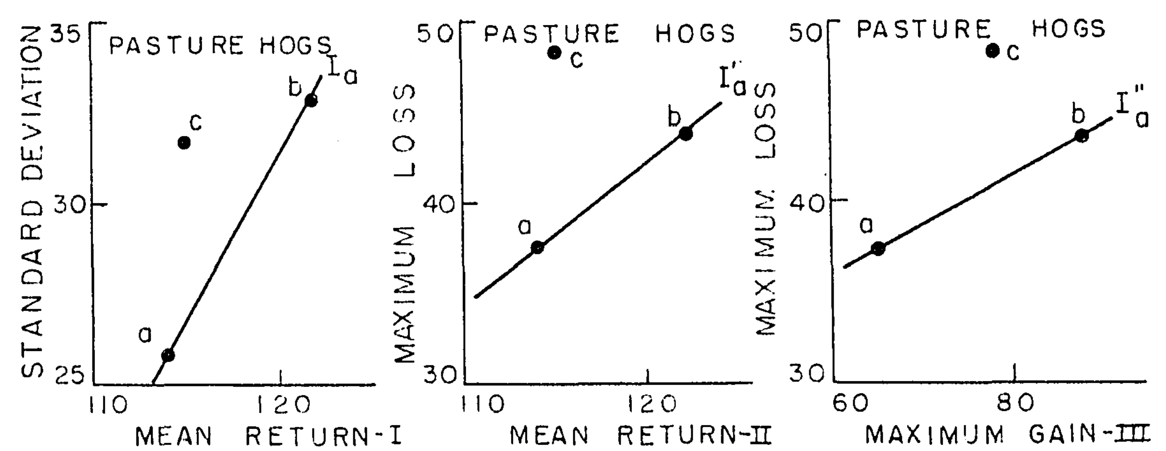

Fig. 17 Relative attractiveness of alternative pasture hog systems.

slope, (linear) indifference curves passing through any of the points representing these three systems will lie to the right of (be greater than) those passing through the points representing the two year old steer system or the high-grain yearling steer system. On the basis of the criteria of choice employed no unique "most attractive" feeder cattle system can be determined since "most attractive" to each individual depends on his attitude toward uncertainty.

Optimum hog feeding system. The hog systems used in this analysis consist of (a) three systems based on an experiment by the United States Department of Agriculture involving different proportions of chopped legume hay and grain fed in dry lot and (b) three systems of handling hogs adapted from an Iowa experiment involving different proportions of forage and grain fed hogs on pasture. Because these two experiments were conducted under such different conditions each set of feeding systems is analyzed separately.

The three feeding systems involving different proportions of chopped hay and grain fed in dry lot show remarkably small differences both as to mean returns per $100 of all costs and as to variability of returns. Returns for the hogs on the high-grain ration (System a) averaged $122 per $100 of all costs, for those on the medium-forage ration (System b) the returns averaged $121, and returns for those on the high-forage ration (System c) averaged $118 over the thirty-two year period. The standard deviation of returns were $27.10, $27.10, and $26.80 respectively. If, in choosing one from among these three hog feeding systems, only the standard deviation and the mean returns of each are taken into account, System a is clearly more attractive than System b. This is true since the mean returns is larger for System a while the standard deviations of the two systems are identical. Whether or not an individual prefers System a to System c depends on his attitude toward uncertainty, since the standard deviation as well as the mean is smaller for System c. Diagram I of Figure 16 shows that an individual having a risk indifference curve such as Ia is indifferent as to whether he follows System a or System c. Anyone having a stronger aversion to risk taking prefers System c. Those less cautious prefer System a.

A comparison of the dry lot hog systems on the basis of minimum loss in relation to mean returns is made in Diagram II of Figure 16. The relative position of the points representing the three feeding systems indicates that any individual, unless he enjoys contemplating losses, prefers System a. In Diagram III of Figure 16 the three hog systems are compared on the basis of maximum loss in relation to maximum gain. Again any rational individual employing these criteria will choose System a since any positively sloping indifference curve passing through the point representing System a must lie to the right of the points representing Systems b and c.

The set of hog systems involving different proportions of pasture in the ration show considerable differences in both mean returns and variability of returns. The hogs on the high-grain ration (System a) gave an average return of $114 per $100 of all costs; those receiving a medium-forage ration (System b) returned an average of $122, and those on the high-forage ration (System c) returned an average of $115 per $100 of all costs. The standard deviations of returns were $25.70, $32.90, and $31.60, respectively. While the expected returns from System a are considerably lower than for System b, some individuals may prefer System a because of its lower variability of returns. Anyone having a stronger risk aversion than that represented by Curve Ia in Diagram I of Figure 17 prefers System a.

If the decision in choosing between alternative systems involves the maximum loss associated with each rather than the standard deviation the analysis is not much different from that above. As shown in Diagram II, System b is preferred by those who have less risk aversion than that indicated by Curve I'a, while System a is preferred by those individuals whose risk indifference curve is less steeply sloped than I'a. In Diagram III of Figure 17 the comparison of the three hog systems on the basis of maximum loss and maximum gain leads to a similar conclusion. Either System a or System b will be preferred, depending on the slope of the individual's risk indifference curve.

Optimum livestock system. In the above sections alternative forage grain feed combinations have been compared with a view toward determining the relative attractiveness of alternative feed combinations for a particular type of livestock. Similar comparisons can be made to determine the relative attractiveness of different kinds of livestock. In doing so two important limitations of such comparisons should be recognized. First, these comparisons cannot take into account important enterprise relationships. For most farm situations a single livestock enterprise cannot make efficient use of available resources; some combination of livestock enterprises will ordinarily constitute the optimum livestock program. In the second place, the data on which these comparisons are based do not take into account technical uncertainty. This may be very unimportant in comparing different rations for a particular kind of livestock as differences in technical uncertainty may then be assumed to be small or unrelated to the composition of the ration. In comparing different kinds of livestock such an assumption appears less valid. These limitations should be kept in mind in drawing inferences from the following comparisons.

If unique solutions had been obtained in determining the "best" feeding system for each kind of livestock these best systems could then be compared on a risk indifference map. But different individuals may consider different feeding systems most attractive depending on their attitudes toward risk taking. All of the feeding systems for the three types of livestock are therefore compared in determining the type of livestock to produce. These comparisons are made on the basis of mean returns per $100 of all costs and standard deviations of returns in Figure 18. Comparisons in Figure 19 are on the basis of mean returns and maximum loss. In Figure 20 the fifteen systems are compared on the basis of maximum loss and maximum gain.

When all fifteen systems are compared on a plane involving the standard deviations and mean returns six different systems may be considered the optimum choice, depending on the slope of the risk indifference

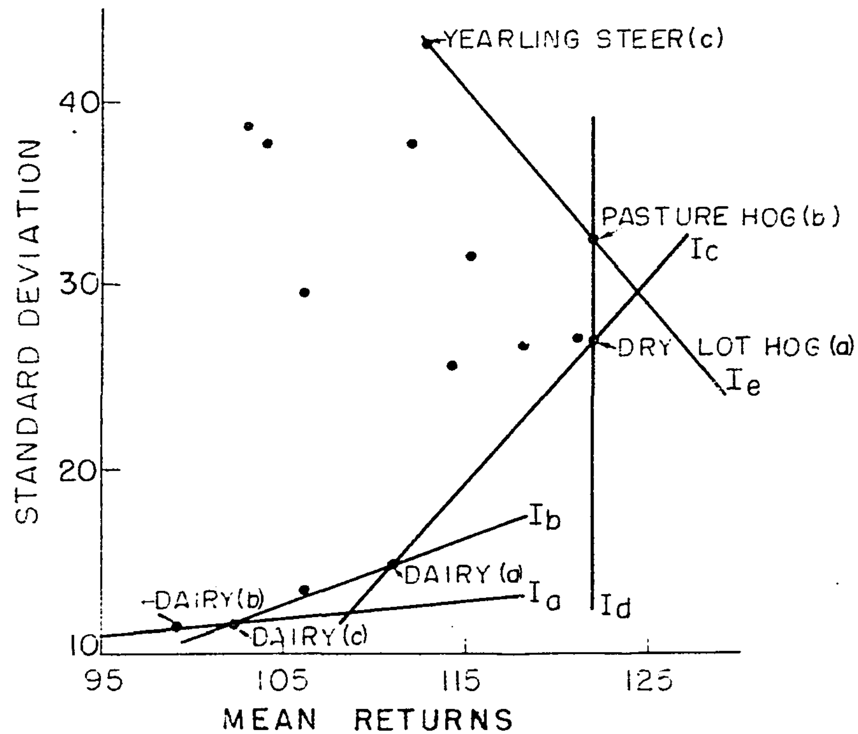

Fig. 18 Standard deviations and mean returns for alternative livestock systems.

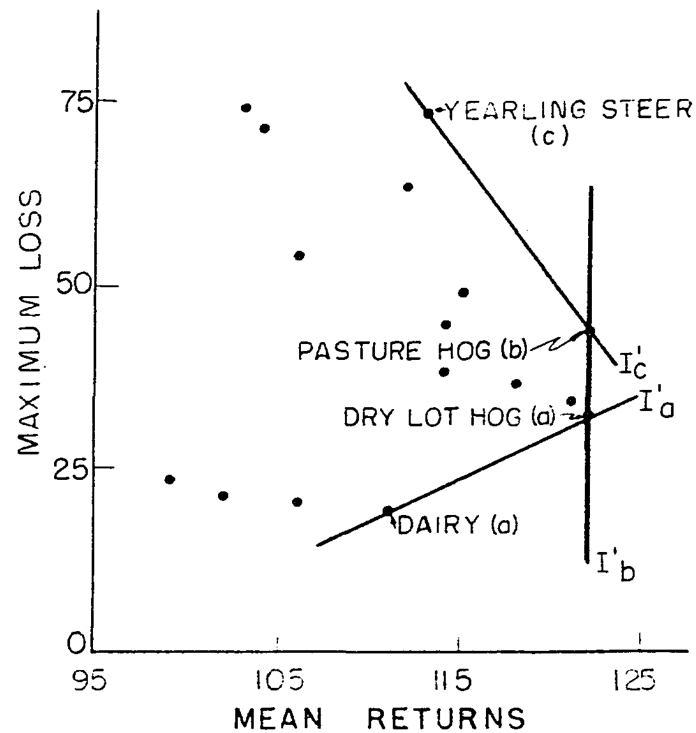

Fig. 19 Maximum loss and mean returns for alternative livestock systems.

curve. An individual having a risk indifference curve of less positive slope than Ia in Figure 18 prefers dairy System d to all other livestock feeding systems considered. Anyone having risk indifference curve with a slope less than Ib but more than Ia prefers dairy System c. An individual possessing more aversion to risk taking than that expressed by Curve Ic but more than that expressed by Ib prefers dairy System a to all the other livestock feeding systems. If an individual's risk indifference curve slopes more than Ic but less than Id he prefers the dry lot hog System a. A negatively sloped indifference curve falling between Id and Ie indicates a preference for pasture hog System b. Only if his indifference curve was negatively sloped less than Ie would an individual prefer the yearling steer System c. The remaining nine feeding systems would never fall on as high indifference curves as some of these six systems regardless of the slopes of indifference curves (i.e. unless the indifference curves were non-linear).

The comparison of all fifteen systems in Figure 19 on the basis of maximum loss and mean returns reduces the number of possible "best" choices to only four. Line I'a indicates indifference between dairy System a and dry lot hog System a. More gently sloping positive curves indicate a stronger risk aversion and a preference for dairy System a. Line I'b indicates complete indifference to the magnitude of the maximum loss and indifference between pasture hog System b and dry lot hog System a. Only if an individual had a strong affinity for risking large losses, characterized by a risk indifference curve having less negative slope than I'c, would he prefer the yearling steer System c.

The comparisons in Figure 20 are based on the maximum losses and maximum gain associated with each feeding system. Here again either of the same four systems may be considered most attractive depending on the degree of risk aversion a person has. Any linear indifference curve passing through the points representing these four feeding systems must lie to the right of indifference curves passing through points representing any of the other eleven systems.

These comparisons suggest that most individuals prefer hog feeding systems to other livestock systems. Only persons with a strong risk aversion prefer dairy cows, and only people who are very indifferent to uncertainty or are foolhardy have a preference for feeder cattle. The limitations pointed out earlier, however, need to be kept in mind. While no data were examined to determine the technical variability of production for the different kinds of livestock, a priori knowledge of technical relationships in livestock production is to the effect that physical hazards of production are considerably greater for hogs than for dairy or beef cattle. If this is taken into account the relative attractiveness of the hog feeding systems is diminished. Even so, many farmers may still consider hogs the most attractive type of livestock from the standpoint of probable returns relative to the uncertainty associated with it but still raise considerable numbers of other kinds of livestock; enterprise relationships may be such that a combination of hogs with beef and/or dairy cattle gives the most satisfactory combination of mean returns and variability of returns.

Comparisons on the basis of feed and labor costs

Net returns for the above comparisons were calculated in terms of returns per $100 of all costs. Expenses connected with buildings and equipment, including interest and depreciation, make up an important part of that total cost. However, buildings and equipment often do not involve any actual cost to the farm operator. For example, tenants are ordinarily provided buildings by the landlord.[a] Also, on many farms buildings and equipment have been provided in a previous period; their present use for livestock may involve no more expense than if they were permitted to stand idle. Farmers in such situations are not concerned with building and equipment costs.

Feed and labor costs account for nearly all of the costs of livestock production aside from the costs associated with buildings and equipment needed for handling the livestock. Thus many farmers are primarily concerned with feed and labor costs. In this section the relative attractiveness of investments in alternative livestock feeding systems is based on the frequency distributions of the returns per $100 of feed and labor costs for each system.

The mean returns and the variability of returns per $100 of feed and labor costs are shown in Table 3 for each of the feeding systems. Again it appears that for each class of livestock the variability of returns is generally positively correlated with the mean returns. Both the

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[a]The rent paid may include a charge for the buildings, but most commonly rent is charged by the acre or on the basis of a share of the crop. In any event, the amount of rent paid is ordinarily not dependent on the use made of the buildings.

Table 3. Variability of returns per $100 feed and labor costs for var

Returns per $100 feed & labor costs	Dairy cows				Feeder cattle			
						Yearling steers		
	High grain (a)	Medium high grain (b)	Medium high forage (c)	High forage (d)	Feeder calves	High grain (a)	Medium grain (b)	High forage (c)
0- 19	-	-	-	-	-	-	-	-
20- 39	-	-	-	-	-	1	-	1
40- 59	-	-	-	-	2	-	1	1
60- 79	-	-	-	-	3	5	1	1
80- 99	2	3	5	4	3	5	5	4
100-119	11	13	10	13	3	8	7	6
120-139	9	9	14	12	11	5	6	7
140-159	8	7	3	3	6	1	4	1
160-179	2	-	-	-	3	5	2	3
180-199	-	-	-	-	1	1	5	4
200-219	-	-	-	-	-	-	-	2
220-239	-	-	-	-	-	-	-	1
240-259	-	-	-	-	-	1	1	-
260-279	-	-	-	-	-	-	-	1
Average returns	128	122	117	117	120	118	131	136
Variance	410	300	234	227	1462	1914	2046	2766
Standard deviation	20.25	17.32	15.28	15.05	38.24	43.75	45.23	52.59
Coef. of var.	15.88	14.19	13.02	12.82	31.97	36.96	34.40	38.57
Range	82.27	56.32	52.43	55.75	140.57	213.22	211.11	229.35
$\bar{x} - 2\sigma$	87.50	87.36	86.44	86.90	43.52	30.50	40.54	30.82
$\bar{x} + 2\sigma$	168.50	156.64	147.56	147.10	196.48	205.50	221.46	241.18
Maximum loss	12.50	12.64	13.56	13.10	56.48	69.50	59.46	69.18
Maximum gain	68.50	56.64	47.56	47.10	96.48	105.50	121.46	141.18

$100 feed and labor costs for various livestock feeding systems, 1917-1948.

Feeder cattle					Hogs					
	Yearling steers				Dry lot hogs			Pasture hogs		
Feeder calves	High grain (a)	Medium grain (b)	High forage (c)	2-yr.-old steers	All grain (a)	Medium forage (b)	High forage (c)	All grain (a)	Medium forage (b)	High forage (c)
-	-	-	-	1	-	-	-	-	-	-
-	1	-	1	-	-	-	-	-	-	-
2	-	1	1	1	-	-	-	-	-	-
3	5	1	1	2	1	1	1	2	1	1
3	5	5	4	6	1	1	2	1	2	3
3	8	7	6	7	6	4	7	13	9	10
11	5	6	7	3	10	12	8	5	6	4
6	1	4	1	4	4	4	7	4	3	6
3	5	2	3	4	6	6	3	3	4	1
1	1	5	4	1	1	2	3	4	2	4
-	-	-	2	1	3	2	1	-	3	2
-	-	-	1	2	-	-	-	-	2	1
-	1	1	-	-	-	-	-	-	-	-
-	-	-	1	-	-	-	-	-	-	-
120	118	131	136	129	142	142	139	131	144	138
1462	1914	2045	2766	1926	1159	1139	1036	1036	1778	1646
38.24	43.75	45.23	52.59	43.88	34.05	33.75	32.19	32.19	42.17	40.57
31.97	36.96	34.40	38.57	33.94	23.96	23.74	23.18	24.63	29.27	29.28
140.57	213.22	211.11	229.35	170.47	140.82	142.75	140.91	146.31	169.52	163.15
43.52	30.50	40.54	30.82	41.24	73.90	74.50	74.62	66.62	59.66	56.86
196.48	205.50	221.46	241.18	216.76	210.10	209.50	203.38	195.38	228.34	219.14
56.48	69.50	59.46	69.18	58.76	26.10	25.50	25.48	33.38	40.34	43.14
96.48	105.50	121.46	141.18	116.76	110.10	109.50	103.38	95.38	128.34	119.14

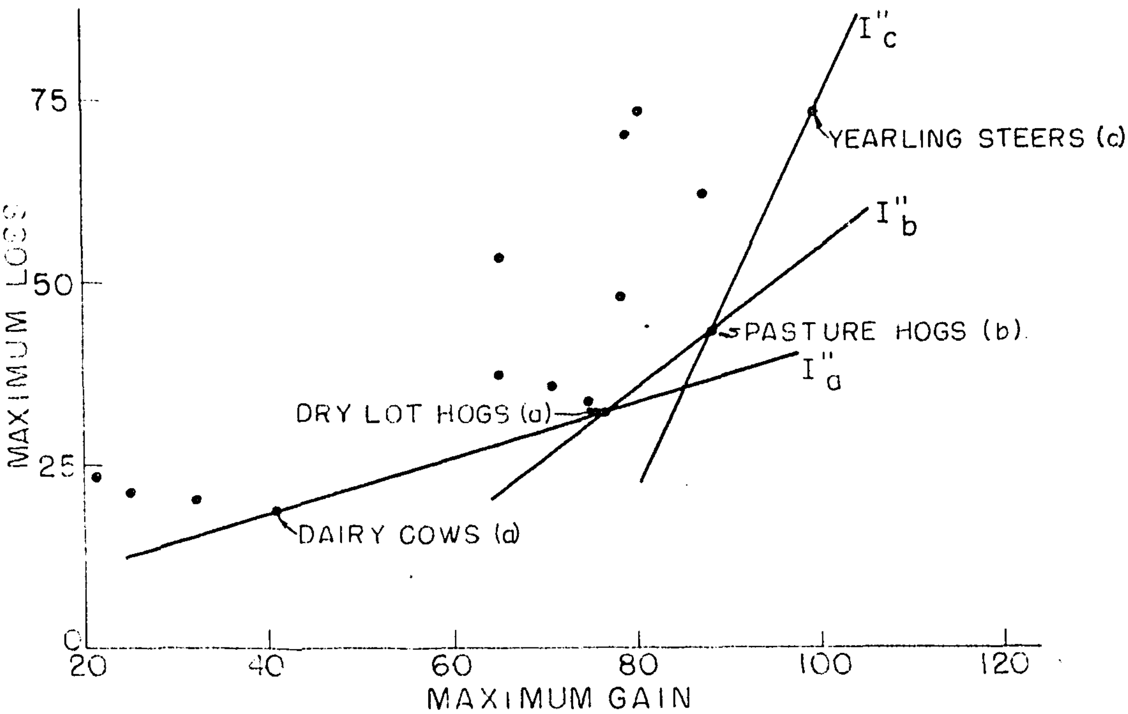
means and the dispersions for each of the distributions are larger than their corresponding values in Table 2, where all costs were considered. But, just as in Table 2, the frequency distributions show remarkably symmetrical dispersion about the mean. Computed measures of skewness and kurtosis also indicate that the values are approximately normally distributed in each case.

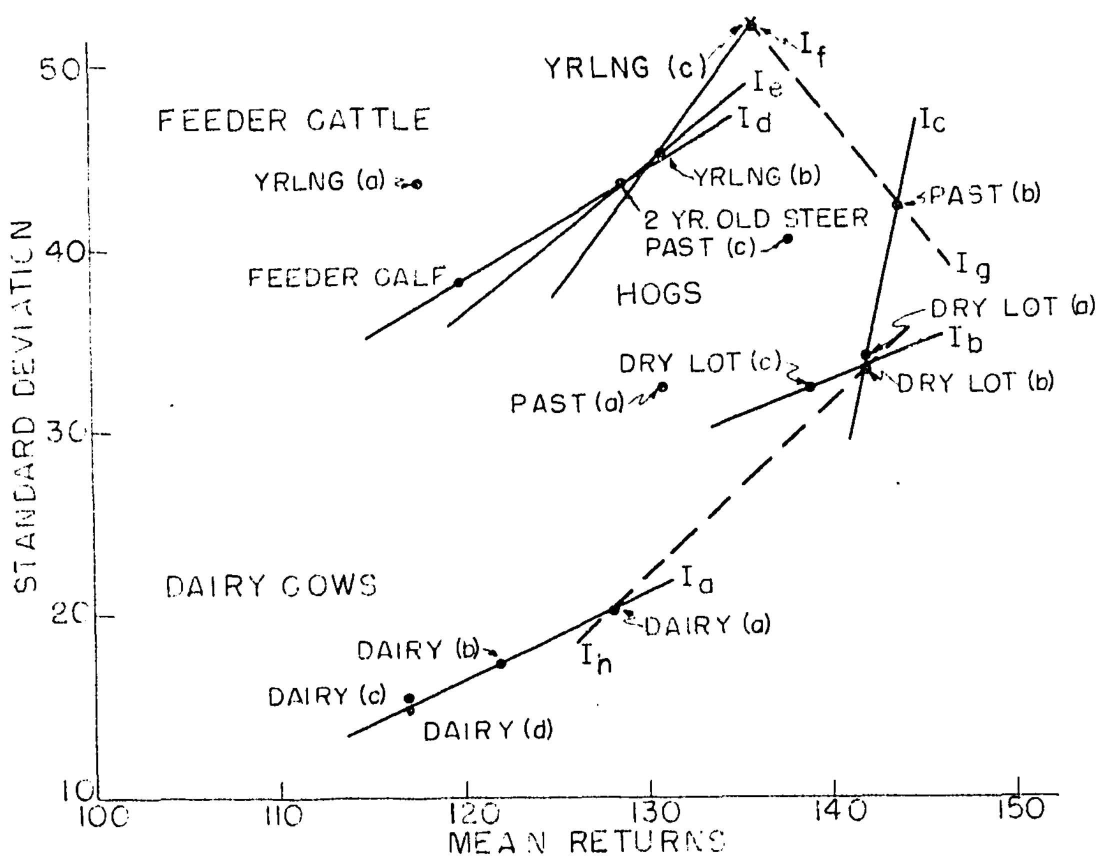
The relative attractiveness of the alternative feeding systems may, as before, be compared on the basis of the following criteria: (a) the mean return relative to the standard deviation of returns, (b) the mean return relative to the maximum loss, and (c) the maximum gain relative to the maximum loss. These comparisons are shown graphically in Figures 21, 22 and 23. All fifteen systems are represented on each indifference map. The solid lines represent the possible highest indifference curves between different feeding systems for a given type of livestock. The broken lines represent the highest indifference curves between types of livestock.

The comparisons in Figure 21 are on the basis of mean returns and the standard deviations of returns per $100 feed and labor costs. The choice between alternative dairy feeding systems is not clear cut; it depends on the nature of an individual's indifference map. Those whose risk indifference may be represented by solid Line Ia are indifferent as to whether they follow dairy System a, System b, or System d; each of these are slightly preferred to System c. Those possessing indifference curves more gently sloping than Ia prefer System d; those whose indifference curves are characterized by a slope greater than that of Ia prefer

Fig. 20 Maximum loss and maximum gain for alternative livestock systems.

Fig. 21 Standard deviations and mean returns per $100 feed and labor for alternative livestock systems.


I"c
YEARLING STEERS (c)
I"b
PASTURE HOGS (b)
I"a
DRY LOT HOGS (a)
DAIRY COWS (d)
75
50
25
0
MAXIMUM LOSS
20
40
60
80
100
120
MAXIMUM GAIN


YRLNG (c)
If
Ie
Id
Ic
FEEDER CATTLE
YRLNG (a)
YRLNG (b)
PAST (b)
2 YR. OLD STEER
PAST (c)
Ig
FEEDER CALF
HOGS
DRY LOT (a)
Ib
DRY LOT (c)
DRY LOT (b)
PAST (a)
DAIRY COWS
Ia
DAIRY (a)
DAIRY (b)
In
DAIRY (c)
DAIRY (d)
50
40
30
20
10
STANDARD DEVIATION
100
110
120
130
140
150
MEAN RETURNS

System a.

Of the five feeder cattle systems considered, it appears, according to Figure 21, that any of the systems except the yearling steer system involving a high-grain ration (System a) may be the optimum system, depending upon the slope of an individual's indifference curves. The feeder calf system appeals to those who have very strong aversion to risk (in terms of standard deviation), while the yearling steers fed the high-forage ration (System c) are most attractive to individuals who are primarily concerned with the mean returns and are quite indifferent to the amount of variation in returns associated with alternative investments.

The six hog systems are also compared in Figure 21 on the basis of mean returns and the standard deviation of returns. Of the three dry lot systems, System b (moderate forage) is preferred to System a (high grain) by all except those who are completely indifferent to the magnitude of the standard deviation. The mean returns are identical for the two systems butthe standard deviation about the mean is slightly smaller for System b. Individuals possessing very gently sloping indifference curves (less than Ib) prefer dry lot System c to either System a or System b. Of the pasture hog systems, the choice is between System a and System b. When all six systems are considered together the optimum may be dry lot System b, dry lot System c, or pasture System b, depending on the slopeof an individual's indifference curves.

The comparison of all feeding systems in Figure 21 shows that five of the fifteen systems are possible optima. Individuals possessing indifference curves flatter than Line Ia prefer dairy System d to all other feeding systems considered. For individuals having indifference curves with slopes between that of Ia and Ih dairy System a is preferred. If the indifference curves fall between Ih and Ic dry lot hog System b appears most attractive. Pasture hog System b is the optimum for individuals whose indifference curves are steeper than Ic. Only if an individual's indifference curves are negatively sloped and flatter than If will he prefer yearling steer System c over alternative livestock systems. On the basis of these comparisons all of the other ten systems must lie on lower indifference curves than one or another of the above five systems, regardless of the slope of an individual's indifference curves.

The comparisons of feeding systems in Figures 22 and 23, on the basis of maximum loss relative to mean returns and on the basis of maximum loss relative to maximum gain, yields results only slightly different from that given by the comparisons in Figure 21. One important difference is found in the comparison of dairy systems. Where Figure 21 showed that some individuals might be indifferent as to whether they followed Systems a, b, or d while others might prefer either System d or System a to all others, Figures 22 and 23 show System a to be clearly more attractive than any of the other dairy systems.

The relative attractiveness of alternative feeder cattle systems does not appear much different in Figures 22 and 23 than in the previous comparison. Any one of the five systems except the yearling steers fed the high-grain ration is a possible optimum.

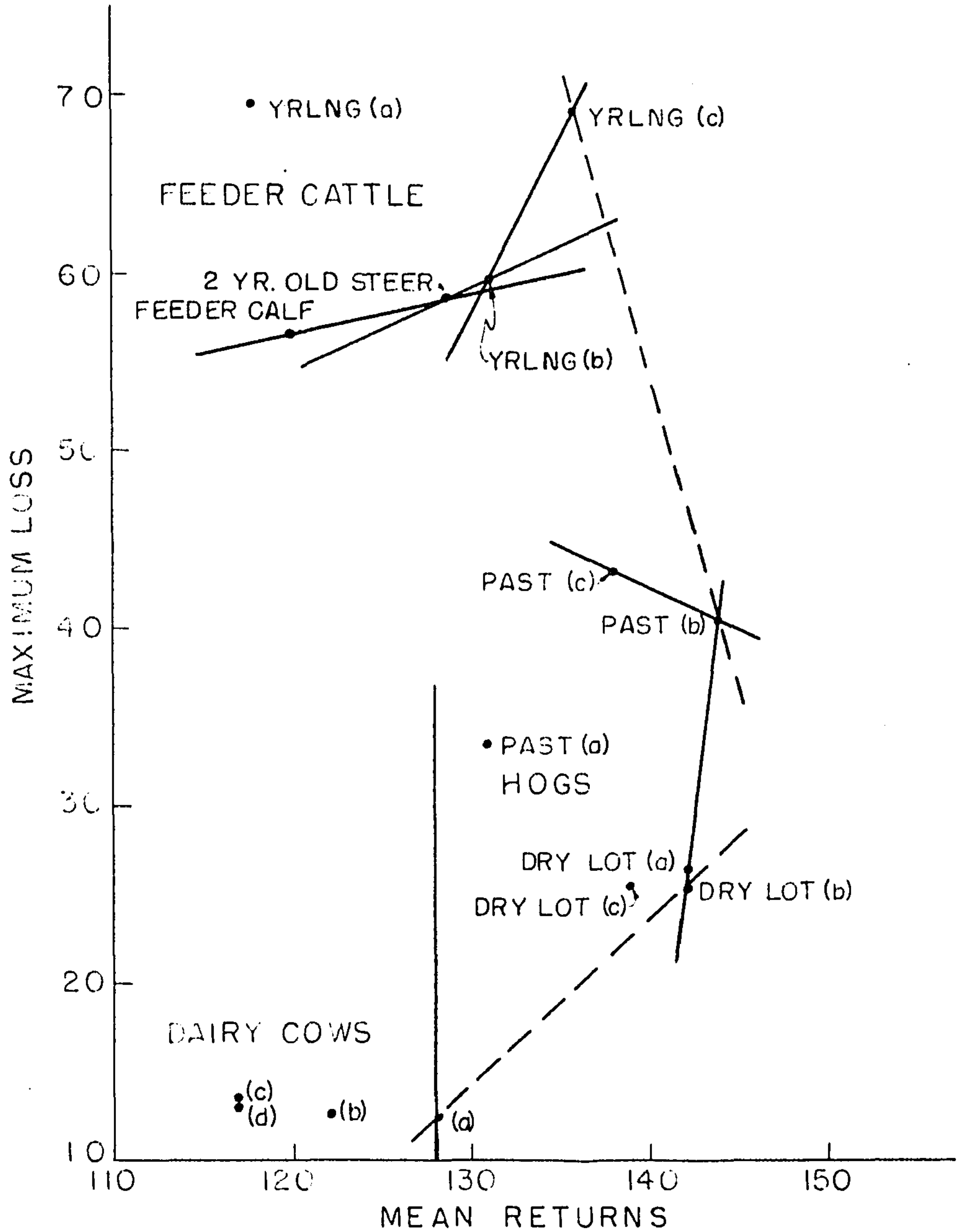


Fig. 22 Maximum loss and mean returns per $100 feed and labor for alternative livestock systems.

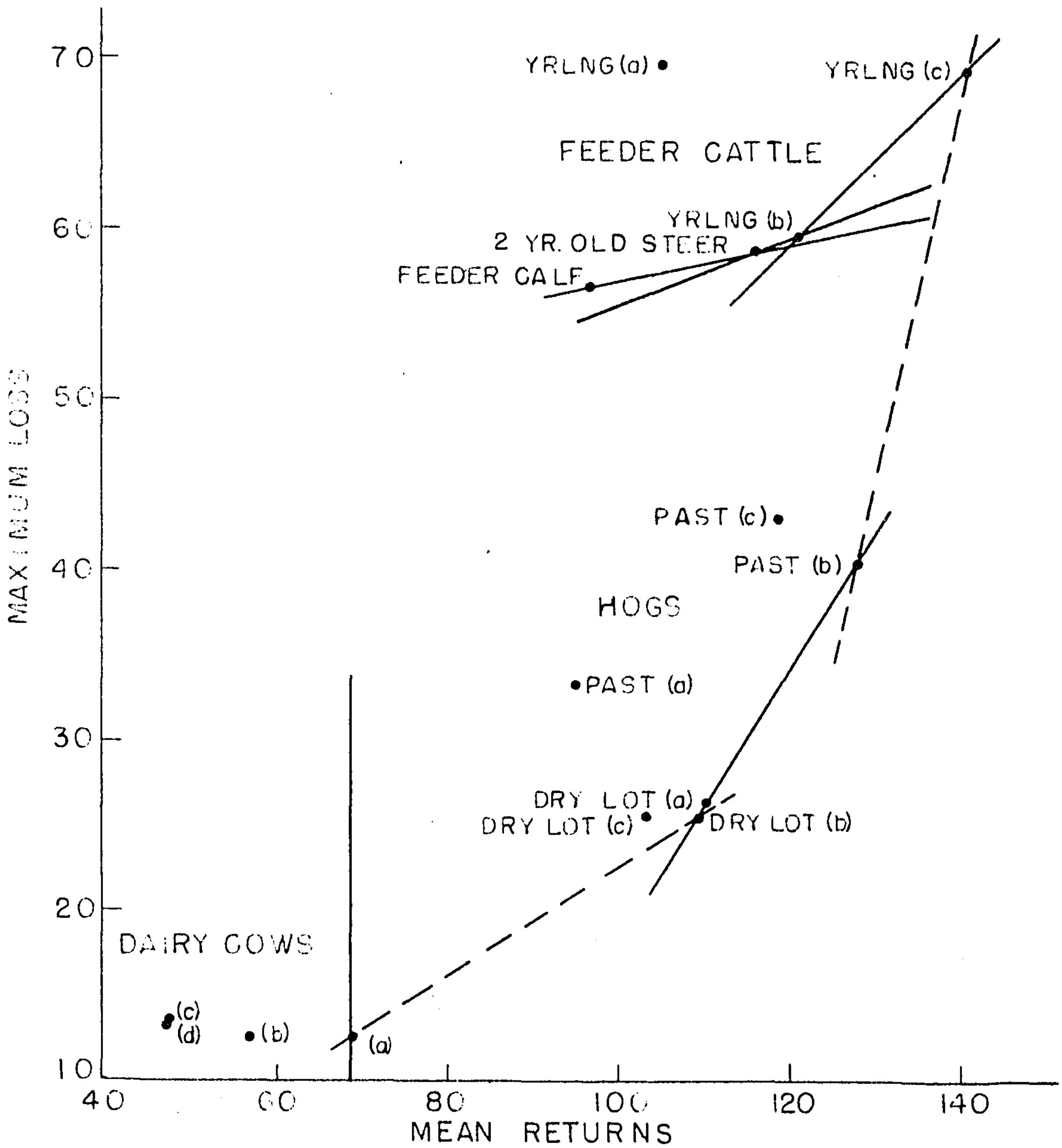


Fig. 23 Maximum loss and maximum gain per $100 feed and labor for alternative livestock systems.

A few differences from Figure 21 appear in the comparison of hog feeding systems. Of the dry lot hogs, Figures 22 and 23 show that System c cannot be an optimum. The comparisons in Figures 22 and 23 of pasture hogs shows that pasture hog System c may be an optimum only for individuals having negatively sloped indifference curves. Such curves are conceivable for Figure 22, where the criteria are mean returns and maximum loss, only if an individual associates the possibility of extremely high returns with the possibility of high losses. In the comparisons of Figure 23 a backward sloping indifference curve is inconceivable except for someone completely foolhardy.[a] Where all six hog feeding systems are considered, either dry lot System b or pasture System b are preferred.

Only four of the fifteen feeding systems considered are possible optima according to the comparisons in Figures 22 and 23. The optimum may be, in order of decreasing risk aversion (increasing slope of indifference curve), as follows: (1) dairy System a, (2) dry lot System b, (3) pasture System b, and (4) yearling steer System c. At least one of the linear indifference curves passing through the points representing these four systems must lie to the right of the points in the planes representing the other eleven systems.

Comparison on the basis of feed costs only

In computing costs for the above comparisons the value of labor

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[a]Since we are dealing with normally distributed populations, an individual who prefers a venture involving higher maximum losses and lower maximum gain to another venture promising lower maximum losses and higher maximum gains prefers, in effect, a lower to a higher income.

used was imputed at the going wage rate (average annual daily wage rate, without board). On many farms, however, labor costs do not represent an actual outlay of cash; often only family labor is used. Where no alternative employment opportunities exist the imputed value of labor may be considerably higher than the value placed on the labor by farm operators. Farmers in such situations may be willing to handle livestock even though the returns to labor are very low; they may be more concerned with returns to other resources. In this section alternative feeding systems are compared on the basis of characteristics of the frequency distributions of their returns per $100 of feed costs.

The mean returns per $100 of feed costs over the thirty-two year period and their dispersions are shown in Table 4 for each of the feeding systems being considered. The mean returns for each system are considerably higher than their corresponding values in Tables 2 and 3, with the largest increases in mean returns occurring in the case of the dairy systems. This is to be expected since labor requirements are relatively higher for dairy cows than for feeder cattle and hogs. The variability of returns is larger for each of the distributions than when all costs or feed and labor costs are considered. Again, the symmetry of each of the distributions is evident. Tests of kurtosis and skewness also indicate that each population is approximately normally distributed.

The relative attractiveness of the alternative feeding systems is compared on the basis of standard deviation of returns relative to mean returns per $100 of feed costs in Figure 24. In Figure 25 the comparisons are made on the basis of maximum loss relative to mean returns, and in

Table 4. Variability of returns per $100 feed for various livesto

Returns per $100 feed costs	Dairy cows: High grain (a)	Dairy cows: Medium-high grain (b)	Dairy cows: Medium-high forage (c)	Dairy cows: High forage (d)	Feeder cattle: Feeder calves	Feeder cattle: Yearling steers: High grain (a)	Feeder cattle: Yearling steers: Medium grain (b)	Feeder cattle: Yearling steers: High forage (c)	2- o st
0- 19	-	-	-	-	-	-	-	-	
20- 39	-	-	-	-	-	1	-	1	
40- 59	-	-	-	-	1	-	1	1	
60- 79	-	-	-	-	3	4	-	1	
80- 99	-	-	-	-	4	5	6	3	
100-119	-	-	-	-	2	5	2	5	
120-139	3	4	5	2	7	7	9	7	
140-159	3	3	3	4	6	3	3	2	
160-179	4	6	7	4	6	1	3	3	
180-199	7	7	5	7	2	5	3	4	
200-219	5	4	6	6	1	-	2	1	
220-239	-	2	1	1	-	-	2	2	
240-259	4	4	3	2	-	-	-	1	
260-279	4	1	2	2	-	1	-	-	
280-299	1	1	-	2	-	-	1	1	
300-319	1	-	-	2	-	-	-	-	
Average returns	205	193	189	206	134	128	144	144	13
Variance	2406	1877	1720	2472	1670	2346	2611	3189	272
Standard deviation	49.05	43.33	41.47	49.72	40.87	48.43	51.09	56.47	5
Coef. of var.	23.88	22.40	21.98	24.13	30.60	37.93	35.39	39.18	3
Range	183.63	159.74	147.67	182.35	164.32	236.27	238.89	245.84	23
$\bar{x} - 2\sigma$	106.90	106.34	106.06	106.56	52.26	31.14	41.82	31.06	3
$\bar{x} + 2\sigma$	303.10	279.66	271.94	307.44	215.74	224.86	246.18	256.94	24
Maximum loss	-6.90	-6.34	-6.06	-6.56	47.74	68.86	68.18	68.94	6
Maximum gain	203.10	179.66	171.94	207.44	115.74	124.86	146.18	156.94	14

ns per $100 feed for various livestock systems, 1917-1948.

	Feeder cattle				Hogs					
	Yearling steers				Dry lot hogs			Pasture hogs		
Feeder calves	High grain (a)	Medium grain (b)	High forage (c)	2-yr.-old steers	All grain (a)	Medium forage (b)	High forage (c)	All grain (a)	Medium forage (b)	High forage (c)
-	-	-	-	1	-	-	-	-	-	-
-	1	-	1	-	-	-	-	-	-	-
1	-	1	1	1	-	-	-	-	-	-
3	4	-	1	1	1	1	1	1	1	1
4	5	6	3	5	1	1	1	1	1	1
2	5	2	5	7	1	1	1	7	4	4
7	7	9	7	3	8	9	9	8	6	9
6	3	3	2	5	8	5	5	5	7	3
6	1	3	3	4	4	6	6	3	2	3
2	5	3	4	1	2	2	3	3	2	3
1	-	2	1	1	3	3	3	4	4	2
-	-	2	2	2	4	4	3	-	-	3
-	-	-	1	1	-	-	-	-	3	2
-	1	-	-	-	-	-	-	-	2	1
-	-	1	1	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
134	128	144	144	136	160	162	159	146	166	162
670	2346	2611	3189	2729	1661	1672	1614	1457	2790	2709
40.87	48.43	51.09	56.47	52.24	40.76	40.89	40.18	38.17	52.82	52.05
30.60	37.93	35.39	39.18	38.50	25.46	25.21	25.25	26.18	31.82	32.04
164.32	236.27	238.89	245.84	234.04	155.79	159.83	158.97	146.31	207.10	202.37
52.26	31.14	41.82	31.06	31.52	78.48	80.22	78.64	69.66	62.36	57.90
215.74	224.86	246.18	256.94	240.48	241.52	243.78	239.36	222.34	269.64	266.10
47.74	68.86	68.18	68.94	68.48	21.52	19.78	21.36	30.34	37.64	42.10
115.74	124.86	146.18	156.94	140.48	141.52	143.78	139.36	122.34	169.64	166.10

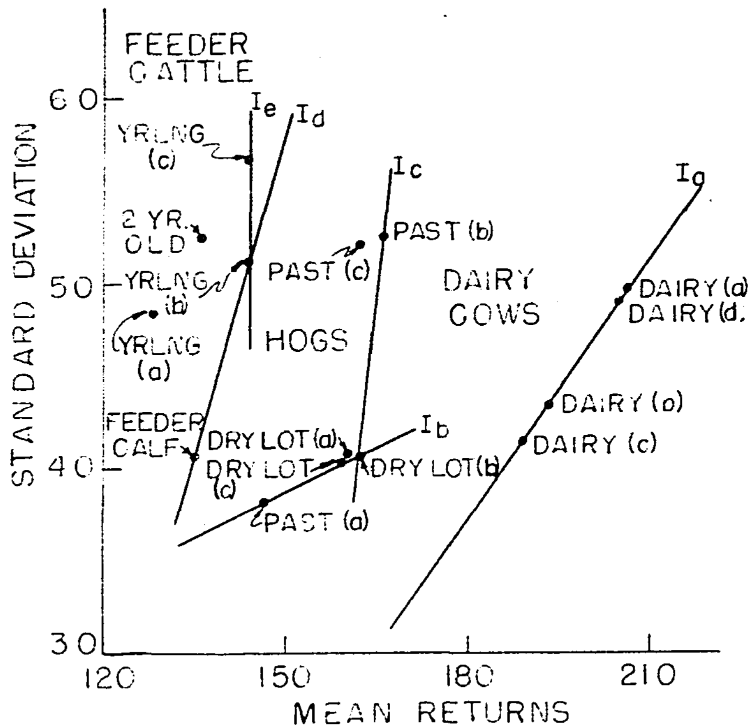

Fig. 24 Standard deviation and mean returns per $100 feed costs for alternative livestock systems.

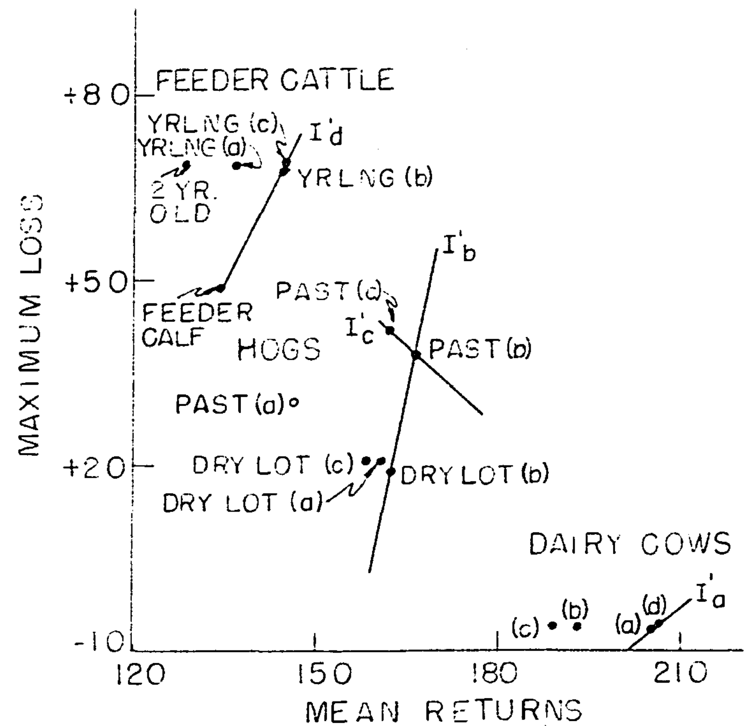

Fig. 25 Maximum loss and mean returns per $100 feed costs for alternative livestock systems.

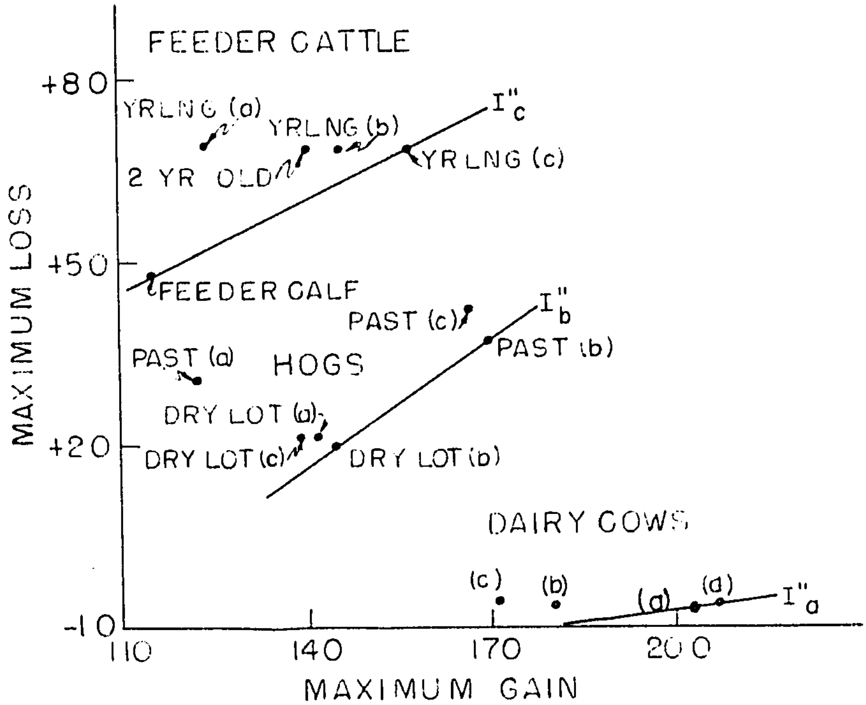

Fig. 26 Maximum loss and maximum gain per $100 feed costs for alternative livestock systems.

Figure 26 the systems are compared on the basis of minimum losses relative to maximum gains.

By disregarding labor costs the relative attractiveness of the different feeding systems is altered considerably. One important consequence is the change in relative position of the alternative types of livestock. The dairy systems appear considerably more attractive than the other feeding systems when only feed costs are taken into account. This holds true even for individuals who are completely indifferent to the amount of uncertainty (in terms of standard deviations of returns or maximum losses). The only persons who consider feeder cattle or hogs more attractive than dairy cows are those having unusually high preferences for risk taking.

The positions of alternative feeding systems for a particular kind of livestock relative to each other are also affected by disregarding the cost of labor. In the case of dairy cows, the position of the high-forage ration (System d) is enhanced considerably. According to the comparisons in Figure 25 and 26 System d is considered superior to other dairy systems by livestock producers having less risk aversion than that indicated by Lines I'a or I"a. More cautious individuals prefer dairy System a.

The positions of the alternative feeder cattle systems to each other are changed only slightly by disregarding labor costs. The most significant change among the feeder cattle systems is the less favorable position given two year old steers. The possible optima choices among the five feeder cattle systems are reduced from four to three when the comparison is made on the basis of mean returns relative to the standard deviation of returns; the possible optima systems are reduced from four to only two when the comparison is on the basis of maximum loss relative to mean returns or maximum loss relative to maximum gain.

Analysis of the relative attractiveness of investments in alternative hog feeding systems is unaffected by considering only feed costs rather than feed and labor costs or all costs. The optimum hog system remains either pasture System b or dry lot System b, depending on the individual's attitude toward income variability.

Limitations of analysis

In the above analysis the probability distributions of returns from alternative feeding systems have been compared in an attempt to determine which feeding system offers the most desirable investment opportunity. Certain limitations of this analysis which need to be emphasized are: (a) the inadequacy of historical probability distributions in assessing the uncertainty of income from alternative ventures, and (b) the inappropriateness of the assumption that a particular system is followed consistently year after year.

The frequency distributions for each feeding system used in the analysis were for an historical period. In making plans for future production these can only serve as rough guides of the future outcomes. The probability distributions viewed by a producer must necessarily be subjectively determined. The influence of past relationships in establishing the probability distributions viewed by individual producers in a situation of true uncertainty is not known and is likely to be quite different for different individuals. Use of the historical population in determining optima feeding systems was based on the assumption that, while the level of returns expected in the future might be quite different from the average over a previous period, the ordering of mean returns and of measures of dispersion will bear a very close resemblance to their past relative values. In some of the comparisons, it may have been noted, the differences in mean values or in measures of dispersion among the feeding systems were slight. Bearing in mind that these values are merely bases for subjective evaluation of the relative positions of the alternative plans for the future, it is doubtful that the probability distributions actually visualized by the producer in formulating future plans would in each case carry over with precision the same ordering of mean incomes and variability. Thus the historical probabilities must be viewed as only crude indices of the relative values of the various characteristics of the probability distributions upon which plans for future production are based. One must be cautious, therefore, in concluding that a particular system is considered more attractive than another by an individual, especially when the calculated values of the historical populations being compared differ only slightly.

The assumption that a particular feeding system is to be followed consistently through time was useful in simplifying the comparisons but is not altogether realistic. Farmers need not follow the same system year after year. They may alter the proportion of forage in the ration from time to time. Also, there is often some opportunity to shift from one kind of livestock to another from one year to the next.

Adjustments in the ration fed to a particular type of livestock are usually quite easily accomplished. The dairy ration, for example, can be changed frequently during the year in accord with changes in relative prices of feeds. In cattle fattening somewhat less flexibility may exist, depending to some extent upon the system of handling and type and grade of feeder. High quality cattle being fed on a high grain ration offer little flexibility; it will seldom be profitable to shift such cattle to a ration containing more forage, and the time at which to sell the cattle is determined, within a rather narrow range, once the cattle are put on full feed. Calves or young steers on a ration containing considerable forage, on the other hand, permit more turning points. Decisions as to when to finish these for market may be delayed awaiting more certain expectations; thus several changes in the production plan can be made during a single production period.

Changes in the feeding system for a particular kind of livestock from year to year are usually very easily accomplished. The size and grade of cattle purchased, the ration fed, and length of time kept on hand can be varied from year to year without important changes in facilities. Similarly, changes in methods of handling hogs and milk cows are very easily changed from year to year.

Changes in the type of livestock fed are ordinarily less easily accomplished. Specialized facilities and special skills are often required for each type of livestock. Once investments have been made in a dairy herd and dairy buildings and equipment, for example, these investments cannot be recouped except as consumed in dairy production, since these facilities may not be suitable for feeder cattle or hog production. It is possible, of course, to plan facilities to permit greater flexibility between enterprises. Ordinarily, the more suited facilities are for a particular type of livestock, the less flexible is their use. Flexibility will often be achieved at the expense of somewhat less efficient production for any one enterprise (39, pp. 14, 168, 240-257).

Thus, while decisions concerning the type of livestock to feed involve expectations over considerable lengths of time, decisions as to the feed combination to feed a particular kind of livestock need be made to cover only a relatively short period of time, and plans can be revised frequently to take account of new information regarding prices and costs. As the period of time involved (between the time a decision is put into effect and when results of that decision are realized) is shortened, the degree of uncertainty (in terms of the deviation of actual outcomes from the expected) will ordinarily be reduced. If this is true, the degree of uncertainty assigned to each feeding system in the comparisons in Tables 2, 3 and 4 exaggerate the degree of uncertainty actually associated with alternative ventures. However, unless the amount of flexibility inherent in each of the feeding systems is different, the ordering of the "degrees of belief" concerning the possible outcomes may still be no different than that indicated by the above analysis of the historical data.

Effect of Capital Limitations

Up to this point in the analysis nothing has been said about the availability of capital. The assumption was implicit that adequate capital was available to invest in any of the fifteen rival feeding systems. Actually, many farmers are faced with a shortage of savings and inability to borrow as much capital as they would like. In this section some of the effects of limited capital on the optimum livestock system are examined.

As a farmer's borrowed capital increases relative to his assets lenders tend to view additional loans to him as increasingly "risky". The uncertainty as to returns forthcoming from the use of additional capital as well as the uncertainty as to the responsibility and integrity of the borrower take on more importance as the possibility of collecting the entire amount of the obligation from the collateral seems less certain. One possible way for the lender to deal with this situation is to increase the rate of interest charged. This should have the dual effect of discouraging further borrowing and compensating for the added risk. If the lender deals with the situation in this way the farmer may still borrow additional money as long as the marginal value productivity of the capital exceeds the marginal cost. No capital rationing is involved in such a case.

Another manner in which the lender may react to the more unfavorable position of the borrower is to refuse to make additional loans to him. This is frequently done. Many farmers find themselves in a position where it is impossible for them to obtain additional capital. Farmers in this position may make an optimum selection of livestock systems quite different from that of farmers having adequate capital.

A livestock producer having a large accumulation of savings or having access to an unlimited amount of capital at a given rate of interest makes the optimum allocation of capital by investing in each enterprise up to the point where the marginal returns equal the interest rate, providing he has perfect expectations. In the usual case, where uncertainty is involved, such an individual would stop short of the point where marginal cost equates marginal revenue; how far short of that equilibrium depending upon his attitude toward uncertainty and the uncertainty he associated with the various ventures. That is, a livestock producer may impose capital rationing on himself (in the sense of restricting capital investments below their ex post equilibria) because of uncertainty. In general, the more precarious his financial position (the greater the proportion of capital is borrowed capital) the more severe will the self imposed rationing be. That is to say, the lower his equity, the stronger his risk aversion.

The farmer faced with a severe shortage of capital and inability to borrow additional funds must necessarily restrict his investments in various livestock enterprises to less than the expected equilibrium. In allocating the scarce capital among alternative opportunities he is still guided to some extent by the uncertainty he associates with each rival venture and also by the expected returns he visualizes from investments in each.

In the absence of uncertainty the optimum adjustment for a farmer faced with capital rationing is to equate the marginal returns to capital from all investment opportunities open to him (this would be at a rate somewhere above the interest rate). The presence of uncertainty may not cause such a farmer to reduce his total investment, as would be expected for the farmer having adequate capital; rather, the adjustment made to uncertainty is likely to involve a reduction in investments in ventures considered more uncertain and an increase in the investments in the more certain ventures.

SUMMARY AND CONCLUSIONS

Farmers, and others interested in agricultural programs and policies, are concerned with the question of what is the most profitable forage acreage to produce. The most profitable forage acreage for any individual farmer is dependent on (a) the relationship of forage to grain in crop production and (b) the relationship between forage and grain in livestock feeding. This investigation focuses on the relationship between forage and grain and the problems involved in forage utilization through livestock feeding.

The specific objectives of the study are: (a) to indicate some of the alternative possibilities for increasing forage consumption by livestock, (b) to evaluate alternative feed utilization systems with respect to potential returns and variability of returns, and (c) to suggest criteria for determining the optimum forage-grain feed combinations in feeding livestock for individual farmers in different situations, with special emphasis on the basis for choice in a setting of uncertain market expectations.

In a static setting the criteria of choice between alternative forage-grain feed combinations is that the marginal rates of substitution between forage and grain equal the inverse of their price ratios; or, where feeds produced on a farm are used entirely for livestock production, the least cost combination is that which equates the marginal rate of substitution of forage for grain in livestock feeding with the marginal rate of substitution of the two feeds in crop production.

Previous empirical research, as well as production economic logic, indicates a diminishing marginal rate of substitution between forage and grain in livestock production. The following substitution relationships between forage and grain have been found for various classes of livestock:

a. Dairy cows producing 8500 pounds of 4 per cent fat corrected milk were found to substitute forage and grain according to the following production contour:

$$X_2 = \left(\frac{8500}{3.56X_1} \right)^{2.5}$$

where X_1 is the pounds of forage fed and X_2 is the pounds of grain fed per cow to achieve an annual production of 8500 pounds of milk.

b. Good to choice feeder steers fed to a good to choice finish were found to produce one hundred pounds of gain with various combinations of forage and grain indicated by the following iso-quant:

$$X_2 = 1111.15 - .4219X_1 + .0000686X_1^2.$$

c. The product contour for one hundred pounds of pork production was estimated to be:

$$X_2 = 327.5 - .5113X_1 + .00423X_1^2.$$

d. The product contour for production of one hundred pounds of prime or choice lamb on feeder lambs was estimated as:

$$X_2 = \frac{2.3118 - .0037X_1 - \left[(2.3118 - .0037X_1)^2 \ .021175X_1 - .000031X_1^2 - 5.4267\right]^{1/2}}{.014792}$$

The least cost feed combination is easily found by equating the inverse ratio of forage prices to grain prices with the tangent to each of the above iso-quants.

The above analysis fails to take into account the time variable. As forage is substituted for grain the length of the feeding period required to obtain a given livestock output may be lengthened. In extending the analysis to include the effect of timing of production, costs and returns from several discrete livestock feeding systems were derived by budgeting technique and compared.

Costs and returns for each of thirty-two years (1917-1948) were estimated for (a) four different feed combinations for dairy cows, (b) five systems of handling feeder cattle, and (c) six feed combinations for hogs. All systems are representative of feeding systems which are either common in the corn belt or offer possibilities for forage utilization under corn belt conditions.

In order to simplify comparisons between classes of livestock, returns were measured in terms of returns per $100 of costs. Computations were made on the basis of (a) returns per $100 all costs, (b) returns per $100 feed and labor costs, and (c) returns per $100 feed costs. Comparisons on the basis of feed and labor costs only are applicable in the many situations in which buildings and equipment are provided at no cost to the farm operator. Comparisons on the basis of returns per $100 of feed costs only are appropriate where labor has no alternative profitable employment opportunities.

In choosing between alternative feeding systems it is assumed that livestock producers are guided by (a) their expectations regarding the probability distribution of future returns from each system and (b) their attitudes toward risk taking. While expectations regarding uncertain events must be subjectively determined, it is assumed here that various characteristics of the historical frequency distributions of returns from alternative ventures are helpful in ordering the relative attractiveness of the alternatives.

First, alternative plans are compared on the basis of mean returns over the thirty-two year period and the standard deviation of returns. Generally, the higher the mean returns for a feeding system the higher the variability of returns. Where this is true no unique "best" system can be determined; the system appearing most attractive to a particular individual depends on the intensity of his aversion to risk taking (i.e. the nature of his indifference map between standard deviation of returns and mean returns). In general, rational individuals will prefer a plan with a low variability (standard deviation) to a rival plan offering the same mean returns but with greater variability. But the extent to which individuals are willing to sacrifice mean returns (or total returns over time) in order to secure less variability of returns is different for different individuals, depending on such things as previous experience, educational background, financial position, and personality traits.

An alternative criterion of choice between rival feeding systems is the maximum loss relative to mean returns associated with the alternatives. Maximum loss is defined as the level of net loss given by the mean return minus two standard deviations. Again, no unique solutions are found unless a single feeding system has higher mean returns as well as a lower maximum loss associated with it.

A third criterion of choice is the maximum loss relative to the maximum gain associated with alternative plans, where maximum gain is defined as the level of returns two standard deviations above the mean.

The employment of the three criteria of selection, while it does not lead to determination of unique best feeding systems, narrows down the number of systems which might be optimum. The best choice for any one individual can be determined only as the nature of his risk preference is known.

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APPENDIX

BASIC DATA USED IN COMPUTING COSTS AND RETURNS FROM VARIOUS LIVESTOCK SYSTEMS

Estimates of physical data for computing costs and returns from alternative livestock systems were obtained from published and unpublished results of studies conducted at the Iowa Experiment Station, the U. S. Department of Agriculture and several other agricultural experiment stations. In some cases the various sources differed considerably in their estimates of input requirements; the estimates used were the ones which in the judgment of the authors most nearly represented requirements under present corn belt conditions. The data used and the method of computation followed in deriving the annual cost and returns estimates for each livestock system are described in the following sections.

Costs and Returns from Alternative Dairy Cow Feeding Systems

Each of the four dairy cow feeding systems considered in this study are based on the study by Einar Jensen and others (25, p. 80) of the United States Department of Agriculture. System (a) corresponds to level of feeding 13, System (b) corresponds to level of feeding 9, System (c) corresponds to level of feeding 5, and System (d) is representative of level of feeding 1, as discussed in Table 27 of Jensen's publication.

Costs of production per cow were considered to be the same for each system of handling except in respect to labor and feed costs. A summary of the costs included in the computations follows. Miscellaneous costs (including grinding, veterinary expenses, cow testing association dues, supplies, and repairs), were based on estimates given in an Iowa study (2). The figure $6.93 was used as the miscellaneous cost per cow for the year 1948. This was adjusted for the other years (1917-1947) by the index of prices paid by farmers for supplies.[a] The investment in silo, fences, and buildings per cow were also based on Iowa Experiment Station Research Bulletin 278. The figure $234.14 was used for 1948. This was adjusted by the index of building costs[b] for each of the other years. Interest on this investment was computed on the basis of 4 per cent. Depreciation was figured at 3 per cent.

Investment requirements per cow in dairy equipment (including milking machine, separator, and miscellaneous equipment) was figured at $12.09 for 1948 and adjusted by the index of farm machinery costs[c] for the preceding thirty-one years. Interest and depreciation on dairy equipment were each computed at 6 per cent.

The annual Iowa average price of good milk cows was used as the investment per cow in dairy cows each year. Replacement stock was figured on the basis of one-third of a calf and one-third of a yearling per cow, with a total value of 20 per cent the value of a dairy cow. The value of the bull per cow was computed at 10 per cent of the value of the cow (2).

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[a]Index of prices paid by farmers for equipment and supplies used in production, United States (47).

[b]Index of prices paid by farmers for building materials other than for houses, United States (47).

[c]Index of prices paid by farmers for farm machinery, United States (47).

Interest on the investment in cow, bull, and replacement stock per cow was figured at 6 per cent.

Labor requirements varied with the feeding system on the basis of milk production (2). The amount of labor required for handling the bull, replacement stock, and calves sold were figured at 6 days per cow for each system (6). The total days of labor required for each system (see Table 5) were multiplied by the Iowa annual average daily wage rate (without board) (8) to get labor costs per cow.

Feed inputs also varied with different systems, as shown in Table 5. Grain costs were computed by multiplying grain fed per cow under each system by the price of corn the preceding October (8). Hay costs were found by multiplying the tons of hay fed by the price of alfalfa hay the preceding November (8). An annual pasture charge per acre was computed on the basis of annual cash rents and crop yields. These pasture charges were then applied to the acres of pasture used per cow. Costs for protein supplement were based on the price of cottonseed meal the preceding December (8).

Gross returns from dairy cows include returns from butterfat produced, the value of skim milk produced, the value of calves sold, and the gain in value of replacement stock. The gain in value of the replacement stock per cow for each system was estimated as 25 per cent of the value of one dairy cow. Beef produced (calves sold) was estimated on the basis of 200 pounds of beef sold annually per cow for each system. The Iowa farm price of medium grade feeders in October[a] was used to get the annual value

[a]Monthly average at Chicago adjusted for transportation and commission costs (48).

Table 5. Quantities of various resources used per cow under alternative feeding systems.[a]

Item	Dairy cow feeding system			
	(a)	(b)	(c)	(d)
Labor, days	20.0	19.3	18.3	17.6
Grain, bu.[b]	105.1	73.0	40.8	8.7
Hay, tons[b]	1.1	2.8	3.2	3.2
Pasture, acres	.44	.44	1.21	1.53
Protein, supplement cwt.	3.66	3.45	3.15	2.5

[a]Feed requirements are based on Jensen (25, p. 80). System a corresponds to level of feeding 13, System b corresponds to level 9, System c corresponds to level 5, and System d corresponds to level 1.

[b]Includes cow feed plus bull and young stock feed per cow.

Table 6. Production of butterfat and skim milk per cow for specific dairy cow feeding systems.[a]

Product	Dairy cow feeding system			
	(a)	(b)	(c)	(d)
Butterfat, lbs.	399	374	323	258
Skim milk, cwt.	99.8	93.5	80.1	64.0

[a]Source of data was study by Jensen (25).

of beef produced for sale. The annual production of butterfat and skim milk per cow was different for each system (see Table 6). The pounds of butterfat per cow was multiplied by the annual average price of butterfat in Iowa (8). The value of skim milk was figured on the basis of one hundred pounds of skim milk being worth 12 per cent of the price of a bushel of corn.

Costs and Returns from Alternative Feeder Cattle Systems

Costs and returns for five distinct feeder cattle systems were computed. One of these systems involved the purchase of good-choice calves weighing about 440 pounds in October, wintering them, and then feeding them out in dry lot for sale as choice cattle in August at a weight of 1000 pounds. Feed requirements for this system were based on a study by Beresford (1).

Another system involved the purchase of choice two-year-old steers weighing 800 pounds in August. These were pastured abouta month in the fall, then put in dry lot and finished to choice cattle weighing 1150 pounds in January. Feed requirements for this system were also adapted from Beresford's (1) study.

Three systems of handling yearling steers were considered. These systems were based on five years of experiments by the Iowa Agricultural Experiment Station in Page County, Iowa (24). Choice feeders weighing an average of 610 pounds were purchased in November. All were wintered on the same ration to gain about one pound per day. In May they were separated into four lots. One lot (System a) was placed in dry lot and fed to a choice finish in October at a weight of 1060 pounds. A second lot (System b) was pastured 60 days, placed on full feed on pasture for an additional 90 days, then finished in dry lot for sale as choice cattle weighing 1120 pounds in October. A third group (System c) was put on alfalfa brome pasture in May and grazed continuously for about 130 days without any grain feeding. The pastures were subdivided into three parts and the cattle rotated on the three areas at two to three week intervals. After 130 days on pasture they were placed in dry lot, brought to full feed, and finished to choice cattle weighing 1135 pounds in December. The fourth group, which was not considered in this study, was handled in a manner similar to System c except that the cattle were not rotated on pasture.

In computing annual costs and returns from the different feeder cattle systems the following procedures were used: The initial cost of the livestock sold in a particular year was computed by multiplying the purchase weight by the average Chicago price of the particular grade of feeder cattle in the appropriate month of the preceding year (48), adjusted for transportation and commission costs. The value of steers at the end of the feeding period was based on sale weight and the average Chicago price (48), adjusted for transportation and commission, for the appropriate grade and month of sale.

Investment in buildings and equipment per head were computed for 1948 on the basis of current costs of building materials and labor required to provide the minimum housing for each system of handling the feeders. These figures were adjusted for the other years by the index of building costs (47). Interest on the investment in livestock was figured at 6 per cent per year of the purchase value adjusted for the length of time the livestock were on the farm. Taxes were computed at 1.1 per cent of purchase value. Insurance was figured at .4 per cent of purchase value.

Feed requirements per steer under each system of feeding are shown in Table 7. The value of feeds per head was computed on the basis of the average Iowa price of corn the preceding October, the price of alfalfa hay the preceding November, and the price of cottonseed meal the preceding December (8). Pasture was evaluated on the basis of the current annual value of pasture per acre.

The value of labor per head was computed by multiplying the Iowa average daily wage rate each year (without board) (8) by the days of labor required under each system.

Costs and Returns from Beef Cows

Two systems of handling beef cows were considered. The differences in the two systems are in the disposition of the calf drop. Under System a the calves were sold each fall at a weight of 400 pounds as good-choice feeder calves. Under System b the calves were wintered through the first winter, pastured the following summer and fall, wintered through the second winter, and grazed through part of the following summer. They were then fed out in dry lot from July to October and sold as good grade cattle weighing about 1200 pounds. This latter system of handling the calves follows System V described in a Missouri study (46).

Table 7. Feed, labor, and certain miscellaneous requirements per steer for specific feeder cattle systems.

Item	Choice calves	Yearling steers (a)	Yearling steers (b)	Yearling steers (c)	2 yr. old steers
Corn, bu.[a]	63.00	53.71	47.46	37.0	48.0
Hay, tons[a]	.70	1.50	1.24	1.32	.48
Pasture, acres[a]	.06	.11	.90	1.39	.03
Protein supplement, cwt.[a]	2.6	1.48	.38	.73	1.7
Labor, days[b]	1.74	1.53	1.90	1.09	1.26
Veterinary[c]	.18	.18	.18	.18	.18
Value tractor & horse labor[d]	7.79	3.23	5.70	7.26	7.10
Investment in bldg. & equip.[e]	115.00	115.00	115.00	115.00	125.00
Annual bldg. & equip. costs[e]	3.33	3.33	3.33	3.33	3.33
Death loss, %	2.5	1.5	1.5	1.5	1.5

[a]Based on an Iowa Agricultural Experiment Station study (24).

[b]Based mostly on a study by Wilcox and others (52).

[c]Figures shown are for 1948. Previous years adjusted by index of daily wage rate (w/o board) (47).

[d]Figures shown are for 1948. Previous years adjusted by index of machinery costs (47).

[e]Figures shown are for 1948. Previous years adjusted by index of building costs (47).

Costs and returns per cow under System (a) are considered first. The investment per cow in beef cows was found by multiplying the average annual Chicago price per hundred pounds of good grade cows, less transportation and commission costs, by 1100 pounds. Figuring one calf retained for replacement for each eight cows and assuming one bull for twenty cows (35), the value of bulls and replacement stock per cow was computed at 13.3 per cent of the value of the cow. Interest on investment in cattle was calculated at 6 per cent. Taxes and insurance per cow was computed at 1.5 per cent of the livestock investment. The investment in building and equipment per beef cow was estimated at $125 for 1948 based on current costs of building materials and labor and adjusted by the index of building costs for other years. Interest on investment in buildings and equipment was figured at 4 per cent; depreciation was figured at 3 per cent.

Miscellaneous cash expenses (including veterinary, salt, supplies, etc.) per cow were estimated at 47 cents for 1948 (35). This figure was adjusted by the index of prices paid by farmers for equipment and supplies for previous years. The cost of tractor and horse power was estimated as $1.44 (35) per cow in 1948. This was adjusted by the index of prices paid for farm machinery for other years.

Days of labor per cow were estimated at 1.2 days per year for the beef cows and .3 day per cow for replacement stock and bull, making a total of 1.5 days labor annually per beef cow. The value of labor was calculated on the basis of the annual daily wage rate, without board.

Feed requirements per cow, including replacement stock and bull, were estimated at 6.7 bushel of corn, 1.15 tons hay, and 1.8 acres pasture (21). The values of these feeds were computed on the basis of the average price of corn the preceding October, the Iowa average price of alfalfa hay the preceding November, and the current annual pasture charge. Gross product per cow from the beef herd included 150 pounds of beef from cull cows (on the basis of a 90 per cent calf crop and replacement every 8 years) and 310 pounds of feeder calves sold per cow annually. The 150 pounds of beef from cull cows was evaluated on the basis of the annual average price of good cows at Chicago, less freight and commission costs. The value of the feeder calves was based on the October price for good-choice calves at Chicago, less transportation and commission costs.

Costs per cow under beef System b included the costs of maintaining the beef herd and the costs of raising the calves to finished cattle. Costs for maintaining the herd were identical with System a in all respects except that annual costs for a particular year were based on prices in the second preceding year. Costs of raising the calves for sale as finished cattle were calculated on the basis of prices in each of the three years covered by the production process. Thus the cost and returns figures for a particular year represent costs incurred over a three year period and returns in the year of sale. Taxes, insurance and miscellaneous costs were calculated at the same rates as used for the other feeder systems. Total feed requirements per feeder was estimated at 18.75 bushels of corn, 2.16 tons hay, 1.88 acres of pasture, and 105 pounds of protein supplement (46). Assuming a 90 per cent calf crop, 3 per cent death loss, and one-eighth of the calf crop retained for replacements, only .775 head of finished cattle were marketed per beef cow. Thus feed requirements per cow, in addition to requirements for maintenance of the herd, were estimated as 77.5 per cent of the above figures. Labor requirements per cow, in addition to that required for maintenance of the herd were estimated at 1.8 days. Building and equipment investments per cow were estimated at $115 for 1948 and adjusted for previous years by the index of building costs. Returns per cow were calculated on the basis of 921 pounds of (1189 x .775) good grade cattle sold in October.

Costs and Returns for Hog Feeding Systems

Seven systems of feeding swine were considered. Input requirements for one of these, System I, were based on the 1945 Iowa Capacity Studies (49). Systems IIa, IIb, and IIc, are representative of systems followed in an experiment conducted at the Beltsville Experiment Station by the U. S. D. A. (7). Hogs fed under System IIa received no forage; hogs fed under System IIb received 10 per cent of their feed in the form of chopped legume hay; those fed according to System IIc obtained 20 per cent of their feed as chopped legume hay. All three groups were fed in dry lot. Systems IIIa, IIIb, and IIIc were adapted from pasture studies carried out at the Iowa Agricultural Experiment Station (23). Each of these three systems (a, b, and c) used a different proportion of forage (pasture) in the ration. Hogs fed according to System (a) received no pasture; those following System (b) were fed grain equal to 3 per cent of their body weight while on good pasture; and those following System (c) were limited to grain equal to 1 per cent of their body weight while on pasture.

Costs for all seven systems were considered to be the same except with respect to feed, labor, and tractor and horse power costs. Miscellaneous costs, including insurance, taxes, veterinary, and other miscellaneous supplies, were estimated at $1.45 per pig for 1948 (23). This was adjusted by the index of prices paid by farmers for supplies for other years. Investment per pig in buildings and equipment was estimated to be $8.17 for 1948 (23) on the basis of building material and labor costs for providing the minimum buildings and equipment under corn belt conditions. Annual building and equipment costs were figured at $1.00 per pig for 1948 (23) and adjusted by the index of building costs for other years.

The annual investment in breeding stock per pig was calculated by multiplying 250 pounds (the average weight of the brood sow) by the average price of hogs in the preceding October and dividing the product by 6 (the assumed number of pigs saved per litter). The interest on investment in breeding stock per pig was calculated at the rate of 6 per cent per year and adjusted to a 9 month basis -- the length of time the sow would normally be kept. No depreciation was assumed on the breeding stock. Estimates of the days of labor and quantities of feed required per pig are given in Table 8. The value of labor was calculated by multiplying the days of labor required per pig by the Iowa annual average daily wage rate (without board). Corn was evaluated on the basis of the price of corn the preceding October. The value of hay required was figured on the basis of the average Iowa price of alfalfa hay the preceding November. The value of protein supplement was based on the price of soybean oil meal the previous December.

Table 8. Estimated feed, labor, and power requirements per pig for specific hog feeding systems.

Item	Hog feeding system						
	Iowa average[a] System I	Dry lot, System II[b]			Pasture, System III[c]		
		(a)	(b)	(c)	(a)	(b)	(c)
Corn, bushel	13.5	10.8	9.8	9.3	13.4	11.8	10.2
Soybean oil meal	.39	.91	.91	.92	-	-	-
Tankage	-	-	-	-	.83	.45	.42
Hay, tons	-	-	.035	.077	-	-	-
Pasture, acres	.004	-	-	-	-	.036	.022
Labor, days	.59	.59	.65	.70	.59	.65	.70
Tractor & horse power[c]	$1.33	$1.33	$1.46	$1.58	$1.33	$2.09	$1.80

[a]Based on unpublished data from Iowa Capacity Studies (49, p. 35).

[b]Based on study by Ellis and others in the U. S. Department of Agriculture (7).

[c]Based on unpublished data from Ia. Agr. Exp. Sta. Project 101 (23).

The hogs in each of the systems were considered sold at a weight of 225 pounds. Gross returns per pig from each feeding system was calculated by multiplying the average Iowa price of butcher hogs in the month of sale by 225 pounds. The hogs fed according to Systems IIa, IIb, IIc, and IIIa were considered sold in September; those fed according to Systems I and IIIb were treated as sold in October; and those fed according to System IIIc were considered sold in November.