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IDENTIFYING ECONOMIC AND MANAGEMENT PARAMETERS FOR THE USE OF SEPARATED DAIRY MANURE SOLIDS AS FREE STALL BEDDING FOR DAIRY CATTLE

By

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ABSTRACT

IDENTIFYING ECONOMIC AND MANAGEMENT PARAMETERS FOR THE USE OF SEPARATED DAIRY MANURE SOLIDS AS FREE STALL BEDDING FOR DAIRY CATTLE

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Economic justification of manure separation facilities occurs more readily on larger farms where increased bedding usage increases savings realized by replacing conventional bedding with dairy manure solids. Since a lower percentage of bedding savings of larger farms would go towards servicing the fixed costs of separation, variations in economic feasibility parameters (herd size-bedding price combinations) due to fluctuations in tax rate, rate of return and loan interest rate and repayment period are less pronounced than on smaller farms. Savings of $17.48 realized from a ton of bedding services variable costs and can be imputed to be the variable cost of a ton of dairy manure solids.

Overall, passive composting dairy manure solids was inadequate in preventing rapid regrowth of coliform bacteria once solids were placed in free stalls. Moisture seemed to be the determining factor as dairy manure solids with approximately 20% dry matter containing low levels of coliform bacteria (10^3 per gram bedding wet weight) contained over 10^6 coliforms per gram bedding wet weight within four days after application to free stalls. Duration of exposure of teats to bedding containing

high numbers of coliform bacteria may be a factor contributing to coliform mastitis. Sweeping dairy manure solids from the rear two feet of free stalls daily was apparently ineffective in preventing mastitis or maintaining low coliform numbers in our research.

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INTRODUCTION

The trend of Midwest dairy farms is an increased herd size, with cold free stall barns being the predominant housing facility. Confinement housing for dairy cows requires roughly three pounds of bedding per cow per day (Dairy Chore Reduction, 1978). Thus, cost and availability of adequate bedding as well as its compatibility with manure handling systems has become an increasingly important concern for dairy managers. Bedding should be easy to handle, maintain cow comfort and cleanliness and be constantly available at a low cost. Furthermore, it should be compatible with manure systems. Separating solids from liquid manure can be an economical alternative of producing a constant, local supply of bedding that is easy to handle and works well in dairy operations having liquid manure systems.

Economic evaluation of manure separation systems is difficult due to many varying costs and returns associated with different farms. Size differences among farms and differing prices paid for other types of bedding all affect the economic feasibility of separation. Reports by Keys et al. (1976) and Allen et al. (1977) conflict on cost effectiveness of separating solids from manure for bedding. Keys et al. (1976) reported dewatered manure solids cost over twice as much as sawdust to fill a free stall. Allen et al. (1977) found they could separate solids for bedding for less than half the cost of buying

sawdust. Thus, any economic justification of a separation system must look at all costs associated with production of manure solids.

Use of dairy manure solids in free stalls requires special management for proper results. The finely chopped organic nature of dairy manure solids supports coliform bacterial growth. (Smith et al. 1985) Counts of 10^6 coliforms per gram bedding (wet weight) have been shown by Bramley and Neave (1975) to be associated with an increased rate of new coliform infections. Carroll and Jasper (1978) and Bishop et al. (1980) showed that composting dairy manure solids effectively reduced coliform concentrations; however, coliform concentrations of composted solids increased to infectious levels shortly after the solids were placed in free stalls. Thus, proper management is important in reducing coliform mastitis and consequently realizing the benefits of separating solids from manure for use as free stall bedding.

The objectives of this research are, firstly, to determine parameters necessary to justify investment in facilities allowing separation of solids from liquid manure for use as bedding for dairy cattle and, secondly, to identify management techniques which enhance use of separated manure solids as dairy free stall bedding.

REVIEW OF LITERATURE

Free stall housing for dairy cattle requires bedding to encourage free stall use and maintain cow cleanliness (Larsen et al. 1976). Larsen et al. (1976) found that cows preferred deep bedded free stalls over concrete free stalls or concrete free stalls with rubber mats or indoor/outdoor carpet set on top. The authors also reported installation of bedding retainers with free stalls increased free stall use. Yungblut et al. (1974) reported cows preferred sawdust filled free stalls and were cleaner than cows using free stalls with indoor/outdoor carpeting, plastic mats or heated concrete.

Many bedding alternatives exist. Straw is more absorbent than most bedding on a dry weight basis (Battaglia and Mayrose, 1978) and is easily obtained. Long stemmed straw is difficult to handle in large quantities, is quickly dislodged from free stalls, and can plug manure pumps (Chore Reduction, 1979). Allen et al. (1977) reported that chopping straw decreased its removal from free stalls; however, use of chopped straw proved not to be cost effective. Furthermore, Larsen et al. (1976) reported chopped straw plugged slotted floors preventing manure passage and encouraged cows to lie on the resultant manure pack formed in alleys. These researchers also found 30% more chopped straw was needed than sawdust to keep free stalls bedded.

Larsen et al. (1974) reported sawdust and wood chips caused no problems with plugged slats or manure handling equipment. Sawdust works well on hard surfaced free stalls; however, difficulties with coliform mastitis have been experienced when used as a deep bedding (Chore Reduction, 1978). Allen et al. (1977) reported sawdust was an excellent bedding but cost and unavailability forced them to explore other alternatives.

Janzen et al. (1982) suggested crushed limestone as an economical bedding alternative. The high pH of crushed limestone inhibited bacterial growth thus reducing risk of mastitis. Crushed limestone was more expensive per unit of volume than either sawdust or wood shavings; however, substantially less crushed limestone was needed to keep free stalls bedded. The authors reported an overall savings in bedding costs of 30% by replacing sawdust or wood chips with crushed limestone. Primary concerns when using crushed limestone or sand as bedding are the abrasiveness to manure handling equipment and the tendency to settle out in manure pits and plug pipes (Chore Reduction, 1977).

Separating dairy manure solids from liquid manure, if the solids are properly composted and dried, provides an alternative bedding source (Carroll and Jasper, 1978). One drawback is the incompatibility of separation systems with dairy operations not having liquid manure systems. Separation systems require large investments and may not always be economical.

Economic Comparison of Bedding Materials

Average total costs of a new investment (acquisition costs and continuing costs) must be less than current costs of the existing system to economically justify any investment. Economic justification of separation facilities occurs when average total costs of separation facilities are less than average total costs of acquiring conventional bedding. Investment analysis using average annual costs does not adequately handle monetary flows over time. Harsh et al. (1981) report errors can be substantial if the period of analysis of an investment is ten or more years and interest or discount rate is relatively high. Under these circumstances, capital budgeting, which accounts for varying cash flows over time, is much more accurate.

Keys et al. (1975) conducted a budget analysis of three types of bedding; dewatered manure solids (29% dry matter), dehydrated manure solids (90% dry matter), and sawdust. Total energy, labor, and depreciation costs necessary to produce a metric ton of dehydrated and dewatered manure solids were calculated and compared with the cost of having a metric ton of sawdust delivered to their facility. Using this information, the authors then calculated it cost $2.63, $11.46 and $1.27 to fill a 122 X 213 cm free stall to a depth of 10 cm with dewatered manure solids, dehydrated manure solids, and sawdust, respectively.

Moore et al. (1977) evaluated "capital recovery costs," repair costs, taxes, insurance costs, savings from bedding production, energy costs, labor costs, and change in value of manure in an economic simulation study of manure systems. Capital recovery costs were defined as expenses of annual ownership of a piece of a piece of equipment or a

structure. Included were value of the item when purchased, value when salvaged, expected life and current interest rate or cost of money. All the above costs were used to determine average annual costs of separation. The authors concluded that under Oregon conditions an extra annual cost of $7389, $7132, and $6875 would be incurred by installing a separation system into a lagoon-flush system on 100, 200 and 300 dairy cow facilities, respectively. Thus, manure separation systems proved uneconomical under all circumstances.

White et al. (1978) evaluated herd sizes of 200 and 500 dairy cows in an economic simulation study of dairy waste systems in warm, humid; hot, humid; and warm, arid regions. The researchers analyzed all costs and returns on an annual per cow basis, and calculated annual returns on a per cow basis. Savings from use of separated manure solids as bedding were not considered. Annual costs of separation system were $15.52 per cow in a 200 cow herd and $11.02 per cow in the 500 cow herd.

The Relationship Between Bedding and Coliform Mastitis

The association of finely chopped, organic bedding with acute mastitis caused by coliform and streptococcal bacteria has presented another drawback with the use of dairy manure solids for bedding (Smith et al. 1985). Smith et al. (1985) report coliform mastitis is capable of serious and explosive manifestations; especially in uninfected, high producing, mature cows in the first 90 days of lactation. Cows healthy at calving, with bacteria free quarters, have been known to develop peracute coliform mastitis and die within ten hours (Jasper et al., 1975).

Coliform bacteria are Gram-negative, lactose fermenting bacteria. Escherichia coli is the predominant species of coliform bacteria causing mastitis in dairy cows followed by Klebsiella pneumonia and Enterobacter aerogenes (Jasper et al., 1975). There are many different strains of coliform bacteria which vary widely in pathogenicity and infectiousness to the udder (Eberhart et al., 1977).

Coliform bacteria, upon introduction to a susceptible udder, proliferate quickly (from as few as 50 bacteria to 26 million per ml in 10 to 15 hours (Coliform Research Committee, 1975) until mammary defense factors can accumulate to phagotize the coliform bacteria. Phagotized coliform bacteria release an endotoxin which produces an inflammatory response in the udder. This endotoxin can, in more serious cases, enter the blood stream causing the toxemic signs of acute coliform mastitis (Schalm et al., 1971).

Coliform infections are not highly contagious; that is, transmission from one quarter or cow to another quarter or cow is unusual (Eberhart et. al., 1977). Coliform bacteria are poorly adapted to survival on normal teat skin and, thus, colonization on teat skin or teat canal by this bacteria is uncommon (Bishop et. al., 1981). Since there is little evidence that colonization occurs before infection, transient teat end contamination rather than colonization predicates coliform mastitis (Bramley et.al., 1975).

Thirty three percent of cows with teats dipped immediately before milking or immediately after milking with a broth containing 10^{8} colony forming units of Escherichia coli per ml became infected with E. coli (DeHart et al., 1975). Cows not dipped with the Escherichia coli broth

at milking had no coliform infections. DeHart et al. (1975) concluded that teat exposure to coliform bacteria between milkings can predicate coliform infections though time of exposure of the udder to the organisms was unimportant.

Rendos et al. (1975) monitored bacterial populations in sawdust, wood shavings, and wheat straw and on teat ends of cows placed on these bedding. Cows on sawdust bedding had greater teat end populations of coliform bacteria, while cows on straw bedding had greater populations of streptococcal bacteria. Teat end populations of various organisms appeared to be related to bacterial populations in bedding. From their data, Rendos et al. (1975) suggested a possible relationship between numbers of organisms reaching the teat end and incidence of new intramammary infections.

Bramley and Neave (1975) studied the effects of coliform concentration of bedding in five different yards on the rate of new coliform infections. Four situations where coliform numbers were between 10^4 and 10^5 coliforms per gram bedding wet weight resulted in no new coliform infections of cows kept in these yards. Coliform mastitis did occur in cows kept in a yard where coliform counts in bedding approached 10^7 coliforms per gram bedding wet weight. The authors concluded that a relationship exists between coliform levels in bedding materials and the rate of new coliform infections.

In contrast, Natzke and LeClair (1975) compared cows on sawdust where Escherichia coli concentrations were maintained at 10^6 coliforms per gram bedding wet weight with control cows bedded on dry shavings. Cows were in early lactation ranging in production from 31 to 40 kg per day. Cows on contaminated bedding experienced no new coliform infections despite increased contamination of teat ends and low average cow somatic cell concentrations ranging from 233,000 to 428,000/ml. Thomas et al. (1983) found coliform bacteria concentrations were independent of coliform mastitis at his facility. The authors noted a relation between stage of lactation and incidence of coliform mastitis as heifers had lowest levels of coliform mastitis and cows in early to mid-lactation had the highest coliform mastitis incidence. These reports suggest coliform mastitis might have multiple causes besides exposure of udders to high coliform bacteria numbers in bedding.

Schalm (1975) claims milk of uninfected cows has a natural reduction of mammary defense factors, such as leukocytes and polymorphonucleocytes (PMN's). In fact, the Coliform Research Committee (1975) reports it is impossible to superimpose a coliform infection on another infection due to presence of these defense factors. Carroll (1977) cites 500,000 leukocytes per ml is necessary in foremilk to adequately protect udders from invasion by coliform bacteria. Leukocyte reduction can result from many factors.

Carroll (1977) showed stress causes an increase incorticoid levels and a corresponding reduction of leukocytes predicating coliform mastitis. Stress from calving, heavy feeding, and high milk production are reasons early lactation cows are prone to coliform mastitis (Carroll, 1977). Smith et al. (1985) reports stress from hot, humid Ohio summers may have caused the increase in cases of coliform mastitis at this facility during that period.

Physiological factors associated with periparturient cows can also predicate mastitis. Carroll (1977) cites existing PMN's are partially inactivated by fat and case in newly present milk of fresh cows. Also, lactoferrin, another protective factor in the mammary gland, disappears just before parturition leaving periparturient cows more susceptible to coliform mastitis (Neave and Oliver, 1962).

Lastly, nutritional factors have been blamed for increased coliform infections. Weigt (1980) observed many coliform infected cows exhibited mild secondary acetonemia. This was attributed to high grain, low fiber diets fed to fresh cows. Consequential dysfunction of the leukocyte system could have predicated coliform mastitis. Deficiencies of Vitamin E and selenium have also been implicated. Smith, et. al. (1984) found dairy cows deficient in Vitamin E exhibited an elevated incidence of clinical mastitis. Coliform bacteria and species of streptococci other than Streptococcus agalactiae were isolated from 70% of these clinical mastitis cases.

Composting

Composting is an aerobic process based on microbial self-heating in organic wastes (Finstein et al., 1983). It is a dynamic process which can reach temperatures of 60-70°C. (Finstein et al., 1975). Temperatures of 60-70°C during composting for three days will destroy pathogenic bacteria (Wiley and Westerberg, 1969). Composting also serves to dry separated manure solids as most of the heat generated by composting is lost as moisture (Willson, 1971).

Finstein et al. (1986) reports composting involves conversion of organic matter (volatile solids) to CO_2. However, evaluation of completeness of composting by measuring decrease in volatile solids (volatile solids = total solids - ash) lacks sensitivity due to the diversity of organic compounds present, low percentage of ash in compost, and heterogeneity of most composts (Finstein et al., 1986).

Willson (1971) reports that type and rate of composting is primarily influenced by aeration, amount and type of bedding present, settling, and moisture percentage. Long stemmed bedding in appreciable amounts enhances oxygen diffusion by creating pores. Settling and excess moisture (greater than 70 to 75%) can limit porosity of compost piles which restricts oxygen diffusion and, thus, inhibits composting. Mixing of compost piles counteracts settling and water migration by unplugging pores to allow increased oxygen diffusion and better composting (Willson, 1971).

Carroll and Jasper (1978) reported composting of dairy manure solids for several months effectively reduced coliform concentrations in these solids. The authors reported composting temperatures and moisture percentages reflected ambient conditions; wet and cold during their California winters and hot and dry during summers and that composting temperatures increased with increased depth into the pile (0 cm, 15 cm, and 60 cm). Consequently, coliform concentrations are lower in the summer months and towards the middle of the pile. Bishop et al. (1980) monitored temperatures and took random samples from piles of dairy manure solids as they composted for twelve days. Initial concentrations of coliform bacteria were approximately 2×10^7. The authors found temperatures near the centers of these piles rapidly increased, peaking at 71.5°C in twelve days and reducing average coliform concentrations during this time to less than the 10^6 coliform per gram bedding wet weight level found by Bramley et al. (1975) to cause new infections of coliform mastitis.

Free Stall Management

Once dairy manure solids were placed in free stall, Bishop et al. (1980) report, coliform concentrations increased above 10^6 coliforms per gram bedding (wet weight) within 14 days. The authors attributed this to the optimal environment offered by dairy manure solids coupled with increased temperature and moisture associated with cow contact. Zehner et al. (1986) inoculated sterilized bedding samples of dairy manure solids, fine hardwood chips, chopped newspaper, softwood sawdust, and chopped straw with Escherichia coli, Klebsiella pneumoniae, and Streptococcus uberis. The researchers found that when these samples were incubated at 37°C for five days, growth of the coliform bacteria occurred quickest in the dairy manure solid samples.

Bramley et al. (1975) monitored coliform growth in used sawdust bedding samples incubated under laboratory conditions at varying temperatures. He found that temperatures of 30°C and 44°C produced an increase in coliform numbers, 22°C maintained initial numbers and 50°C eventually killed the organisms. Thus, cows coming in contact with bedding in free stalls could cause bedding temperatures to increase above 22°C which could promote coliform regrowth.

Francis et al. (1981) monitored temperatures, moisture percentages and coliform concentrations of bedding in free stalls of high and low producing dairy cows. The researchers reported higher producing cows lying in free stalls caused free stall temperatures to increase 5°C more than low producing cows. Bedding moisture content was lower in free stalls of high producers; yet, coliform populations were higher indicating a potential positive relationship between free stall temperature and coliform growth rate in bedding.

Janzen et al. (1982) unsuccessfully tried to alter this optimal environment by adding crushed limestone to dairy manure solids at a rate of one part limestone to one part dairy manure solids. They bedded free stalls with dairy manure solids, crushed limestone and this dairy manure solid-limestone mixture. They found coliform bacteria, which are sensitive to changes in pH, grew less in crushed limestone bedding than bedding containing dairy manure solids. There was, however, no difference in coliform counts between dairy manure solid bedding and the dairy manure solid-limestone bedding.

Gram negative bacteria such as coliform bacteria are very susceptible to drying, suggesting moisture plays a role in regrowth of coliform bacteria (Carroll, 1977). Allen et al. (1977) dried dairy manure solids to at least 60% dry matter via composting in their climate. This allowed use of dairy manure solids as bedding without the associated fear of coliform mastitis which the authors were unable to do when dairy manure solids were 25% dry matter. Smith et al. (1985) cited elevated temperature and humidity of Ohio summers to explain increased coliform bacterial growth in dairy manure solids used during this season. Thomas et al. (1983) reported increased coliform growth in bedding during wet weather. These researchers attributed this rise to increased moisture associated with the humidity. Bramley (1985) found leakage of milk from the udder onto bedding resulted in rapid coliform growth in that area. Daily removal of the rear meter of bedding from free stalls where moisture tended to accumulate resulted in a 100 fold reduction in coliform numbers. Dodd et al. (1984) investigated a 100 cow dairy farm with 146 coliform mastitis cases a year. Sawdust used as bedding in free stalls had damp patches where udders touched. Free stalls were sanitized and bedding in backs of free stalls was swept out and replace daily. This procedure reduced incidence of coliform mastitis to 17 cases per year.

MATERIALS AND METHODS

Research was conducted at the Kellogg Biological Station Dairy Center starting in early spring and going through the summer. Cows were housed in a cold free stall barn with a center drive through feeding area and flush manure system. Four sets of 32 free stalls maintain 117 lactating dairy cows with a 365 day herd average of 18,500 pounds of milk per cow. Somatic cell count for the herd was 200,000 cells/ml at the start of the research. Free stalls are four feet wide and seven feet long and have a ten inch curb. Neck rails set 18 to 22 inches from the front prevent cows from depositing manure in free stalls. Two sets of 32 free stalls are dirt based. One set of these dirt based free stalls had tires buried in one half of the free stalls to prevent pitting. The other two sets of 32 free stalls are concrete based with a mat filled with straw or straw and wood shavings set on top. The drive through feeding area divides free stall sets so that one dirt and one concrete based free stall set are at each side.

Alleys are flushed at regular intervals to remove manure. Resultant liquid manure flows to pick up channels and then flows via gravity to a collection pit. The collection pit is under a separate building which houses a stationary sieve separator and four bins for storing dairy manure solids.

A 25 hp pump agitates the liquid manure (approximately 3.5% dry matter) and pumps the manure to the screen. As liquid manure passes down the screen, the liquid portion goes through the holes while solids (approximately 18% dry matter) are washed down the screen by liquid remaining on the surface. A roller press at the base of the separator screen further squeezes out moisture. Effluent (approximately 1% dry matter) is pumped to an outside lagoon.

Dairy manure solids are conveyed to one of four 15 feet by 15.5 feet storage bins for a one week interval. Piles were kept to a height of four feet. This process is continued among the four bins allowing dairy manure solids to compost three weeks before use as a free stall bedding on a weekly basis. Composting dairy manure solids were mixed weekly by loading solids onto a mixing wagon. Solids were mixed for approximately five minutes then unloaded back into the appropriate bins.

Objective 1

The objective of the first part of this research was to determine parameters necessary to justify investment in facilities allowing separation of solids from liquid manure for use as free stall bedding for dairy cattle. Manure separation becomes economically feasible when average total cost of bedding with manure solids becomes less than average total cost of using conventional bedding such as straw or sawdust. In this evaluation, all costs were put in terms of net present values (Capital Budgeting) as this method accounts for varying money flows over time and consequently is useful in investment analysis. A

Lotus spread sheet was used for computer analysis as this is instrumental in budgeting work (Hughes and Ochi, 1984).

Costs and returns were assigned to best mimic actual acquisition of separation facilities. However, we assumed all income and expenses were incurred at the end of each year. In practice this is not true; however, adjustments necessary to account for this are insignificant (Harsh et al., 1981). It was assumed a loan would be taken for the total investment and payments amortized monthly. Length of loan and interest rate would be varied to observe their effects on investment feasibility. Insurance, repairs and taxes were estimated at 1% of initial cost of buildings (assumed by us to be 1/3 of investment) and 3% of initial cost of separator and allied components per year for machinery (assumed by us to be 2/3 of investment) (Oregon State Extension Service, 1982). Electricity use was estimated at 63.42 KW-HR per cow per year (Oregon State University Cooperative Extension Service, 1982) and priced at $.08 per KW-HR (approximate farm rate for Michigan). This results in an annual electric expenditure of $5.10 per cow. Labor was priced at $4.00 per hour and estimated at .91 hours per cow per year (Oregon State Cooperative Extension Service, 1982). Thus, labor, also a function of number of cows, is priced at $3.64 per cow annually.

Returns from investment in separation facilities consisted primarily of savings of bedding costs. Bedding use is a function of number of cows and price paid for previous bedding on a per ton basis. A half ton of bedding is needed annually to bed a 1400 pound dairy cow (Chore Reduction, 1978). Tax write offs of all expenditures except principal payments were another return. A seven year double declining balance depreciation was used to write off investments in machinery and buildings up to their salvage values. Salvage value of building after ten years was estimated at 30% of price paid for buildings and salvage value of machinery was 10% of price paid for machinery (Oregon State University Cooperative Extension Service, 1982). Consequently, depreciation and repairs, interest and taxes are in terms of percent investment.

A rate of return (discount rate) was needed to account for the time value of money. An inflation rate of 1.55% was used to estimate price increases in insurance, repairs, taxes, electricity and bedding savings. This figure was estimated from the average inflation of prices paid by farmers from 1981 to 1985 (Agricultural Statistics, 1985). Once inflation adjustments were made and the required rate of return, tax rate and loan schedule were input, all cash flows would be in terms of percent of investment, number of cows, and price paid per ton bedding.

Bedding savings, the largest return from this investment, is a function of amount bedding used, 1/2 ton per cow, and price paid per ton bedding. Depreciation, making up the remaining returns, is a function of investment.

Expenditures consist primarily of the loan taken for the investment which is also a function of investment. The variable costs are electrical usage at $5.10 per cow and labor at $3.64 per cow.

Justification of a separation system occurs when costs of acquiring facilities equal returns from the investment. This is illustrated below where cost of separation (i.e. a loan for acquisition, insurance, repairs and taxes, and cost of operation of facilities) equals returns

from separation (i.e. savings from not buying bedding and depreciation credit from the separator acquisition).

Loan expenditures + Ins., Rep'rs, Taxes + Variables Costs
= Bedding savings + Depreciation credit

These parameters are net present values of cash flows over a ten year life investment. Putting parameters that are functions of investment on one side and putting parameters that are functions of number cows of bedding prices on the other side gives us the following equation:

Loan expenditures + Ins., Rep'rs, Taxes - Depreciation credit
= Bedding Savings - Variable Costs

This can be put in a mathematical formula by setting loan expenditures and tax savings as a percent (A) of maximum investment (*) and setting this equal to bedding savings (.5XY) minus variable costs (5.1X + 3.64X) where X equals number of cows and Y equals price paid for previous bedding. Both bedding savings and variable costs would be multiplied by a constant (B) since factors such as time, inflation and taxes affect these parameters equally.

$$A(*) = (.5XY - 8.74X)B$$

Thus, maximum investment (*) equals B(.5XY - 8.74X)/A. This can be put in other terms as follows where K equals B/A.

$$(*) = KX(.5Y - 8.74)$$

Different values for X and Y were input to calculate maximum investment (*) a farmer with X amount of cows and paying Y amount for bedding could spend and receive the input return on his investment. Effects of varying tax rates, rates of return and loan schedules on economic feasibility were also investigated as they affect the constant, K. The below work sheet was used to analyze the mentioned parameters.

DMS INVESTMENT ANALYSIS

```
1.  What is your yearly cost for bedding?
            If known enter here ------------------------>        0
              and go to step 2, then step 6.
            If unknown, enter 0 and go to step 2.

2.  How many milking and dry cows do you have? ---------->      500
            Based on University data which estimates 1/2 ton
    bedding per 1400 lb cow is needed annually;       250
    tons bedding is used in your milking herd annually.

3.  Enter your estimate of tons bedding used annually.--->      250

4.  What price do you pay for bedding ($/ton)?  --------->       20

5.  Using the above information in 2, 3, and 4:

              $5,000.00 is estimated spent annually  for bedding.


6.  Rate of return expected from this investment(%)------>       10
      (Ten year treasury note produces 7.71%)
7.  Tax bracket(%)                                --------->       25
       (25% is 'average'for a 100 cow operation)
8.  Expected Annual Loan Interest Rate (%)--------------->       12
9.  Expected Loan Repayment Period (months)-------------->       60
```

ASSUMPTIONS

Equal monthly loan payments of $252.16
Two thirds investment goes to separator and allied components
One third investment for buildings
Seven year double declining balance depreciation allowance
Inflation is 5.5% per year
Labor at 4.00/hr

$11,335.76 maximum can be justified for installing separation facilities in your operation

Objective 2

The objective of the second part of this research was to determine management practices which enhance use of separated manure solids as free stall bedding for dairy cattle. Management practices studied focused on minimizing coliform growth in dairy manure solids used to bed free stalls. Effects of composting, daily removal of bedding from the back two feet of free stalls, free stall base (concrete versus dirt), and production levels of cows frequenting free stalls were studied.

1. Experiment 1

Free stalls were bedded weekly with dairy manure solids at a rate of approximately 90 pounds dairy manure solids per free stall (one six foot skid loader bucket of dairy manure solids per four free stalls). All possible interactions of the above mentioned parameters were studied by depositing composted dairy manure solids in the sixteen free stalls closest to the dead end alley and depositing dairy manure solids fresh from the separator in the remaining sixteen free stalls farthest from the dead end alley and depositing dairy manure solids fresh from the separator in the remaining sixteen free stalls farthest from the alley. Fresh dairy manure solids were less than four days old, yellowish in appearance and showed no signs of heating. Composted dairy manure solids were piled for twenty days and were undisturbed during composting in the this first trial. The sixteen free stalls located farthest from the feeding alley had dairy manure solids removed from the back two feet daily while dairy manure solids in sixteen free stalls closest to the feeding alley were allowed to accumulate.

The herd was divided into two groups of cows based on production level. Fifty eight cows averaging 72 pounds of milk per day were in the high production group and 57 cows averaging 43 pounds of milk a day were placed in the low production group. Each production group of cows was equally divided by production so half of each production group was on dirt based free stalls and the other on concrete based free stalls. This scheme is illustrated below.

Eight samples of dairy manure solids were collected from each set of free stalls. All samples of this bedding were taken approximately eighteen inches in from the rear curb of each free stall. Two samples were taken from free stalls where fresh solids were allowed to accumulate, two from free stalls where composted solids were allowed to accumulate, two from free stalls were composted solids were swept from the rear two feet of free stalls daily and the last two from free stalls where fresh manure solids were swept daily. Two sets of samples were to be taken weekly, once when free stalls were initially bedded with dairy manure solids and one week later before free stalls were bedded again.

Samples (approximately 100 grams each) were placed in sterilized sample bags, placed on ice and transported to the laboratory to be tested for coliform numbers, moisture percentage, and ash concentration. Coliform numbers were determined within 24 hours from the time that samples were collected. Coliform numbers of a particular sample did not vary when tested at two or twelve hours after collection.

Coliform numbers were determined using the most probable number method with a lauryl tryptose broth as described in Standard Methods

for the Examination of Water and Waste Water Text (1985). This procedure was adapted for our purposes by Dr. Frank Peabody, Department of Microbiology, Michigan State University as follows: One gram of dairy manure solids was added to 99 ml sterile distilled water to obtain 100 ml of solution (weight/volume). This solution was then shaken manually for approximately fifteen seconds and then added, one milliliter at a time, to eight sets of five fermentation tubes; each set of fermentation tubes being inoculated with a solution containing 1/10 the concentration of dairy manure solids then received by the preceding set. These tubes were incubated at 35°C for 48 hours. Positive results were indicated by gas production in the tubes. Coliform numbers were calculated by observing number of positive results in each dilution's fermentation tube set. Results indicated number of coliform bacteria per gram bedding wet weight of dairy manure solids. To verify coliform number, random manure solid samples were cultured by the Michigan State Veterinary Microbiology Laboratory.

We recorded beginning and ending moisture percentages of dairy manure solids to observe their effects on coliform growth. Moisture content was determined by weighing samples on dried and tared weighing containers then placing these samples in a drying oven at 105°C for 24-36 hours. Percent moisture was calculated by comparing initial and ending weights of dairy manure solid samples. (Percent moisture = 1 - dried weight/initial weight).

Ash percentages were determined by placing dried samples in a muffle furnace set at 550°C for at least six hours. Ashed samples were then allowed to cool overnight before being placed in a drying

oven at 105°C for 24 hours. Percent ash was calculated by comparing initial dried sample weight with weight of resultant ash (percent ash = weight ash/weight dried sample).

2. Experiment 2

The objective of this experiment was to better understand composting's role in effectively reducing coliform concentrations in dairy manure solids. Composting temperatures were monitored daily by inserting thermocouples one, two, three and four feet into the center of 15 foot by 6 foot by 4 foot high piles of composting dairy manure solids. Ambient temperatures were also monitored. Dairy manure solid samples were taken by digging to these different depths just before the pile was mixed. Coliform numbers were observed in the samples to determine the effect of temperature on coliform survival. Internal temperatures were again measured after mixing of the piles.

Each pile was mixed in a mixer wagon before use and eight random samples were taken as dairy manure solids were being placed in free stalls. These samples were analyzed for coliform numbers and moisture percentages. Average coliform concentration and moisture percentage were plotted over time to analyze effects of a weekly pile-mixing regime and ambient temperature.

3. Experiment 3

The objective of this experiment was to identify if daily sweeping of the back two foot of free stalls affected incidence of coliform infections in lactating cattle. Two sets of 32 concrete free stalls

with mats were used for this experiment. Bedding (composted manures solids only) was initially applied at a rate of 90 pounds per free stall. This was not sufficient to maintain adequate bedding for one week so application rate was doubled to 180 pounds per free stall. One set of free stalls housed 30 cows averaging 78 pounds of milk per day and thirty cows averaging approximately 34 pounds of milk a day were housed on the other set of free stalls. Cows in each set of free stalls were separated into two groups of equal average milk production by a chain dividing each set of 32 free stalls into two subsets of 16 free stalls. Manure solids were swept from backs of one of the subsets of free stalls in each free stalls set daily while dairy manure solids in the other free stall subsets were allowed to accumulate.

Four bedding samples from four different stalls (eighteen inches from rear curb) were collected from each subset of 16 free stalls for a total of sixteen samples. These dairy manure solid samples were taken when dairy manure solids were first applied and one week later just before addition of fresh manure solids. These samples were tested for coliform numbers and moisture percentage. Samples were also taken from the front of stalls for comparison with samples taken from the rear of stalls to analyze possible benefits of sweeping off the rear two feet of free stalls.

In addition, effects of daily sweeping the back two feet of bare cement free stalls on coliform numbers when free stalls were subject to decreased animal contact was also examined. Approximately 35 heifers ranging from 800 to 1100 pounds were bedded on these free stalls. These heifers also had access to an outside lot when weather permitted,

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further decreasing heifer contact with bedding placed on these free stalls.

The free stall set containing heifers had forty 3.5 foot by 6 foot concrete free stalls. Initially, an approximated 170 pounds of composted dairy manure solids were used per free stall to maintain manure solids in free stalls for a period of two weeks. Later this was reduced to approximately 110 pounds of manure solids per free stall. Dairy manure solids were swept daily from the back two foot of free stalls located on one side of the free stall set. Dairy manure solids were allowed to accumulate on free stalls on the other side of the free stall set. Samples were collected from the rear of four free stalls in each side of the free stall set for a total of eight samples per collection period. Samples were taken from free stalls when dairy manure solids were first applied to free stalls, seven days after application and two weeks after application (prior to addition of fresh manure solids). These samples were tested for coliform concentration and moisture percentage.

A three way factorial design was used to statistically analyze effects of free stall base, composting, sweeping out the back two feet of free stalls and production level on final coliform concentration. Lastly, beginning moisture percentages, ending moisture percentages, beginning coliform concentrations and final coliform concentration were statistically correlated. This showed the effect each parameter has on final coliform counts to determine what parameters could possibly be altered to minimize coliform concentrations in free stalls.

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RESULTS

Parameters necessary to justify investment in facilities allowing separation of solids from liquid manure for use as free stall bedding are described by the below equation. In this equation, (*) = maximum investment, X = number of cows, Y = price paid for previous bedding and K is a constant which accounts for other parameters.

$$(*) = KX(.5Y - 8.74)$$

As can be seen, number of cows is directly related to maximum investment at a rate of (*) = XT where T replaces K(.5Y - 8.74). Graph one illustrates the effect of increasing herd size on maximum investment under four different bedding prices. Tax rate, return on investment, loan rate and loan length are held constant at 25%, 10%, 12% and 60 months, respectively. The line at $30,000 is our approximation of the minimal cost of installing a separation system.

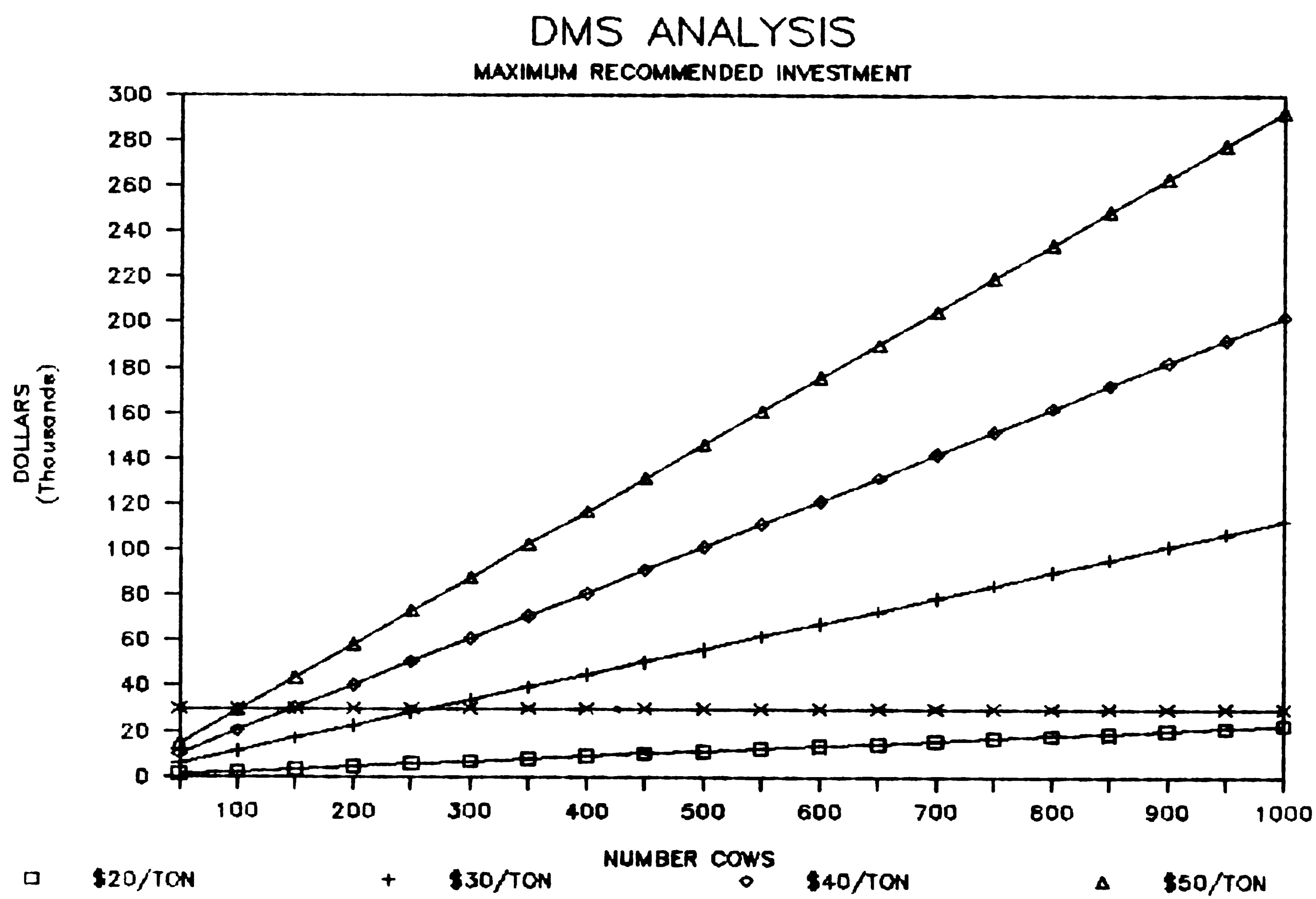

DMS ANALYSIS
MAXIMUM RECOMMENDED INVESTMENT
DOLLARS
(Thousands)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
100
200
300
400
500
600
700
800
900
1000
NUMBER COWS
$20/TON
$30/TON
$40/TON
$50/TON

Figure 1

As expected, herd size is directly related to maximum investment as doubling herd size doubled maximum investment. Also, under these parameters, farmers obtaining bedding for $20 a ton or less cannot justify separation facilities, even with a herd of 1000 cows.

Analysis of the previous equation,

$$(*) = KX(.5Y - 8.74)$$

shows bedding cost is not as directly related to maximum investment as herd size though its impact is more dramatic. Further observing the above equation shows when $.5Y = 8.74$ or, in other words, when bedding price (Y) equals $8.74/.5 or $17.48, maximum investment equals 0. This holds true for all size herds and input parameters.

Graph 2 illustrates this idea. Effects of bedding costs on maximum investment is examined using four different sized herds. Once again, tax rate, return on investment, loan rate and loan length were fixed at 25%, 10%, 12%, and 60 months, respectively. A line drawn at $30,000 illustrates our estimation of costs of obtaining separation facilities.

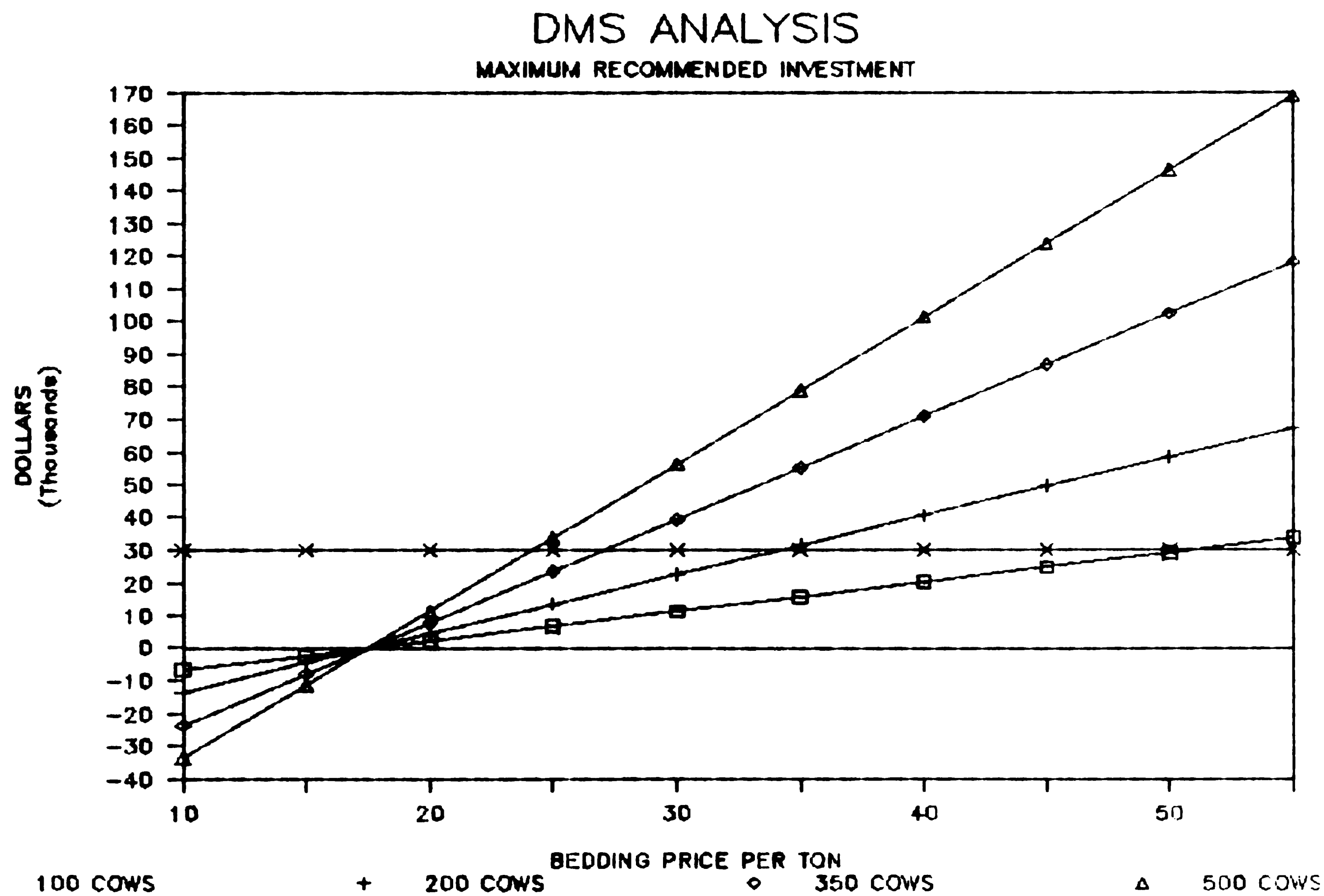

DMS ANALYSIS
MAXIMUM RECOMMENDED INVESTMENT
DOLLARS
(Thousands)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
10
20
30
40
50
BEDDING PRICE PER TON
100 COWS
+ 200 COWS
◇ 350 COWS
Δ 500 COWS

Figure 2

As expected, when bedding costs are $17.48 per ton, maximum investment equals 0 with all herd sizes. Bedding costs lower than this do not generate enough savings to cover variable costs. Consequently a negative maximum investment is realized.

Graph 3 plots herd size with bedding price to determine combinations of parameters necessary to justify spending $30,000, $50,000, and $70,000 in separation facilities. Tax rate, rate of return, loan interest rate and loan length are once again fixed at 25%, 10%, 12%, and 60 months.

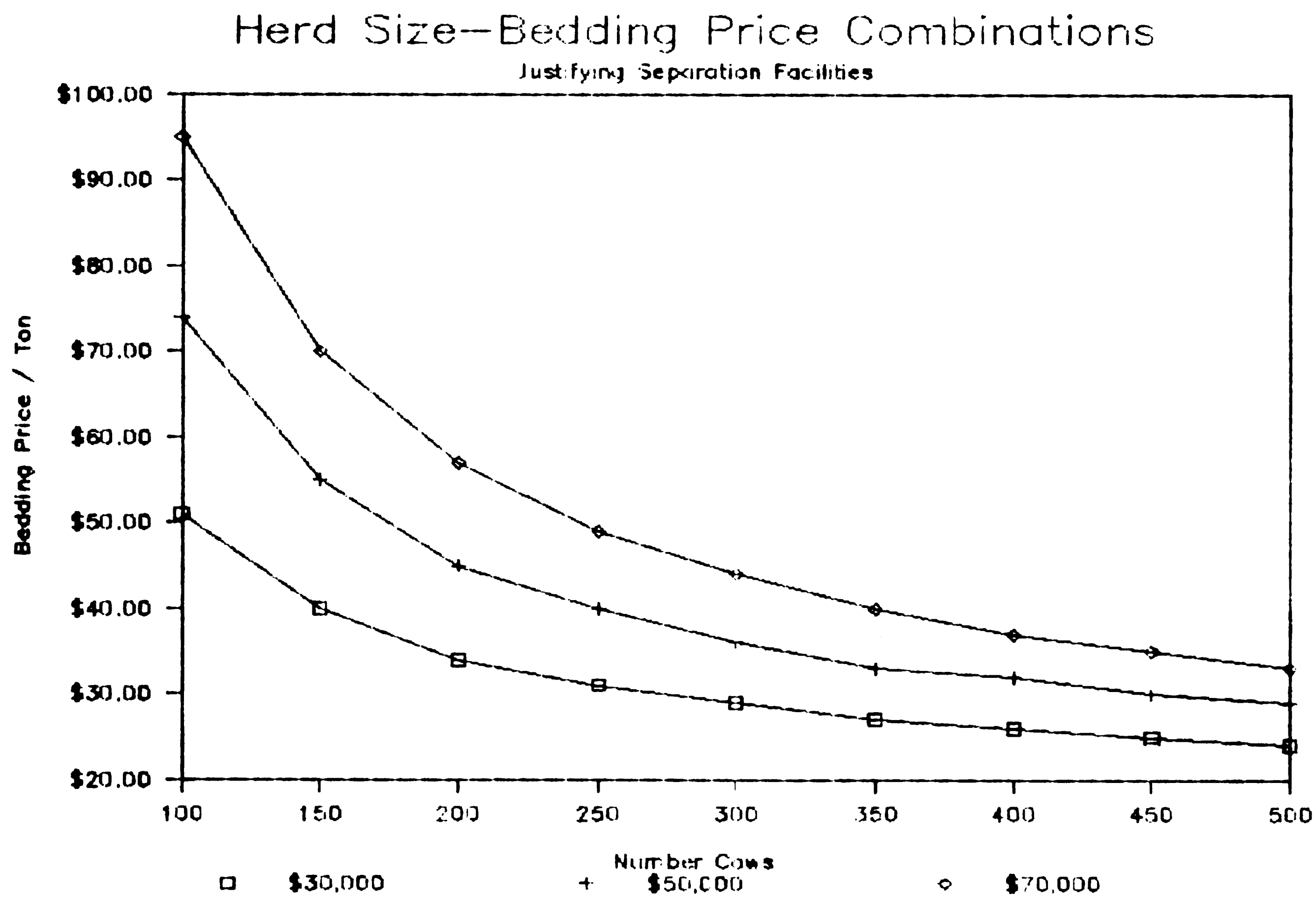
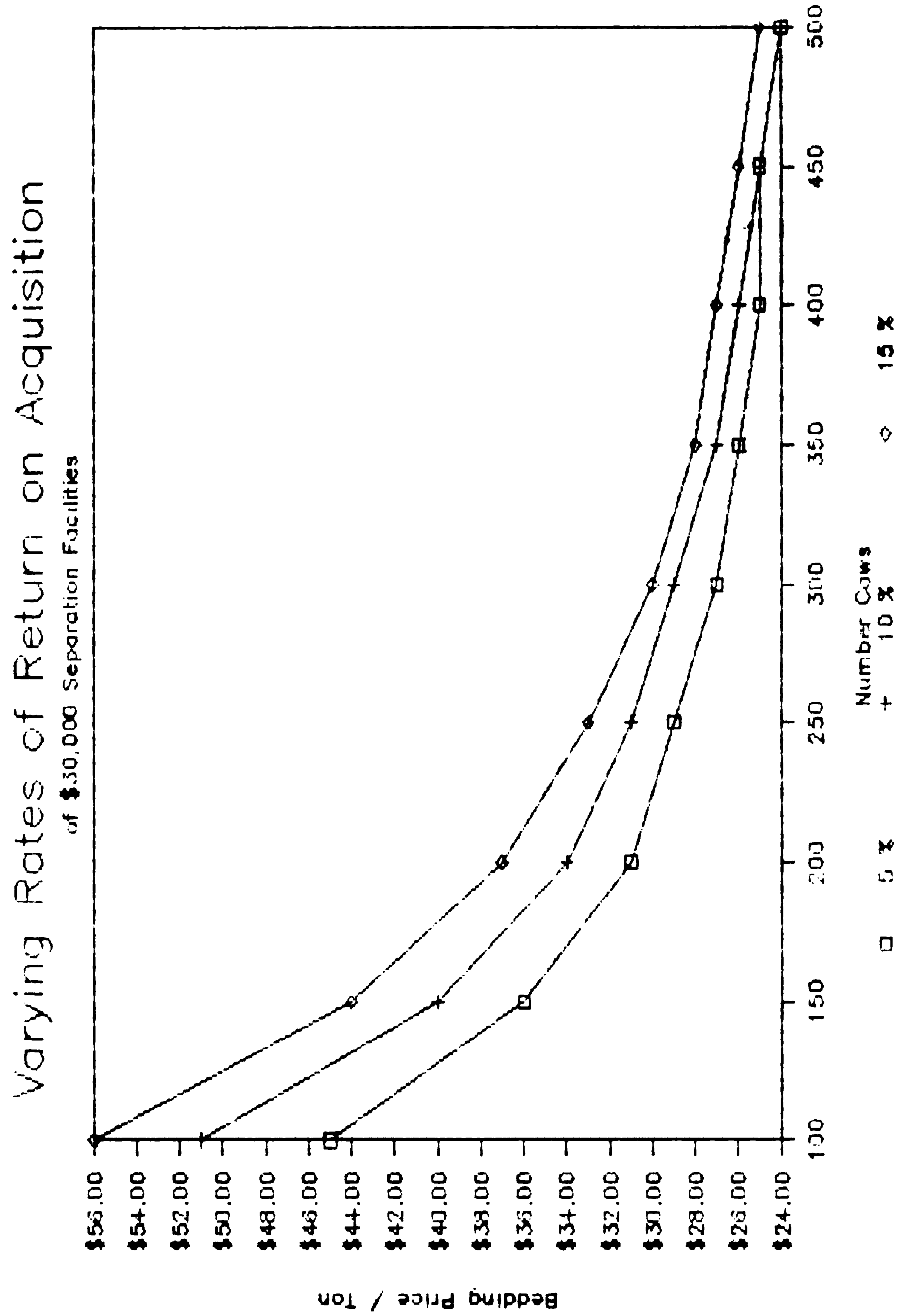

Herd Size—Bedding Price Combinations
Justifying Separation Facilities
Bedding Price / Ton
$100.00
$90.00
$80.00
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
100
150
200
250
300
350
400
450
500
Number Cows
$30,000
$50,000
$70,000

Figure 3

As can be seen, as herd size increases, bedding price necessary to justify investing in separation facilities decreases. This curve approaches the $17.50 bedding price.

Tax rates, return required on investment, loan interest rate and loan repayment period all affect required bedding price-herd size combinations necessary to justify investing $30,000 in separation facilities. Graphs 4, 5, 6, and 7 look at effects of varying each parameter on the feasibility of a $30,000 separation facility when the other parameters are fixed as described previously.



Varying Rates of Return on Acquisition
of $30,000 Separation Facilities
Bedding Price / Ton
$56.00
$54.00
$52.00
$50.00
$48.00
$46.00
$44.00
$42.00
$40.00
$38.00
$36.00
$34.00
$32.00
$30.00
$28.00
$26.00
$24.00
100
150
200
250
300
350
400
450
500
Number Cows
5 %
+ 10 %
◇ 15 %

Figure 5

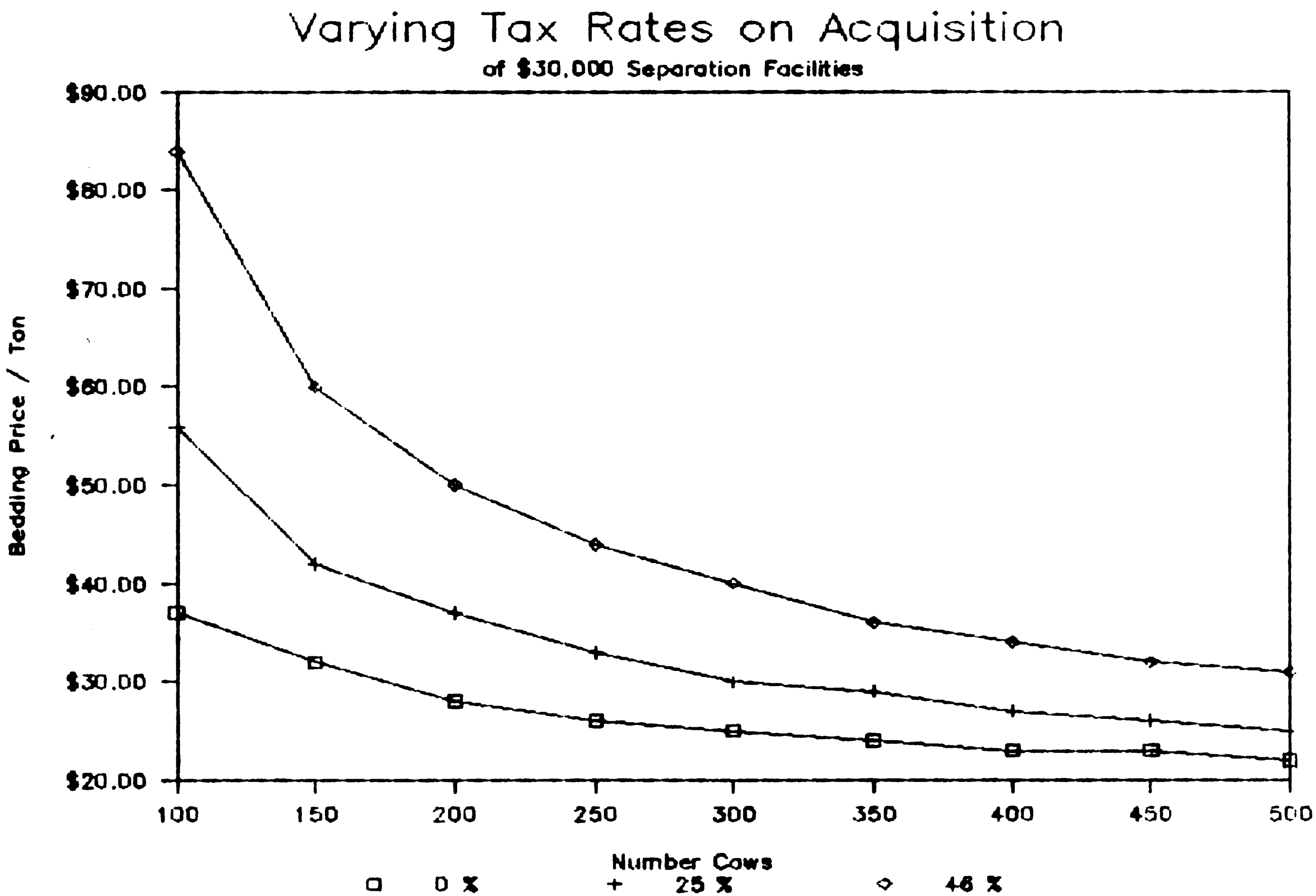

Varying Tax Rates on Acquisition
of $30,000 Separation Facilities
Bedding Price / Ton
$90.00
$80.00
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
100
150
200
250
300
350
400
450
500
Number Cows
0 %
25 %
46 %

Figure 4

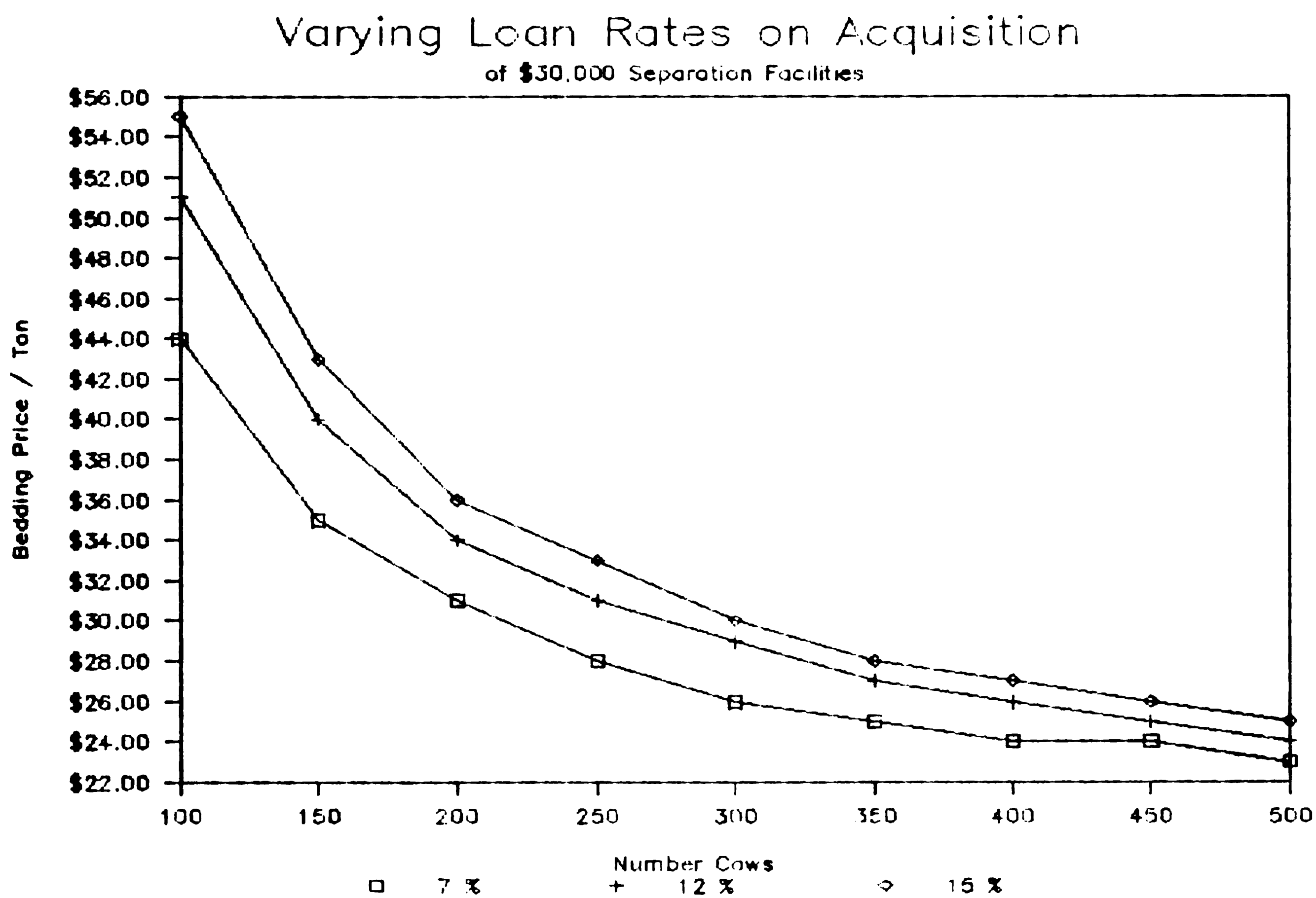
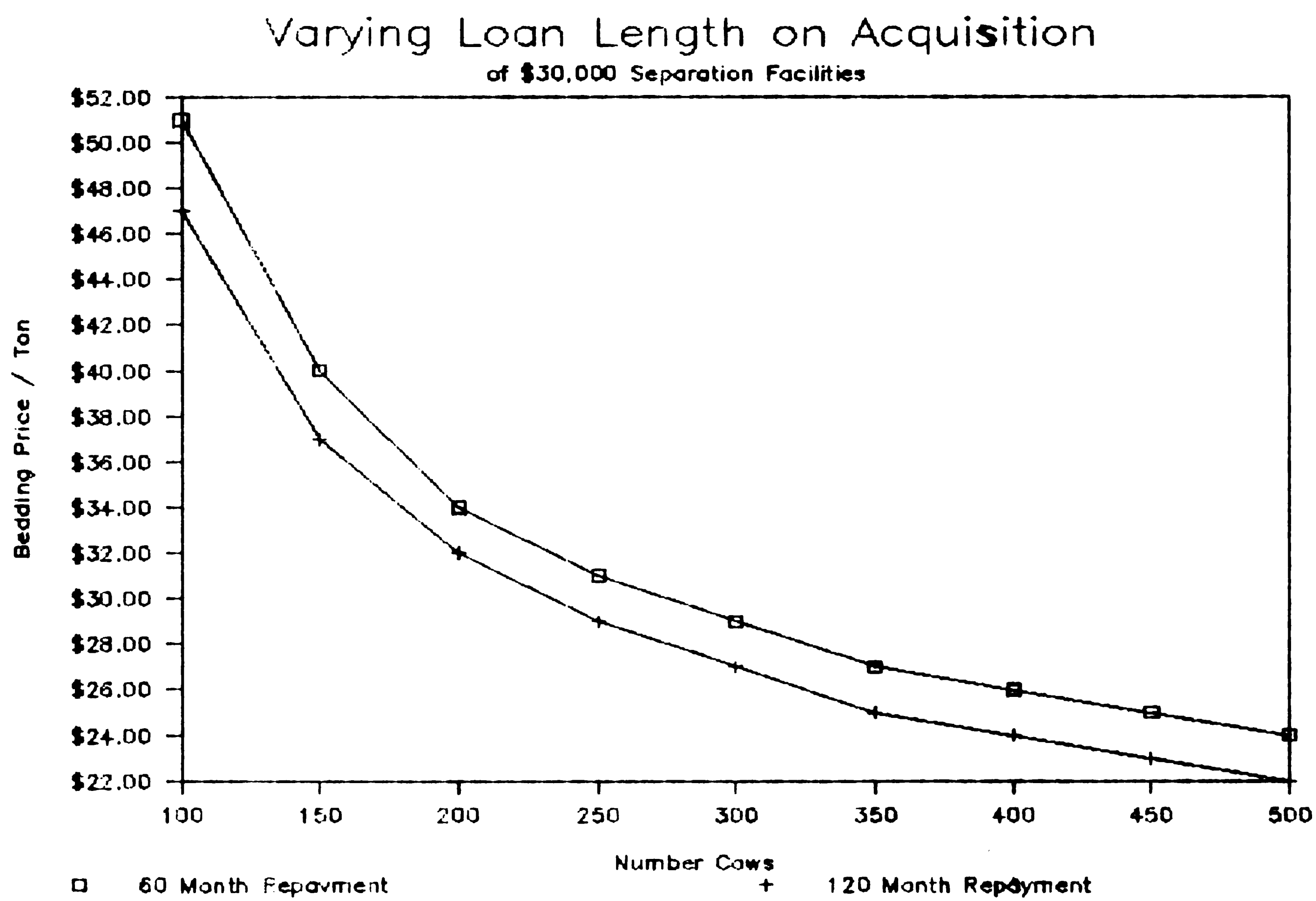

Varying Loan Rates on Acquisition
of $30,000 Separation Facilities
Bedding Price / Ton
$56.00
$54.00
$52.00
$50.00
$48.00
$46.00
$44.00
$42.00
$40.00
$38.00
$36.00
$34.00
$32.00
$30.00
$28.00
$26.00
$24.00
$22.00
100
150
200
250
300
350
400
450
500
Number Cows
7 %
12 %
15 %

Figure 6



Varying Loan Length on Acquisition
of $30,000 Separation Facilities
Bedding Price / Ton
$52.00
$50.00
$48.00
$46.00
$44.00
$42.00
$40.00
$38.00
$36.00
$34.00
$32.00
$30.00
$28.00
$26.00
$24.00
$22.00
100
150
200
250
300
350
400
450
500
Number Cows
60 Month Repayment
120 Month Repayment

Figure 7

It is difficult to assess actual effects each parameter has due to interactions between parameters. Overall, these parameters seemed to affect smaller farms more where higher bedding prices had to be incurred to justify investment into a $30,000 separation facility.

The dairy herd at the Kellogg Biological Station was divided for this next part of research by level of milk production and place on dirt and concrete free stalls bedded with composted and fresh dairy manure solids as described earlier. Composted dairy manure solids were dark brown and hot to the touch. Fresh solids were yellow and showed no signs of heating. Initial coliform concentrations, moisture percentages and ash percentages of composted and noncomposted dairy manure solids are compared below in Table 1.

TABLE 1--COMPARISON OF COMPOSTED VS FRESH DAIRY MANURE SOLIDS

	COMPOSTED[a]	NONCOMPOSTED[a]
COLIFORM CONCENTRATION	2.5×10^5	5.3×10^5
MOISTURE PERCENTAGE	77.18*	78.36*
ASH PERCENTAGE	13.4	13.1

[a] Results based on average of 16 observations
[b] Coliform bacteria per gram bedding net weight
* Denotes difference ($p < .01$)

Composting did not have a significant effect on coliform concentration or percent ash, though observed differences were as expected. Composted dairy manure solids were slightly drier.

Table 2 summarizes coliform numbers and moisture percentages of manure solid samples taken from free stalls four days after application. Dairy manure solids in dirt free stalls had some dirt mixed in. Approximately 80% of dairy manure solids placed on concrete free stalls with mats were removed by cows regardless of whether dairy manure solids in backs of free stalls were swept out daily or allowed to accumulate. Comparisons of final coliform concentrations and moisture percentages of each parameter ignored others parameters. For example, composted and fresh dairy manure solid samples were compared across all free stall sets, production groups and management practices (sweeping versus accumulation).

TABLE 2-COMPARISON OF COLIFORM CONCENTRATION AND MOISTURE PERCENT

EXPERIMENT 1

COMPARISON[a b]	COLIFORM CONCENTRATION[c]	MOISTURE PERCENTAGE
Dirt Stalls	1.4×10^7	49.5
Concrete Stalls	2.1×10^7	56.0
Composted Solids	2.7×10^7	54.6
Noncomposted Solids	8.7×10^6	50.9
Swept Stalls	1.9×10^7	52.6
Accumulated Stalls	1.7×10^7	52.9
High Producers	2.2×10^7	53.5
Low Producers	1.3×10^7	52.0

[a] Comparisons of each parameter ignores other parameters
[b] Results based on averages of 16 observations taken
[c] Coliform bacteria per gram bedding wet weight

Bedding in dirt based free stalls was drier than bedding in cement based free stalls in this first trial. Composted dairy manure solids had higher final coliform concentrations than uncomposted dairy solids despite lower initial coliform concentrations. Sweeping out dairy manure solids from the back two feet of free stalls daily had no effect on coliform concentration or moisture percentages. There was a slight difference in coliform concentration or moisture percentages of bedding in free stalls between high and low production cows. A trend of higher coliform concentrations in free stalls containing wetter bedding was apparent.

Two of the 28 higher producing milk cows on dirt free stalls contracted coliform mastitis three days after dairy manure solid bedding was added. At time of infection, one cow was producing 74 pounds of milk daily and had a somatic cell count of 400,000 leukocytes per ml. The daily milk production of the other cow was unrecorded due to recent freshening but it had a somatic cell count of 100,000 leukocytes per ml. The first cow freshened 58 days previous to mastitis and the second cow was 41 days postpartum.

2. Experiment 2

Ambient temperatures and temperatures one, two, three, and four feet into composting piles of dairy manure solids were monitored as described previously. Graph 1 illustrates temperature differences within a pile over a period of time. Ambient temperatures are also plotted. Effects of mixing are illustrated between day 29 and day 30 as indicated on the graph. A line placed at 60°C indicates temperatures found

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found to be lethal to coliform bacteria if exposed for three days during the composting process (Wiley and Westerburg, 1969).

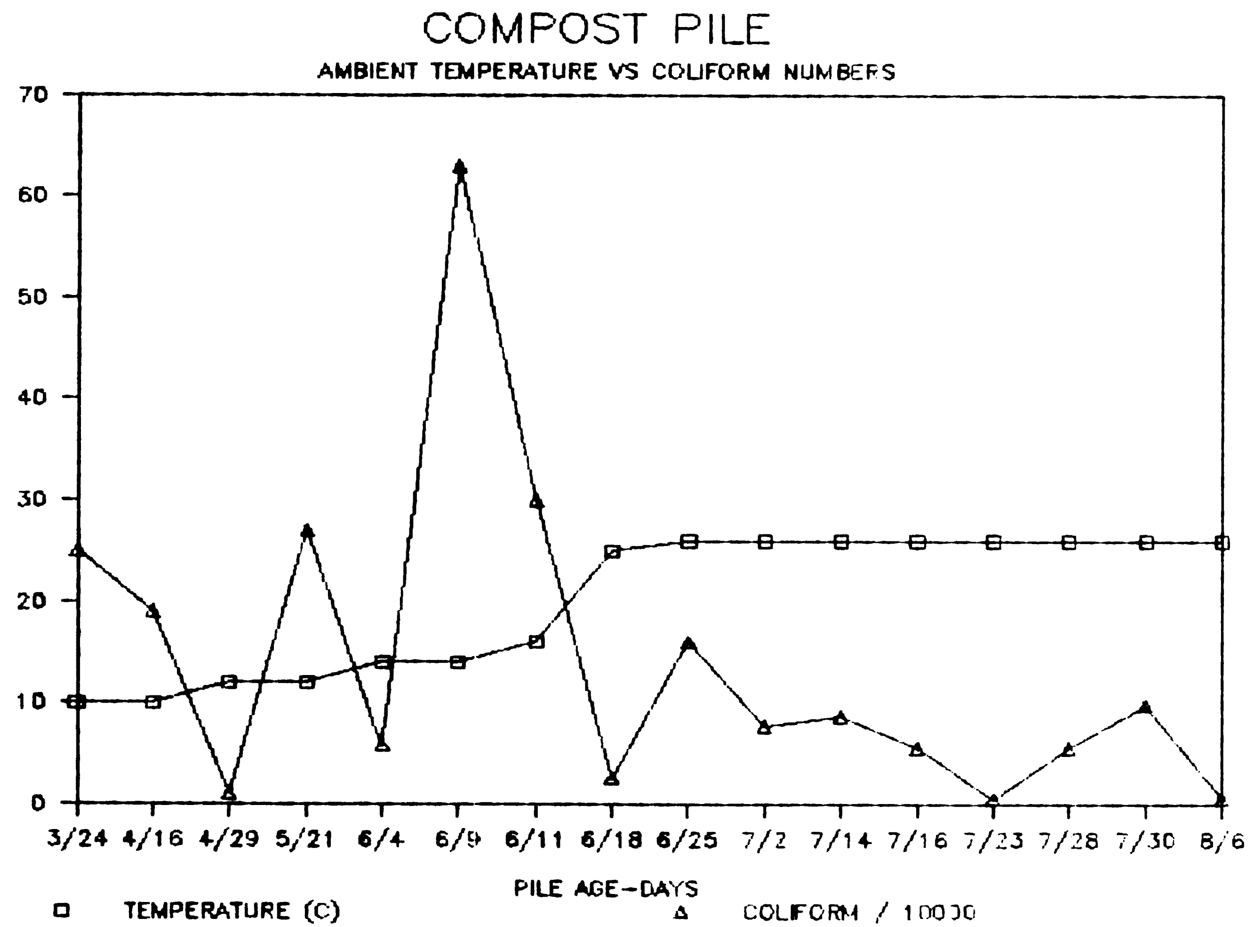

COMPOST PILE
AMBIENT TEMPERATURE VS COLIFORM NUMBERS
70
60
50
40
30
20
10
0
3/24 4/16 4/29 5/21 6/4 6/9 6/11 6/18 6/25 7/2 7/14 7/16 7/23 7/28 7/30 8/6
PILE AGE-DAYS
TEMPERATURE (C)
COLIFORM / 10000

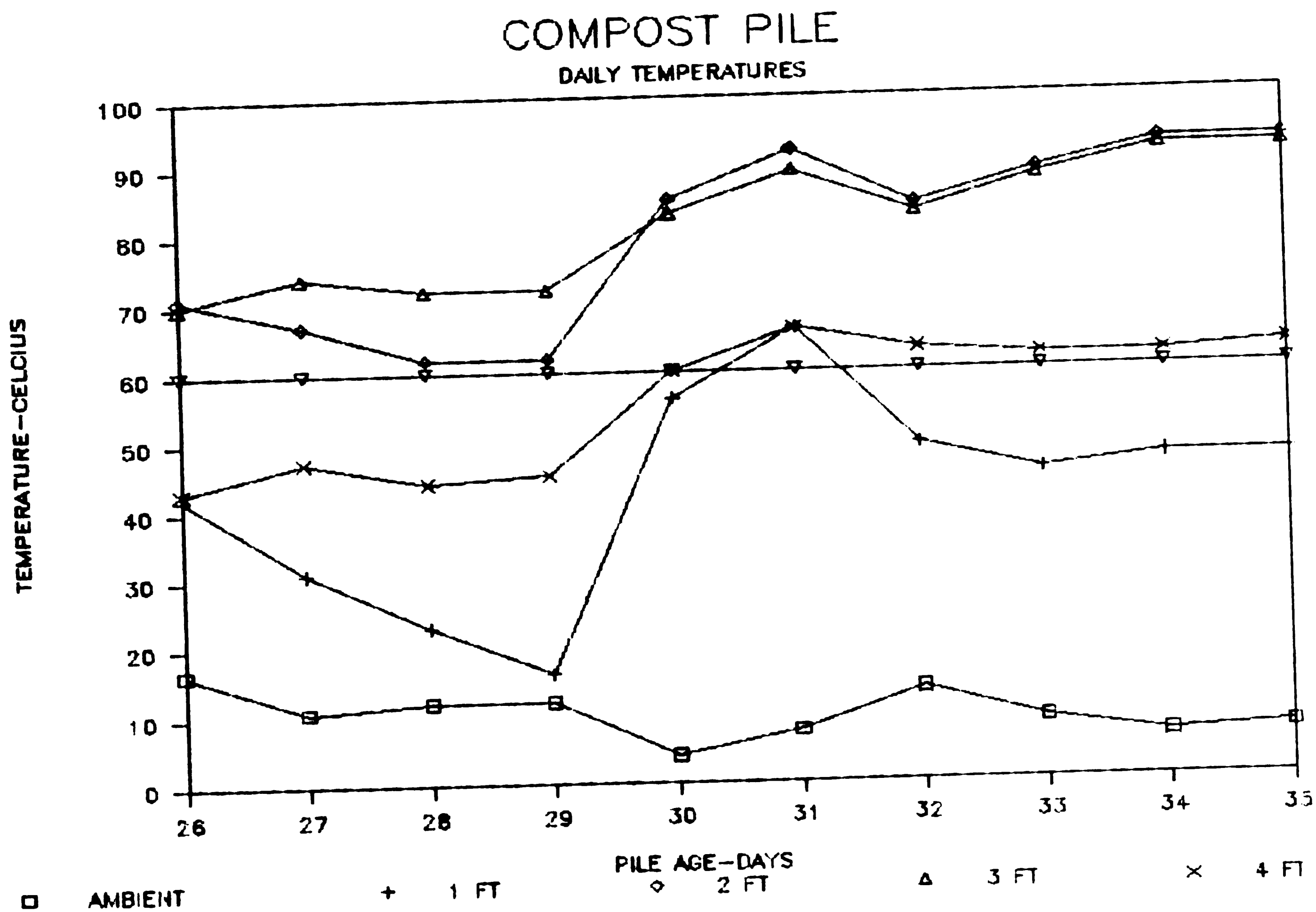
Figure 9

Temperatures were highest two and three feet into a pile. As shown above in graph 1, temperatures immediately rose upon mixing, especially at depths of two and three feet. Temperatures one foot into a pile rapidly decreased within two days due to low ambient temperatures. Random coliform concentration tests done when a pile has been undisturbed for some time showed coliform bacteria were present at one foot into a pile and at four feet into a pile but not at depths of two or three feet. This is illustrated below in Table 3. Fresh manure solids not discolored by composting were found at depths of four feet.

TABLE 3--COLIFORM CONCENTRATIONS AT DIFFERENT DEPTHS IN COMPOSTING PILES

DEPTH OF SAMPLE	COLIFORM CONCENTRATION
1 FOOT	3.3×10^4
2 FOOT	0
3 FOOT	0
4 FOOT	3.5×10^3

Graph 2 shows average coliform concentration and graph 3 average moisture percentages of manure solid samples taken from 16 compost piles after the piles had been mixed and were to be applied to free stalls. These compost piles were used at successive times as warmer weather approached. Ambient temperatures during composting is also plotted on graph 2 to illustrate any relationships.



COMPOST PILE
DAILY TEMPERATURES
TEMPERATURE-CELCIUS
100
90
80
70
60
50
40
30
20
10
0
26
27
28
29
30
31
32
33
34
35
PILE AGE-DAYS
AMBIENT
1 FT
2 FT
3 FT
4 FT

Figure 8

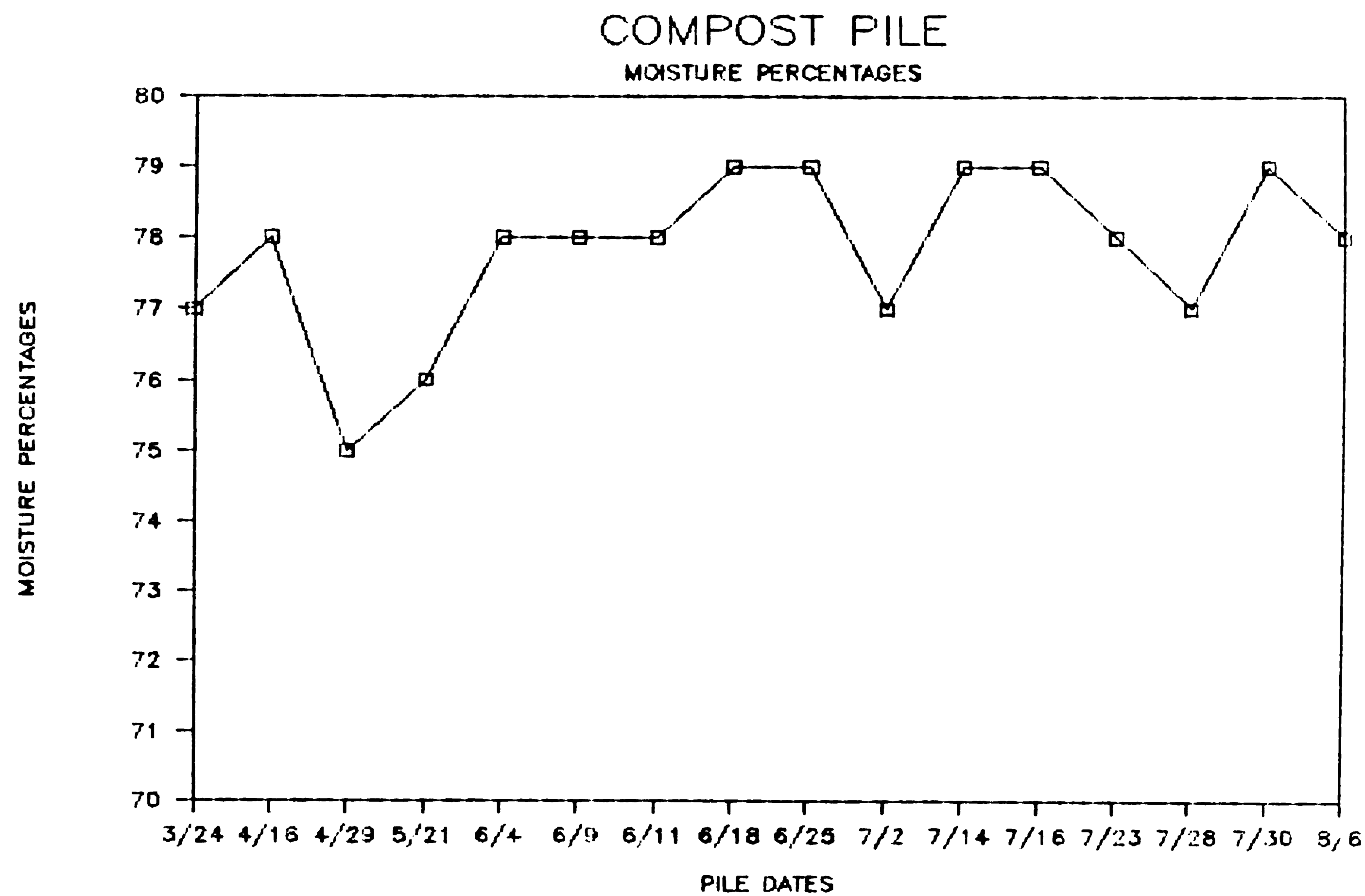

COMPOST PILE
MOISTURE PERCENTAGES
80
79
78
77
76
75
74
73
72
71
70
MOISTURE PERCENTAGES
3/24 4/16 4/29 5/21 6/4 6/9 6/11 6/18 6/25 7/2 7/14 7/16 7/23 7/28 7/30 8/6
PILE DATES

Figure 10

Coliform bacteria numbers varied greatly but remained primarily in the 10^5 range at the beginning of research and the 10^3 to 10^4 range in later trials as ambient temperature increased. Freshly composted dairy manure solids tended to be drier in the beginning of research as summer progressed. These observations are summarized below.

TABLE 4--AMBIENT TEMPERATURE VS COLIFORM CONCENTRATION AND MOISTURE PERCENTAGE

Ambient Temperature	Coliform[a]	Moisture
12°C[b]	2.4 X 10^5	77.1%
25°C[c]	6.3 X 10^0	78.1%

[a] Coliform bacteria per gram bedding wet weight
[b] Results based on averages from first seven piles
[c] Results based on average from last nine piles

3. Experiment 3

Research continued using only composted dairy manure solids on the two sets of concrete stall with mats containing lactating dairy cattle grouped by production as described previously. Manure solids were kicked out by cows within four days of application when bedding was applied at the original rate. Final coliform numbers and moisture percentages were determined from samples taken four days after application.

Application rate was then doubled to maintain manure solids in free stalls for one week. Three days after doubling the application rate of da

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[b] Com
[c] Col

of dairy manure solids to free stalls with lactating cattle, four cows in the high production group contracted acute mastitis; two cows form the free stall subset where dairy manure solids were swept out of backs of free stalls daily and two from the subset where dairy manure solids were allowed to accumulate. Plenty of bedding was present when cows contracted mastitis due to the increased application. Bedding samples were taken from free stalls the next day. Statistical summaries of average coliform numbers and moisture percentages of bedding taken from these free stalls during this part of research are shown below in Table 5. Comparisons of bedding from free stalls of different production level cows ignored whether free stalls within each group were swept or allowed to accumulate. Similarly, effect of sweeping was observed across production level.

TABLE 5-COMPARISON OF COLIFORM CONCENTRATION AND MOISTURE PERCENT EXPERIMENT 4

COMPARISON[a b]	COLIFORM CONCENTRATION[c]	PERCENT MOISTURE
Low Producers	9.0×10^6	51.06%
High Producers	1.4×10^7	55.97%
Swept Stalls	1.1×10^7	55.39%
Accumulated Stalls	1.2×10^7	51.65%

[a] Results based on averages of 56 observations
[b] Comparison of each parameter ignores the other parameter
[c] Coliform bacteria per gram bedding wet weight

The trend of increased coliform bacteria numbers in bedding with higher moisture percentages was still apparent in free stall bedding of high production cows. Sweeping solids from the back two feet of free stalls still had no effect on coliform concentrations. Coliform numbers and moisture percentages of bedding samples taken after the mastitis outbreak were analyzed. The results are shown below and compared with results of samples taken from the same free stalls before the mastitis outbreak. Also, records of cows that contracted acute mastitis are shown in Table 7. All infected cows, in the their first half of lactation, were producing over 73 pounds of milk, and all but one had a somatic cell count less than 400,000 cells per ml. Cow 122 had been infected for several days prior to acute manifestation.

TABLE 6—COMPARISON OF MANURE SOLID SAMPLES TAKEN FROM FREE STALLS AFTER THE MASTITIS OUTBREAK WITH PREVIOUS OBSERVATIONS

	PREVIOUS OBSERVATIONS[a]		LAST OBSERVATIONS[b]	
	COLIFORM[c]	MOISTURE	COLIFORM[c]	MOISTURE
Low Producers	9.0×10^6	51.06%	5.8×10^6	50.93%
High Producers	1.4×10^7	55.97%	4.2×10^6	59.89%

[a] Results bases on averages of 56 observations
[b] Results based on averages of 8 observations
[c] Coliform per gram bedding wet weight

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TABLE 7-RECORDS OF COWS CONTRACTING ACUTE MASTITIS

COW NO.	DAYS POSTPARTUM	MILK PRODUCTION (lbs/day)	SOMATIC CELL COUNT
82	69	104	200,000
361	128	74	300,000
403	50	95	0
122	132	81	5,500,000

Coliform numbers in bedding samples taken from free stalls shortly after cows contracted acute mastitis were not greater than average coliform numbers of samples taken from these free stalls under identical conditions before this outbreak. However, bedding was wetter and more manure solids were present in free stalls when cows contracted acute mastitis.

Coliform numbers of dairy manure solid samples taken from fronts of free stalls were compared with coliform counts of dairy manure solid samples taken from backs of free stalls. Based on 48 observations, manure solid samples from fronts of free stalls had an average of 3.9 X 10^6 coliform per gram bedding wet weight and samples taken from backs of free stalls had an average of 9.4 X 10^6 coliform per gram bedding wet weight. Coliform counts in both cases were still above the 10^6 coliform bacteria per gram bedding wet weight level found to increase the coliform infection rate in lactating cows (Bramley et al., 1975).

After the second mastitis outbreak, research continued using the previous design but only on low production cows on concrete free stall

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[c] Co

[d] Den

stalls with mats and heifers on bare cement free stalls. Results of tests run on samples taken from free stalls with low production cows five and seven days after application are summarized below based on 56 observations each. Comparison of age of samples in free stalls ignored whether samples were taken from swept free stalls or free stalls where manure solids were accumulated. Similarly, comparison of samples taken from swept free stalls and unswept free stalls ignored age of samples in free stalls. However, in table 10, effects of age of samples in free stalls on effectiveness of sweeping free stalls on maintaining low coliform number is studied.

TABLE 8--RESULTS WHEN DAIRY MANURE SOLIDS USED CONTINUOUSLY TO BED LOW MILK PRODUCING COWS

COMPARISON[a b]	COLIFORM CONCENTRATION[c]	PERCENT MOISTURE
Accumulated	8.7×10^6	61.20
Swept	6.3×10^6	64.40
Day 5	6.0×10^6 *	64.46
Day 7	8.7×10^6 *	61.56

[a] Results based on averages of 56 observations
[b] Comparison of each parameter ignores the other parameter
[c] Coliform per gram bedding wet weight
* Denotes difference ($p < .1$)

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TABLE 9--EFFECT OF SWEEPING SOLIDS FROM BACKS OF FREE STALLS OF LACTATING COWS OVER TIME

	Day 5		Day 7	
	Coliform[a]	Moisture	Coliform[a]	Moisture
Accumulated[b]	5.5×10^{6}*	63.75%	1.1×10^{7}*	59.29%
Swept[b]	6.7×10^{6}	65.17%	6.0×10^{6}	63.82%

[a] Coliform Concentration-coliform per gram bedding wet weight
[b] Results based on averages of 28 observations
* Denotes difference ($p < .01$)

Sweeping solids from the back two feet of free stalls daily was once again ineffective in maintaining coliform numbers below the infectious level in free stall bedding of lactating cows. No difference was found between coliform numbers in bedding of free stalls where manure solids were swept off the rear two feet daily over a week's time and bedding from free stalls where manure solids were allowed to accumulate. A trend in differences of moisture percentages and coliform numbers between bedding from swept free stalls and free stalls where manure solids were allowed to accumulate was apparent over time. Hot, humid weather prevailed during this phase of research with temperatures averaging approximately 28°C during the day.

Samples of dairy manures solids were taken from bare cement free stalls maintaining heifers with access to an outside lot. Comparisons of coliform numbers and moisture percentages of samples in swept and unswept free stalls ignored age of manure solids in free stalls.

Similarly, comparisons of samples taken at one week with samples taken at two weeks ignored whether samples were from swept or unswept free stalls. The results of these comparisons are shown below.

TABLE 10–COMPARISONS OF DAIRY MANURE SOLIDS USED FOR BEDDING HEIFERS ON SWEPT AND UNSWEPT FREE STALLS OVER TIME

COMPARISON[a b]	COLIFORM CONCENTRATION[c]	% MOISTURE
One week old bedding	1.6×10^{6}	65.63%
Two week old bedding	1.7×10^{6}	53.67%
Swept stalls	2.1×10^{6}	60.32%
Accumulated stalls	1.3×10^{6}	58.99%

[a] Results based on 16 observations
[b] Each parameter compared ignoring other parameter
[c] Coliform per gram bedding wet weight
* Denotes difference ($p < .01$)

Sweeping dairy manure solids from the back two feet of bare cement free stalls was ineffective in maintaining low coliform counts. Coliform concentrations remained fairly constant over time though moisture percentages decreased. During hot weather, heifers tended to congregate in inside free stalls which happened to be free stalls having manure solids swept from the back two feet daily.

Final analysis of all data involved statistically correlating beginning coliform count, ending coliform count, beginning moisture and ending moisture. These results are shown below in Table 12.

TABLE 11--STATISTICAL CORRELATIONS OF STUDIED PARAMETERS USING ALL DATA

COMPARISON	SIGNIFICANCE
Initial Coliform vs Final Coliform	n.s.
Initial Coliform vs Beginning Moisture	99.9%
Initial Moisture vs Final Moisture	90%
Initial Moisture vs Final Coliform	n.s.
Final Moisture vs Final Coliform	n.s.

Initial moisture content was inversely related to beginning coliform concentration. There was some relationship between initial moisture content and final moisture content but no relation of initial moisture content, final moisture content, or initial coliform numbers to final coliform numbers.

Overall, there was no method of maintaining coliform numbers below 10^6 coliform bacteria per gram bedding wet weight in free stalls bedded with dairy manure solids during Michigan summers; even when the back two feet of free stalls were swept clean of dairy manure solids daily. Probably because of this, high milk producing cows in early lactation with low somatic cell counts contracted acute mastitis when bedded with dairy manure solids.

DISCUSSION

The first part of the research looks at parameters affecting maximum investment a farmer can justify spending on facilities to separate solids from liquid manure for use as free stall bedding.

Larger herds can afford to invest proportionally more for separation facilities than smaller herds assuming other parameters are held constant; however, bedding price is also an important consideration as seen in the first graph where a 1000 cow facility cannot justify investment in separation facilities if alternate bedding can be obtained for $20 a ton. Overall, since smaller herds use less bedding, they must incur higher bedding prices before investment in a separation system can be justified. Effects of tax rate, required rate of return, loan rate and loan repayment period on justification of separation facilities are difficult to assess due to interactions between these parameters. These effects are more pronounced on smaller farms where a larger percentage of bedding savings goes towards covering fixed costs due to economies of scale.

Management practices which enhance use of manure solids as free stall bedding are not clear from this study. Ideally, dairy manure solids should be at least 60% dry matter or higher and have coliform counts below 10^6 per gram bedding wet weight (Allen et al., 1977). Despite high inner pile temperatures that decreased coliform numbers as

low as 10^3 per gram wet weight, static composting was inadequate as moisture percentages and coliform numbers were not reduced enough to prevent rapid regrowth once placed in free stalls.

At the start of research in early spring, low ambient temperatures (never above 15°C) and high pile moisture levels (approximately 77% water) were most obvious inhibitors of composting. Unmixed piles had temperatures considered lethal to coliform bacteria only at depths of two and three feet. Temperatures at depths of one and four feet were adequate for coliform growth. Depressed temperatures at four foot depths were probably due to decreased oxygen diffusion from wet pile conditions as increased moisture blocks oxygen diffusion necessary for adequate composting (Willson, et al., 1980). Temperatures at the one foot level were probably influenced by ambient conditions as low ambient temperatures result in lower composting temperatures (Carroll et al., 1977). Decreased oxygen diffusion would affect deeper levels equally or more so. This is important as over 40% of a compost pile volume was located within one foot of the surface in our four foot piles. Effects of settling and moisture accumulation on composting (Willson, 1980)were evident as temperatures at all depths decreased with time. Coliform numbers would consequently be expected to rise as temperatures fell towards temperatures supporting coliform regrowth (Carroll and Jasper, 1978 and Bishop et al., 1980).

Mixing piles of composting dairy manure solids caused temperatures to increase above the 60°C lethal range at all monitored depths within one day. Temperatures at one foot fell below this range within two days; presumably due to effects of ambient conditions. Bishop et al.

(1980) showed average coliform numbers in composting piles of dairy manure solids leveled off after four days to a level of approximately 10^5 coliforms per gram wet weight and remained constant until pile use at 12 days. Theoretically, since a temperature of 60°C for three days is lethal to coliform bacteria, daily mixing of a compost pile, which increases temperatures above 60° C at depths of one, two, three and four feet for at least one day, should be adequate to optimally reduce coliform numbers if continued daily for three days before use. This procedure would be inadequate where composting is used as a method of drying solids.

To improve composting, piles were mixed on a weekly basis. Average coliform numbers were erratic ranging from approximately 10^4 to almost 10^6 coliform per gram wet weight. This variation was probably caused by other unidentified factors. As summer advanced average coliform numbers were constantly decreased to levels of approximately 10^4 coliforms per gram wet weight with composting due to increased ambient temperatures (Carroll and Jasper, 1978). These lower coliform numbers were sometimes obtained with weekly pile mixing during the cold months early in this study. However, lower coliform numbers (less than 10^4) did not prevent coliform regrowth when these solids were added to free stalls.

Average moisture percentages of freshly composted manure solids remained consistently high. An inverse relationship existed ($p < .001$) between coliform levels and moisture levels in freshly composted solids. Increased ambient temperatures during summer months caused decreased coliform numbers in piles; however, moisture percentages unexpectedly increased. Dale et al. (1975) cites increased humidity retards drying of manure solids in free stalls. High humidity during summer months may have retarded evaporation in compost piles causing higher moisture percentages.

Coliform numbers were higher in composted dairy manure solids than fresh dairy manure solids four days after application of these solids to free stalls despite equivalent initial coliform numbers and lower moisture percentages. High final moisture contents and high temperatures on day of application may have resulted in higher final coliform concentrations in the composted solids. Coliform regrowth above levels of 10^6 occurred under all conditions of free stall base, daily sweeping of dairy manure solid bedding from backs of free stalls and production level of dairy cows frequenting free stalls. Milk production levels of cows frequenting free stalls had no effect on final coliform concentrations in bedding though an increase in coliform concentration in bedding of high producing cows was expected due to higher bedding temperatures (Francis et al., 1981). Daily sweeping the rear two feet of free stalls also did not affect coliform concentrations. Coliform numbers did not vary between backs and fronts of stalls. Bramley (1985) reported a 100 fold decrease in coliform number in bedding of free stalls when bedding was swept from the back meter daily. Thus, factors other than cow contact were apparently contributing to increased coliform growth in bedding of our free stalls.

A trend of higher coliform concentrations in bedding with high moisture percentages was apparent. Statistical analysis correlating final moisture with final coliform numbers showed no relation existed. This was probably due to data where coliform numbers increased and moisture percentages decreased with time. Carroll (1977) cites moisture plays a role in regrowth of coliform bacteria. Freshly composted manure solids in this research contained approximately 77% water, far above the 40% minimum suggested by Carroll et al. (1977) necessary to prevent rapid coliform regrowth. Dale et al. (1975) reports ambient humidity decreases drying of manure solids in free stalls. Consequently, high ambient humidity, which decreased drying of the wet manure solids (77%), and high ambient temperatures may have served as the parameters other than cow contact in stimulating coliform growth in dairy manure solids in free stalls. This agrees with Smith et al. (1985) who cites high temperatures and humidity of Ohio summers to explain increased coliform bacterial growth in dairy manure solids. Since ambient conditions cannot be economically controlled and initial coliform counts were unrelated to final coliform counts, decreasing initial moisture would be one method of controlling bacterial regrowth. Composting in our area does not adequately dry solids and forced drying is not usually cost effective.

No relation existed between coliform numbers in bedding and incidence of mastitis though coliform numbers were always above 10^6 in bedding of free stalls where cows contracted acute mastitis. Consequently, factors other than bedding numbers predicated acute mastitis. Carroll (1977) cites higher milk producing, uninfected cows in early lactation are more susceptible to coliform mastitis due to decreased somatic cell counts and increased stress from recent calving and high milk production. Our few cases of mastitis support results of Carroll (1977); infected cows were in the first half of lactation, produced over 73 pounds of milk daily, and in all but one case had low somatic cell counts.

Duration of exposure of teats to contaminated manure solids may have been another factor contributing to acute mastitis. Mastitis outbreaks occurred first with cows bedded with manure solids on dirt free stalls. Coliform numbers were similar for concrete and dirt based free stalls but a greater amount of dairy manure solids stayed on dirt based free stalls than on concrete free stalls with mats. The second outbreak of mastitis occurred with cows bedded on cement free stalls with mats but only when the application of dairy manure solids was doubled. Coliform concentrations in bedding of these free stalls previous to the outbreak were similar to coliform concentrations in the bedding when mastitis was observed. These increased bedding amounts could have potentially increased duration of exposure of teats to bedding containing high numbers of coliform bacteria. Acute mastitis may have resulted from this increase exposure. Sweeping out solids daily from the rears of stalls may not have been enough to reduce exposure when application rate of solids to free stalls was doubled.

Common practice in Michigan farms is to top freshly applied dairy manure solids with lime, sawdust, etc. to shield dairy cows from wet dairy manure solids until bedding dries. These farmers and farmers quoted by Carroll and Jasper (1978) cite mastitis outbreaks are possible if "wet" dairy manure solids are used directly in free stalls. Bishop et al. (1981) found teats they sampled contained coliform bacteria. They concluded moisture from manure solids used at their facility (74.3% moisture) probably caused adherence of coliform bacteria to these teats as coliform bacteria are poorly adapted to survival on normal teat skin. In the free stalls where cows contracted acute mastitis in the second phase of this research, composted manure solids were not only more abundant but were wetter than solids used in the same stalls previously.

SUMMARY

Economic justification of manure separation facilities occurs more readily on larger farms where increased bedding usage increases savings realized by replacing conventional bedding with dairy manure solids. Smaller farm must incur higher prices for bedding to generate enough savings to justify investing in separation facilities. Since more of bedding savings of small farms goes towards serving fixed costs, variations in economic feasibility parameters (herd size-bedding price combination) due to fluctuations in tax rate, rate of return and loan interest rate are more pronounced for these small farms. Savings of $17.48 realized from a ton of bedding services variable costs. This cost can be imputed to be the variable cost of a ton of dairy manure solids in other analyses.

Overall, composting dairy manure solids was inadequate in decreasing coliform concentrations or moisture percentages enough to prevent rapid regrowth of coliform bacteria once solids were placed in free stalls. Moisture seemed to be the determining factor as coliform bacteria in solids containing 10^3 coliforms per gram bedding wet weight regrew to levels above 10^6 within four days. Duration of exposure of teats to bedding containing high numbers of coliform may be a factor contributing to coliform mastitis. Sweeping solids from the rear two feet of stalls daily was apparently ineffective in preventing mastitis in two high producing, uninfected cows in early lactation.

Consequently, herds with low somatic cell counts and with no staphylococcal or streptococcal infections should not use dairy manure solids to bed early lactation cows with low somatic cell counts due to its association with coliform mastitis. Further research is needed to identify methods to maintain coliform numbers below 10^6 per gram bedding wet weight or to prevent normally susceptible cows from being infected.

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