Design, Construction and Testing of an Animal Operated Device for Coordinated Feeding of Liquid Supplement and Granular Material to Cattle

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DESIGN, CONSTRUCTION AND TESTING OF AN ANIMAL OPERATED DEVICE FOR COORDINATED FEEDING OF LIQUID SUPPLEMENT AND GRANULAR MATERIAL TO CATTLE

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Extensive areas of the United States have considerable beef producing potential due to the climate and vegetation present. However, there are periods when existing vegetation alone can not supply all desired nutritional requirements of the grazing animal. The importance of an adequate diet was noted by Probert (26)[1], who said, "Yearling cattle grazing on summer pasture do not grow at their maximum potential due to energy and protein deficiencies in the feed at various times of the season." Insufficient nitrogen (protein) and the lack of available carbohydrates (energy) in the plant material can constitute major nutritional deficiencies, Pieterse (24). Weber and Vetter (33) stated, "that restriction of maternal protein intake may adversely affect the productive capacity of a beef cow and her progeny."

A primary goal in animal production is to realize optimum efficiency in the conversion of feedstuffs into body growth and high quality animal food products. To reach the goal, protein and energy must be provided to correct the specific nutritional deficiency of the grazing beef animal.

Methods to provide the proper supplement to the grazing animal have included daily feeding with machinery and techniques similar to those of a feedlot. Labor and machinery costs constitute a large

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1. Numbers in parentheses refer to literature cited.

portion of the total supplementation cost by this method. Another practice is daily distribution, either on the ground or in a bunk, of a pelleted or cubed diet supplement. Labor contributes greatly to the total supplementation expense associated with this method. It may also become difficult to deliver the supplement to grazing animals daily by the two methods cited above should the animals be located in remote pastures or should adverse weather conditions persist.

Free-choice, self-feeding systems can also be used to provide the daily diet supplement. These feeders are relatively inexpensive, continue to deliver the supplement during inclement weather, operate with minimum supervision, labor and maintenance, and can be located in the area where the animals are grazing. Liquid supplements are often fed ad libitum from such mechanical feeders, and since cattle are capable of synthesizing protein from a non-protein nitrogen (NPN) source, Reid (27), urea is often mixed with molasses to constitute the principle protein source of liquid supplements. This system is capable of providing the protein often found deficient in the diet. However, additional carbohydrate feed energy may be required to meet the energy requirements of the animal, insure maximum urea nitrogen utilization, and prevent undue wastage of protein in metabolism, Bell, et al. (3). Grain, usually available to the livestock owner, can provide the necessary supplemental carbohydrate energy and also greatly enhance the ruminant's ability to effectively synthesize protein from urea and consequently reduce the possibility of toxic reactions, Pieterse (24). Energy in the plant material (cellulose) should become more available to the bovine because of increased rumen activity with the supplementation of an NPN source and the provision of grain starch energy, Peiterse (24). The difficulty arises in devising a system to coordinate the feeding of liquid protein supplement and grain ad libitum, in controlled quantities and ratios.

Therefore, the objectives of the project were established as follows:

1. Design, develop, and construct an animal operated device to coordinate the feeding of grain and liquid protein supplement to cattle.
2. Test the operation and performance of the feeding device under laboratory and actual feeding conditions.
3. Investigate individual animal participation in the use of the feeding device.
4. Analyze the economic feasibility of the animal operated device compared with current pasture supplementation systems.

REVIEW OF LITERATURE

A comprehensive review of literature of livestock feeding and livestock feeding systems would be voluminous and would not serve the specific needs of this project. Therefore, the literature cited will be that relating to the objectives of this research project and will be presented along the following outline: the need for supplemental carbohydrate energy and protein (nitrogen); liquid feeds, urea, and conventional feeding; and factors which influence liquid feed consumption.

In many parts of the world pasture areas are subject to periods of low rainfall, during which time vegetation is dry, fibrous, unpalatable, and seriously deficient in nitrogen, phosphorus, calcium, salt, vitamin A, available carbohydrates, and possible other trace minerals and nutrients, Pieterse (24). During winter months advanced maturity causes changes to occur in the plant that further reduces its nutritional value. Protein becomes less available and lignification causes an increase in the non-digestible, fibrous portions of the plant, Savage and Heller (28). Whiteman, et al. (34) reported that in North Dakota the native and tame grasses lose about 87% of the carotene content, 66% of the phosphorus, and 71% of the protein by the end of September. With such large losses as these it would seem that nutritional deficiencies in the forage might become apparent, even before the end of the summer growing season.

Irrigated summer pasture has also been found to be lacking in energy and protein to the extent that beef production may not be economically profitable without a diet supplement, Lake, et al. (15).

Lake, et al. (15) reported that energy supplementation significantly increased weight gains in a linear manner for yearling steers grazing irrigated pastures and that 4.0 lb. per day of supplemental feed, comprised mostly of corn, was near the maximum amount justifiable. Time required to finish the steers in the feedlot, following the grazing period, decreased with increased grazing energy supplementation, while carcass characteristics were not affected by grazing energy supplementation. Christenson, et al. (6) found that by providing a higher energy level (high, 196 and low, 127 Kcal. of digestible energy/Kg. $B.W.^{0.75}$ per day), yearling Hereford heifers gained more weight during the last half of gestation, produced heavier calves at birth, and experienced more calving difficulty, but produced more milk and exhibited estrus sooner after calving.

Pieterse (24) asserted that cattle, which are on a low-grade roughage, suffer from both nitrogen and energy deficiencies. But while the lack of available feed energy may be of vital importance, it is secondary to the nitrogen deficiency. Pieterse (24) stated,

> "It has by now been proven beyond doubt that nitrogen constitutes the chief deficiency in low-grade roughages. Because nitrogen is an essential element for the activities of the rumen flora, these microorganisms die in large numbers when the cattle have to subsist on such low-grade roughage. The result is that the feed is not properly digested and the energy it contained is consequently not released and the animal eventually also suffers from a

> lack of energy. If the energy required for the normal physiological functions of the body cannot be obtained from the feed, the fat tissues are broken down and the animal loses condition. If the situation remains critical for a longer period, some of the meat tissues are also broken down to supply the necessary energy and the animal becomes completely emaciated. The critical stage where any further tissue breakdown will result in permanent damage affecting future growth, production and reproduction deleteriously has not yet been experimentally assessed."

Supplemental nitrogen can be provided from natural protein concentrates such as oil-cake meals, meat or fish meals, or from non-protein nitrogen sources, such as urea, Pieterse (24). The usefulness of urea in replacing a portion of the protein in the rations of ruminant animals was recognized as early as 1891 but not accepted to be of any great significance until 1937, Reid (27). It has been found that urea is readily hydrolyzed by rumen bacteria to carbon dioxide and ammonia, Pearson and Smith (22). If sufficient carbon skeletons (alpha-keto acids) arising primarily from dietary carbohydrates are present, McNaught (19), the liberated ammonia can be used to synthesize bacterial protein. However, if there is a shortage of carbon skeletons, and the pH of the rumen fluid is correct, the ammonia will enter the rumen epitheliun and be absorbed into the body, Coome, Tribe and Morrison (9). The ammonia which passes out of the rumen is of little benefit to the animal, Schwartz (29). It is not entirely lost, however, as part may be converted back to urea by the liver and returned to the rumen, Schwartz (29). The hydrolysis of urea in the rumen is unrelated to the ability of the bacteria to use the ammonia produced, with the result that, under unfavorable conditions, the concentration of ammonia in the rumen may reach a level at which it becomes toxic to the animal, Schwartz (29). The ability of ruminal bacteria to utilize ammonia depends on the simultaneous availability of other nutrients required for the synthesis of their cellular constituents. The most important are suitable sources of carbon and energy provided mainly by the carbohydrates in the animals' diet, Schwartz (29). Numerous studies have subsequently shown that grain starch is superior to other carbohydrates in promoting the utilization of urea-nitrogen by rumen bacteria, because sugars disappear from the rumen too rapidly and cellulose is made available too slowly to satisfy the needs of the bacteria; Schwartz (29), Bell, et al. (2), Bell, et al. (3), Reid (27), and Pieterse (24). In vitro experiments have demonstrated that a medium containing moderate amounts of both readily available and complex carbohydrates better supports a satisfactory conversion of urea-nitrogen to protein, Reid (27).

Stangel (32) found a high cellulose diet, such as timothy hay, was a poor medium for the bacterial synthesis of protein from urea. The addition of grain starch to a diet containing timothy hay and molasses promoted the more efficient utilization of urea. Reid (27) also reported the importance of grain starch in the utilization of a timothy hay-urea ration. Another beneficial effect of feeding readily available carbohydrates concurrently with urea and other NPN compounds is that volatile fatty acids are produced as the metobolic product of the bacterial attack on the carbohydrates, Kamstra (12), preventing a rise in the rumen pH, and thereby reducing the rate at which ammonia leaves the organ, Schwartz (29).

Urea and other NPN sources can be fed in either liquid or dry feeds, whereas natural protein concentrates are primarily restricted to dry feed mixes. A basic liquid protein supplement will usually contain molasses as the carrier, a non-protein nitrogen source, vitamin A, and phosphorus. Additional micro- and macro-elements, vitamins, non-nutrient materials such as antibiotics, and other solubles may also be added to comprise the liquid mixture, Klett (13).

Porter (25) reported that performance data for feedlot fattening of cattle indicate that a liquid supplement can be expected to perform on a nearly equal level with dry supplements, providing comparable nutrient levels are fed. Woods, Klopfenstein and Cranfill (37) found in three finishing trials, the rate of gain for cattle fed soybean meal supplement was 1.30 Kg. as compared to 1.28 Kg. for those fed liquid supplements containing urea. Information from Young, et al. (38) indicates that liquid feed may give a slightly inferior average daily gain when compared to soybean meal, but Perry (23) demonstrated that even though a ration with natural protein supplement gave 7% faster gains, liquid protein supplement showed the lowest cost per pound of gain.

While urea is well utilized and an important ingredient in fattening rations containing high levels of grain for cattle and sheep, urea containing supplements have met only limited success in use for cattle consuming rations of mostly poor quality roughages. Nelson and Waller (21) summarized 16 experiments involving 879 cows under winter range conditions in Oklahoma and reported performance to favor natural protein sources. Winter gains of cows and calf weaning weights for animals provided the 20% natural protein supplement, 40% natural protein supplement, and 40% urea based protein supplement were -174, 154; -150, 184; and -169, 173 Kg., respectively, with cottonseed meal the natural protein source. The research also reported that cows could not effectively utilize a supplement containing 50% of the nitrogen from urea. Williams, Whiteman and Tillman (35) found that pregnant and lactating Angus cows, when grazing dead range grasses during the winter season and supplemented with cottonseed meal, lost less weight than those fed an isonitrogenous, urea based supplement. Birth and weaning weights of the calves were not significantly affected by the treatment. However, Williams, Whiteman and Tillman (35) stressed that the combination of the poor quality forage and the urea did not furnish enough carbon fragments for the efficient utilization of the urea nitrogen.

Nelson, Pope and Ewing (20) found similar results for beef cattle wintered on a poor quality prairie hay when urea and isonitrogenous supplements were fed. However, poorer results were noticed with animals fed the urea supplement, when the cattle grazed weathered range forages rather than prairie hay.

Liquid feeds can be conveniently fed ad libitum in a wheel feeder where the liquid supplement is "licked" off a wheel suspended in a liquid container, Klett (13). Lewis, Herndon and Haferkamp (16) recommended that a two to three week adaptation period be allowed for the animals to learn to lick the wheels to obtain the supplement. Consumption from lick-wheel feeders can be influenced by the addition of "bitters material" to the liquid mixture, by making only a specified amount of liquid available per time period, through the use of a continuous time release mechanism, by varying the lick-wheel width, and by limiting lick-wheel exposure surface area available to the animal and thereby influencing the length of turning stroke per lick, Witmer (36). The wheel feeder makes the liquid protein supplement and NPN available to the animals in relatively small amounts over a relatively long time period allowing ammonia release from the NPN in the rumen to be at a slow rate, which is conducive to optimum nitrogen utilization, Braund (5).

Southwell, McCormic and Lowrey (31) reported on trials comparing cottonseed meal and a molasses-urea mixture both limited and self-fed for wintering brood cows in Georgia. Daily gain favored the urea-molasses mixture when self-fed; however, daily feed cost was lower for the cottonseed meal group. Average daily gains for nursing calves were 1.63 lb., 1.78 lb. and 1.91 lb. for the cottonseed meal, urea-molasses limited-fed and urea-molasses self-fed groups, respectively.

Lewis, Herndon and Haferkamp (16) compared a liquid protein supplement (44% protein equivalent from urea and 1% phosphorus from phosphoric acid) with a solid protein supplement (44% protein mainly from soybean meal and 1% phosphorus primarily from dicalcium phosphate) for feeding calves. The liquid was fed free choice (averaging 0.67 lb. per head per day) from a wheel type feeder and the solid supplement was fed by hand in an attempt to match the amount of liquid supplement consumed (averaging 0.80 lb. per head daily), but difficulty was encountered in providing equal quantities of solid supplement. The low liquid consumption was attributed to the high percentage of urea in the mixture. Prairie hay was provided when snow cover and/or severe wind chill reduced the opportunity for grazing the South Dakota winter range. Average daily gains for the calves fed the liquid and solid supplements were -0.18 lb. and 0.07 lb./head, respectively. Poor performance of the calves in both treatments was associated with the limited supplement consumption (daily liquid consumption per animal never exceeded one pound). Part of the deviation in weight gain between calves fed the two supplements can be attributed to the following: different consumption levels, that winter pasture is not conducive to optimum urea nitrogen utilization and the animals fed the solid supplement received a higher level of digestible energy.

Slyter, Embry and Herndon (30) compared a bunk fed, 40% protein equivalent, corn-urea supplement (78% corn and 12% urea) with a self-fed 33% protein equivalent, commercial liquid supplement for calves grazing open range pastures in South Dakota. Palatability was poor with the corn-urea supplement, so the mixture was diluted with additional corn so that the liquid and dry supplements were approximately equal in protein content. Average daily gain favored the corn-urea supplement (0.89 lb. compared to 0.76 lb. for the liquid supplement), which supports Pieterse's (24) contention that grain starch is superior to molasses as a source of carbohydrates in the utilization of urea. Palatability of the self-fed liquid supplement at the same level of urea as the corn-urea mixture appeared superior. Slyter, Embry and Herndon (30) stated that adequate nitrogen intake was difficult to maintain when the level of urea exceeded approximately 8% of the corn-urea mixture.

Luther, Embry and Herndon (18) compared soybean meal and corn urea supplements containing 2, 4, and 8% urea during a 28-day feedlot adaptation period with steer calves fed prairie hay ad libitum. Average daily gains were the same for the cattle fed the soybean meal and 2% urea supplement (1.04 lb. daily). Weight gains using the 4 and 8% urea supplements were, respectively, 0.71 and 0.60 lb. per head daily. A 159-day feedlot wintering period followed the 28-day adaptation period and the daily weight gains that resulted for the combined feeding periods were 1.07, 1.05, 0.99 and 0.85 lb. per head for the supplements with soybean meal (no urea), 2, 4, and 8% urea, respectively. Gains with the 4% urea supplement were nearly equal to those with the soybean supplement after the initial adaptation period. Palatability problems were encountered with the 8% urea supplement, gains were lower, and this level of urea appeared too high, when used with the low energy prairie hay ration. Increasing the content of urea in the protein supplements for the wintering period from 0 to 8, 2 to 8, 4 to 8 and 8 to 12% resulted in daily gains for the combined adaptation and wintering periods of 0.90, 0.96, 0.90 and 0.70 lb., respectively. Feeding the 2% urea supplement during the 4 week adaptation period followed by a supplement with 8% urea appeared to give a superior rate of gain, while a level of 12% urea appeared too high for safe and efficient feed utilization.

Luther, Embry and Herndon (18) compared a pelleted, bunk fed, corn-urea supplement with self-fed molasses-urea supplement for wintering calves fed prairie hay ad libitum. The pelleted supplement was initially fed at the rate of 2.0 lb. per steer per day, but this amount was not readily consumed. When liquid cane molasses and oats were fed with the solid supplement, it was readily palatable. This practice was continued for two months, at which time the steers were fed as much of the pelleted supplement as they would consume daily. Average daily weight gains and average daily crude protein consumption for self-fed liquid supplement and the pelleted corn-urea supplement were 0.50 lb., 0.281 lb., and 0.59 lb., 0.285, respectively. The corn-urea mix gave superior rate of gain but again the urea appeared to be more palatable in a molasses mixture.

Sources of supplemental protein for use in wintering beef cows were compared by Klett (13) where cows were fed sorghum silage and 41% protein cottonseed meal applied as a top-dress, or sorghum silage with

32% liquid protein equivalent self-fed. The cows were fed a quantity of silage equal to the National Research Council (NRC), (1970) energy requirements for pregnant beef cows. Over the 120-day wintering period, weight change differences were slight between treatments, with the group receiving the cottonseed meal gaining an average of 35 lb. per head, and the self-fed molasses-urea group gaining an average of 19.1 lb. per head. Consumption of liquid supplement equaled that of the cottonseed meal on a dry matter basis (1.19 lb. per head daily) with total daily crude protein (CP) intake and average daily silage dry matter (DM) intake also similar for the cottonseed meal and self-fed liquid groups (1.79 lb. CP, 18.08 lb. DM, and 1.77 lb. CP, 18.03 lb. DM, respectively). The sorghum silage in the ration was then replaced with a mixture of 25% milo and 75% cottonseed hulls, again fed to meet energy requirements. The average weight gain per head for the subsequent 51-day feeding period was 6.9 lb. for the cottonseed meal supplemented group and 21.6 lb. for the self-fed liquid supplement group. Klett (13) concluded there was no difference in the effect of type of protein supplementation and noted that when cows were changed from a silage ration (25% DM), to a milo-cottonseed hull ration (75% DM) that average daily consumption of liquid from the wheel feeders increased from 1.59 lb. to 2.25 lb. The cows were bred during the time they were confined, and no differences were noted in conception rate between the supplementation programs.

Klett (13) also discovered that liquid consumption rate from a lick-wheel self-feeder is dependent upon the energy level and total daily dry matter consumption. Hereford cows were allotted to four winter feeding treatments: (1) 100%, (2) 83%, (3) 67% of NRC (1970) energy requirements for dry, pregnant beef cows, and (4) grazing irrigated sorghum stubble. Cows in all treatments were furnished with 32% liquid protein equivalent supplement in mechanical lick-wheel feeders. The cows in the first three treatments were confined in 17 acre lots (25 animals per treatment) and fed sorghum silage to provide the appropriate energy intake. Those in the grazing treatment were stocked at the rate of 1.25 acres per animal during the 94-day wintering period, and all cows were removed from the treatments and fed 100% of their NRC energy requirement for lactating cows after they calved. Daily consumption of liquid supplement was inversely related to energy level and total daily dry matter consumption. Group (1) consumed 1.04 lb. per head daily, group (2) 1.19, group (3) 1.35 and the grazing cows consumed 1.10 lb. per head per day with no toxic or adverse effects noticed. The grazing cows gained an average 13.9 lb. during the wintering period with the 100% energy group losing 8.4 lb., the 83% energy group losing 63.5 lb., and the treatment group receiving 67% of daily energy requirement losing 60.2 lb. Calf birth weights did not vary appreciably, with the calves born in the 67% group the lightest, and those in the 100% group the heaviest. Weaning weights showed the calves from the 100% group the heaviest and the 87% group the lightest. It was concluded that cows could be confined, fed only a portion of recommended energy intake, achieve considerable savings, and not adversely affect production.

Klett (13) also found that as energy level in the ration decreased, liquid consumption increased. It was also discovered in the beef cow wintering study that the cows receiving 75% NRC energy requirements of energy from sorghum silage and 100% protein requirement from cottonseed meal had the highest cost of feeding per day when compared to groups receiving 75% and 67% of NRC recommended energy intake from sorghum silage and self-fed 32% liquid protein supplement. Cows receiving 100% energy requirements and no supplemental protein were the least costly and the low energy level and liquid supplement the next least costly. Weight and percent fat change differences between treatments were minor and not considered detrimental to subsequent cow performance.

Klett (13) also stated that the relation between energy and liquid protein consumption indicates that reduced energy intake appears to be compensated for by increased liquid consumption with resulting small weight change differences. It was concluded that the cattle performed as well in all the trials on liquid supplements as on dry protein sources, when fed rations equal in energy, and furthermore, excessive liquid consumption (over 2.5 lb. per head per day) is indicative of poor range conditions.

Klett (13) concluded that energy intake affects liquid consumption, and Braund (5) demonstrated that protein intake influences consumption of liquid as animals attempt to compensate for insufficient protein in the diet by increasing liquid consumption from wheel feeders. Twenty-four Holstein cows were allowed liquid protein supplement via individual wheel feeders in a stanchion barn and fed dry rations formulated to meet 100% NRC energy requirements on all treatments and to provide 150%, 100%, or 50% of NRC crude protein requirements. The animals did not consume enough of the dry supplement to obtain 150% or 100% protein levels, only 125% and 84% of requirements, respectively. Liquid consumption rate increased as the diet was decreased in crude protein. The cows in the 150% requirement group consumed 1.49 lb. per cow daily, the 100% requirement group consumed 2.53 lb. per cow per day, and the group that was provided 50% of protein requirement consumed 2.91 lb. per animal daily. When total protein intake (dry plus liquid) was calculated, the cows in the 150% requirement group consumed 135% of their crude protein need, the 100% requirement group consumed 102% of their need, and the 50% treatment group consumed 75% of their protein requirement. As the beef cows did in Klett's (13) experiments, the dairy cows in Braund's trials adjusted liquid consumption as an attempt to meet specific nutritional needs.

Research reported by Braund (5) indicated other factors influence liquid consumption from a mechanical lick-wheel feeder. Formulation of the liquid supplement was found to affect free-choice consumption. Three different liquid mixtures, of unspecified content, exhibited daily rates of average animal intake of 2.97 lb., 3.08 lb., and 5.54 lb.

Season of the year also substantially affects average daily consumption. Holstein cows consumed 1.43 lb. per head daily from July through September, 2.76 lb. from October through December, 2.39 lb. from January through March, 1.09 lb. from April through June, with a 12-month average daily intake of 1.95 lb. per animal. During the 6-month barn feeding period (October through March) the average consumption of liquid protein supplement was more than twice that during the pasture season (April through September).

Observations such as these are useful in planning nutrition levels and composition of the liquid mixture and also allowable consumption rates for a given diet so the proper and most economical supplements may be provided.

PROCEDURE AND SYSTEM DESIGN

Design, construction and testing of the animal operated device for feeding liquid protein and granular energy supplements to cattle was initiated on June 1, 1973. Development of the feeding unit progressed from the design, construction and testing of the basic components in the Agricultural Engineering Laboratories at South Dakota State University to the construction of a model feeder, tested in the Farmers Union Grain Terminal Association (GTA Feeds) livestock research facilities near Sioux Falls, South Dakota[2], to the testing of prototype design feeders near Garretson and Winner, South Dakota and to the testing of four production design feeders in North Dakota, Montana and Idaho.

The grain feeding system was developed for use with a commercial liquid feed distribution system[3] employing lick-wheels to provide the protein supplement. The basic liquid supplement feeding unit consists of a 78-inch by 48-inch by 24-inch high liquid storage container (3000 lb. capacity), four 22-inch diameter, 2-inch wide, plastic, spoked lick-wheels (Figure 1) cover and four Posi-Trol[4] units (Figure 2) designed to control daily liquid consumption rate. Typical average

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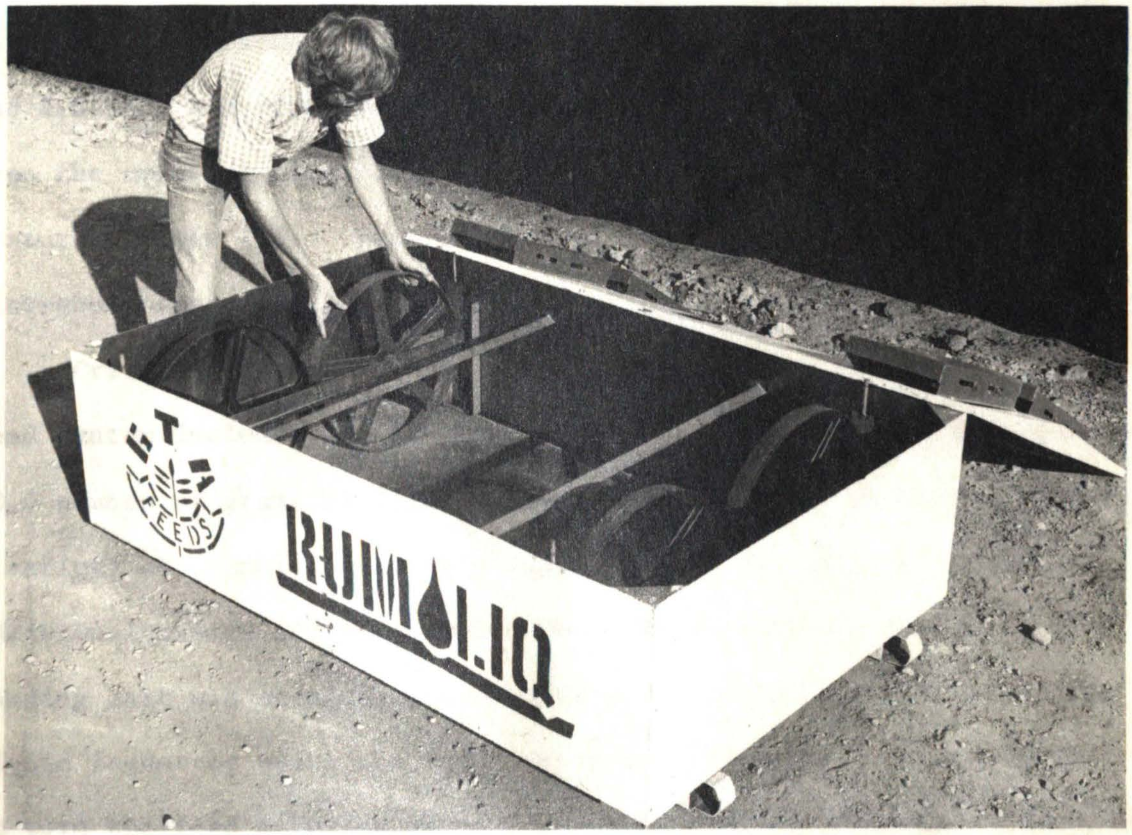
2. Research sponsored in part by Farmers Union Grain Terminal Association, Sioux Falls, South Dakota.

3. Rum-Liq Liquid Cattle Feeder, distributed by GTA Feeds.

4. Posi-Trol devices patented by GTA Feeds.

Figure 1. Basic Liquid Feeder With Lick-Wheels Exposed

Figure 2. Liquid Feeder With Posi-Trol (Consumption Control) Device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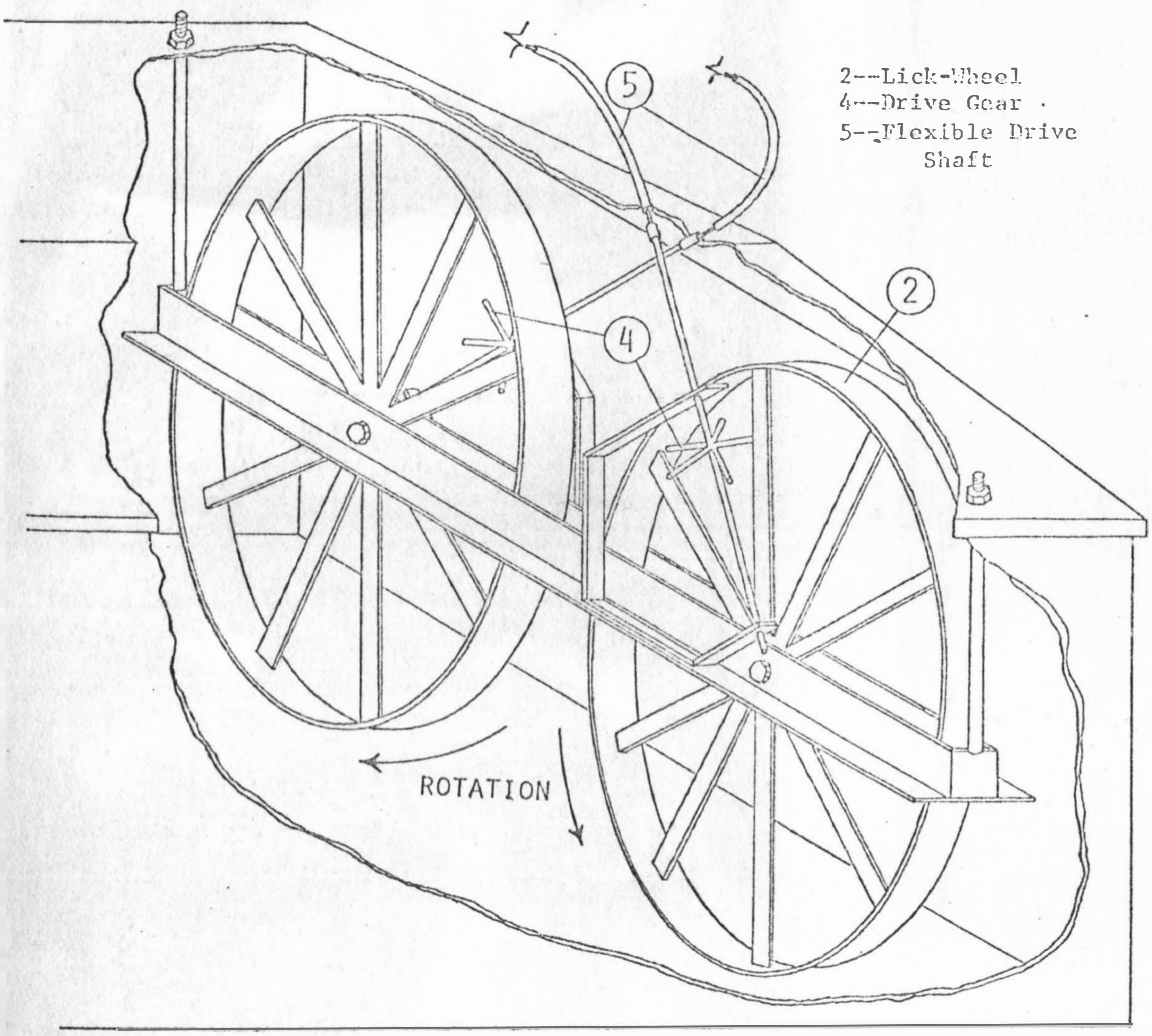

Figure 3. Liquid Feeder Lick-Wheels and Drive Mechanism

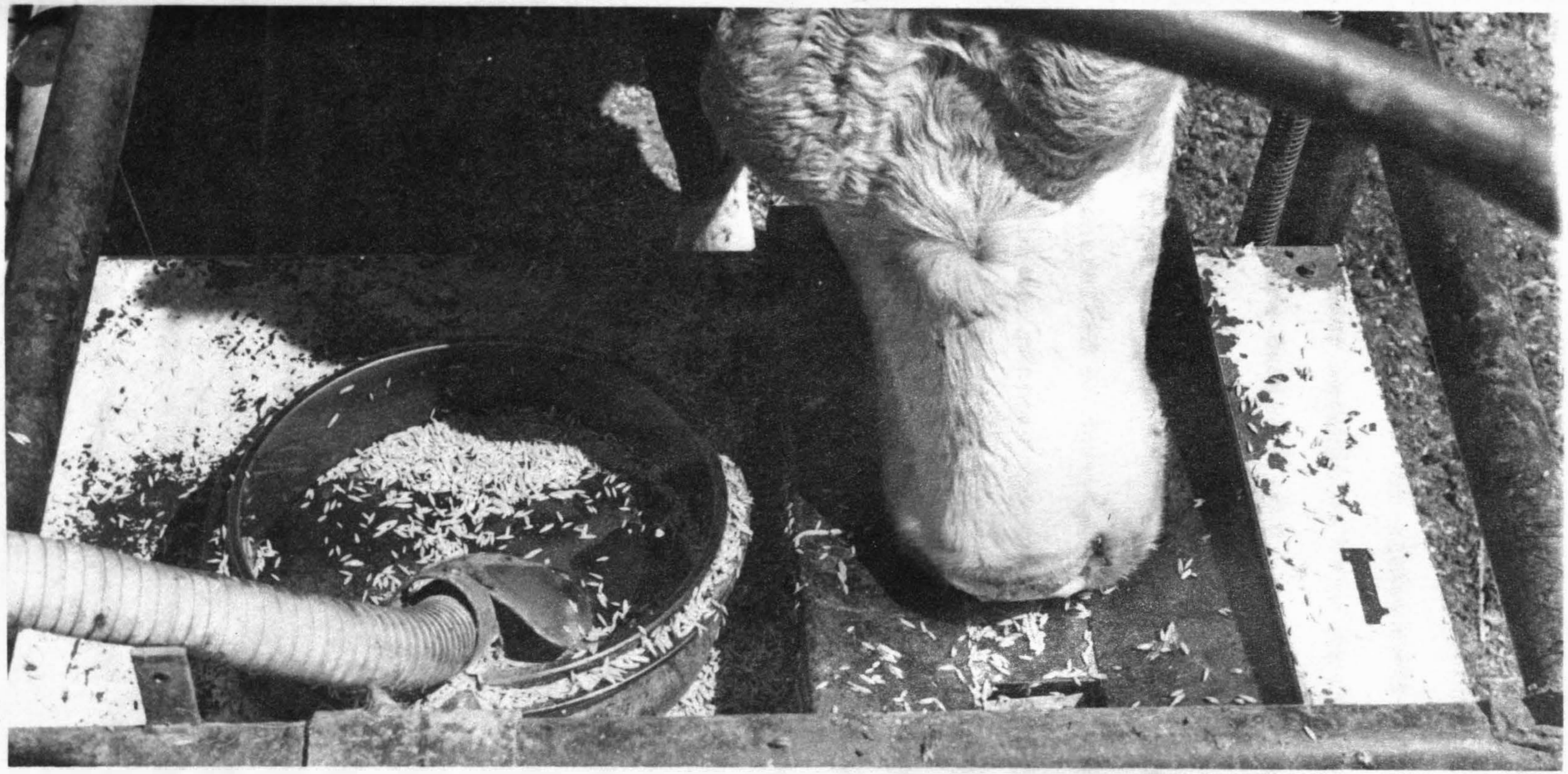

Figure 4. As the Animal Consumes Liquid Supplement by Rotating the Lick-Wheel, Supplemental Granular Feed (Oats) is Released Into an Adjoining Feed Pan.

tests indicate satisfactory performance of this type of feed metering and power transmission system. The model unit was equipped with grain attachments on only two of the lick-wheels with the other two lick-wheels of the feeder secured to prohibit use by the animals. Subsequent feeder models were designed to have grain attachments for each of the four lick-wheels and feeding positions.

The first granular feed metering device tested was a fluted wheel with flow controlled by varying the opening area above the fluted wheel. The device did not provide the precision needed to control feed flow rate and was also severely limited as to the type of material which would pass between the edges of the fluted wheel and its housing.

A variable delivery, horizontal screw meter was then developed and tested. When rotated, the screw gathers an amount of granular feed which is discharged through an exit port. The amount of feed discharged per revolution is determined by the distance which the leading end of the screw penetrates into the feed supply. The position of a parallel slide located above the screw determines the penetration depth. Horizontal adjustment of the slide produces a corresponding change in the position of the angle of repose of the granular feed and the screw delivery rate is proportional to the length of feed penetration by the screw. Improved proportioning of granular feed volume was achieved in subsequent feeder designs by tapering the leading flights of the screw from full flighting dimension to axle diameter (Figure 5). Wire agitators and increased entrance and exit port areas relieved

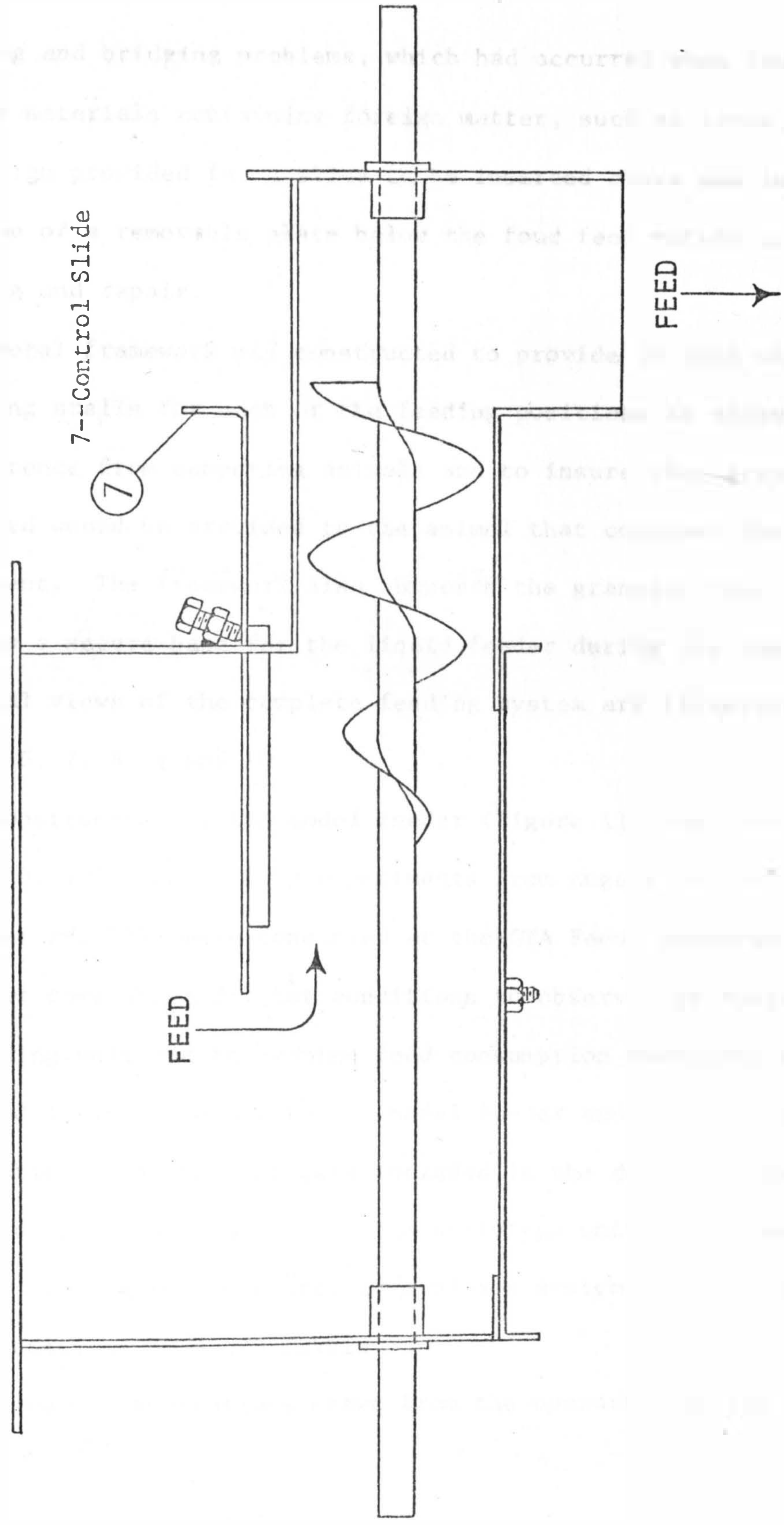

Figure 5. Feed Meter Assembly

plugging and bridging problems, which had occurred when finely ground feed or materials containing foreign matter, such as straw, were fed. The design provided for a slide to be inserted above and included the location of a removable plate below the four feed meters to allow for cleaning and repair.

Metal framework was constructed to provide 30 inch wide by 30 inch long stalls for each of the feeding positions to minimize interference from competing animals and to insure that granular feed delivered would be provided to the animal that consumed the liquid supplement. The framework also supports the granular feed tank and provides a secure base for the liquid feeder during use and transit. Sectional views of the complete feeding system are illustrated in Figures 6, 7, 8, 9 and 10.

Construction of the model feeder (Figure 11) was completed on August 10, 1973 and feeding experiments from August 14, 1973 to September 29, 1974 were conducted at the GTA Feeds research facilities with beef cows under dry-lot conditions to observe the operation of the feeding unit and to examine feed consumption characteristics.

Modifications added to the model feeder and further improvements noted during model testing were included in the design of two identical prototype feeders (Figure 12). The prototype units were completed on February 1, 1974 and were used to evaluate system operations under range conditions in South Dakota.

Based on observations drawn from the operation of the model and plugging and bridging problems, which had occurred when finely ground feed or materials containing foreign matter, such as straw, were fed. The design provided for a slide to be inserted above and included the location of a removable plate below the four feed meters to allow for cleaning and repair.

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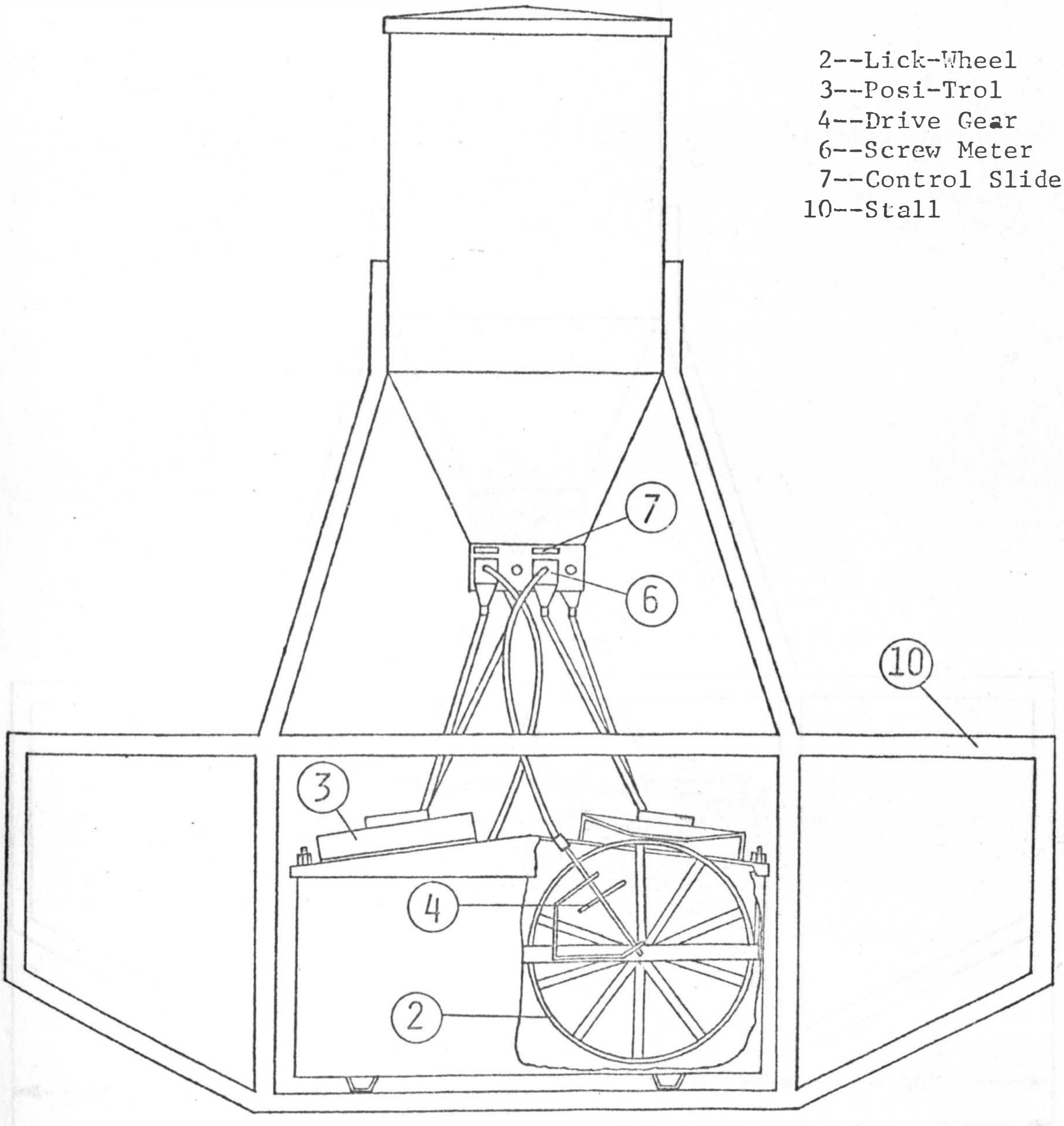

Figure 6. Liquid-Grain Feeding Unit--Side View

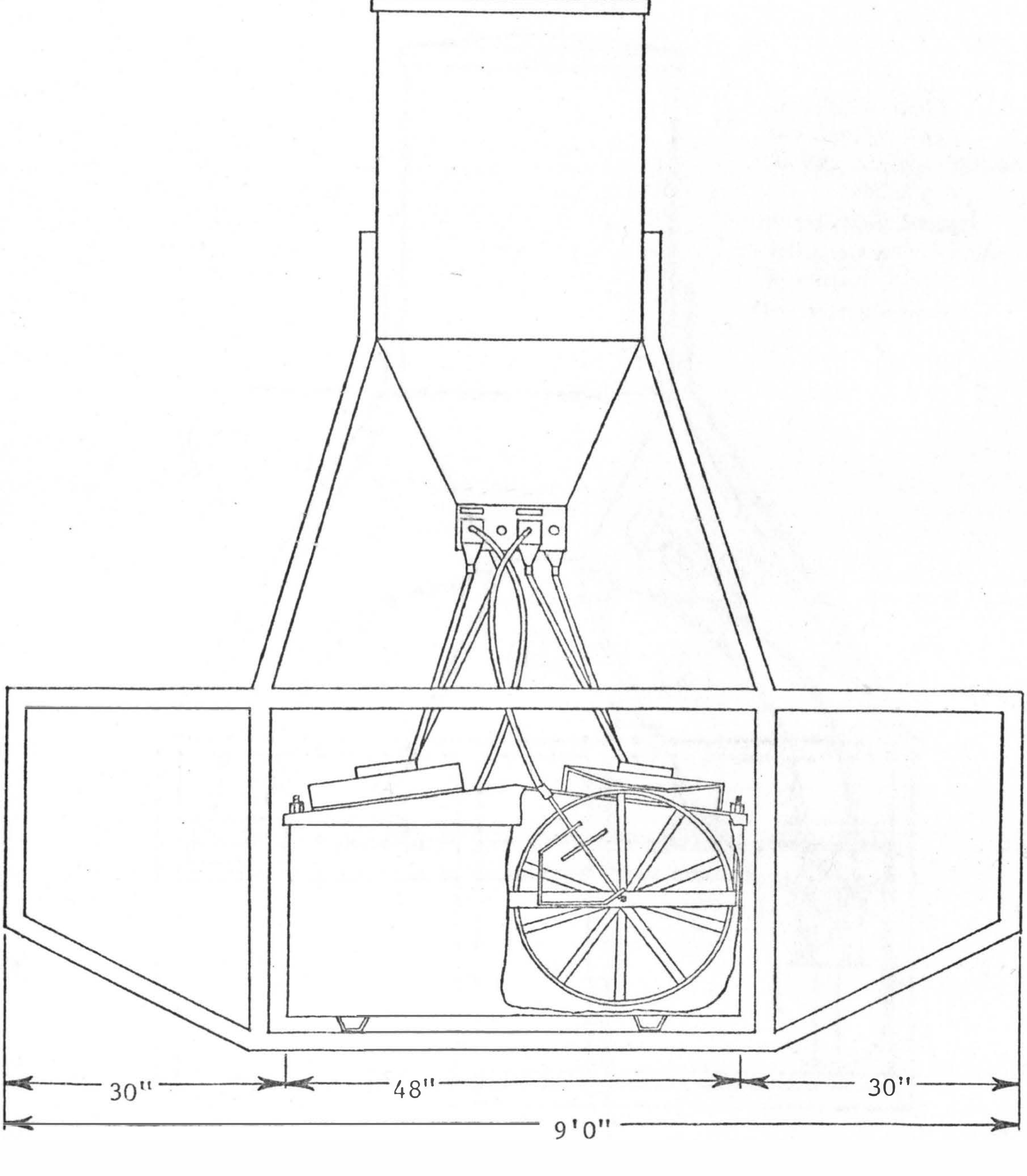

Figure 7. Side View Dimensions of the Model Feeding Unit

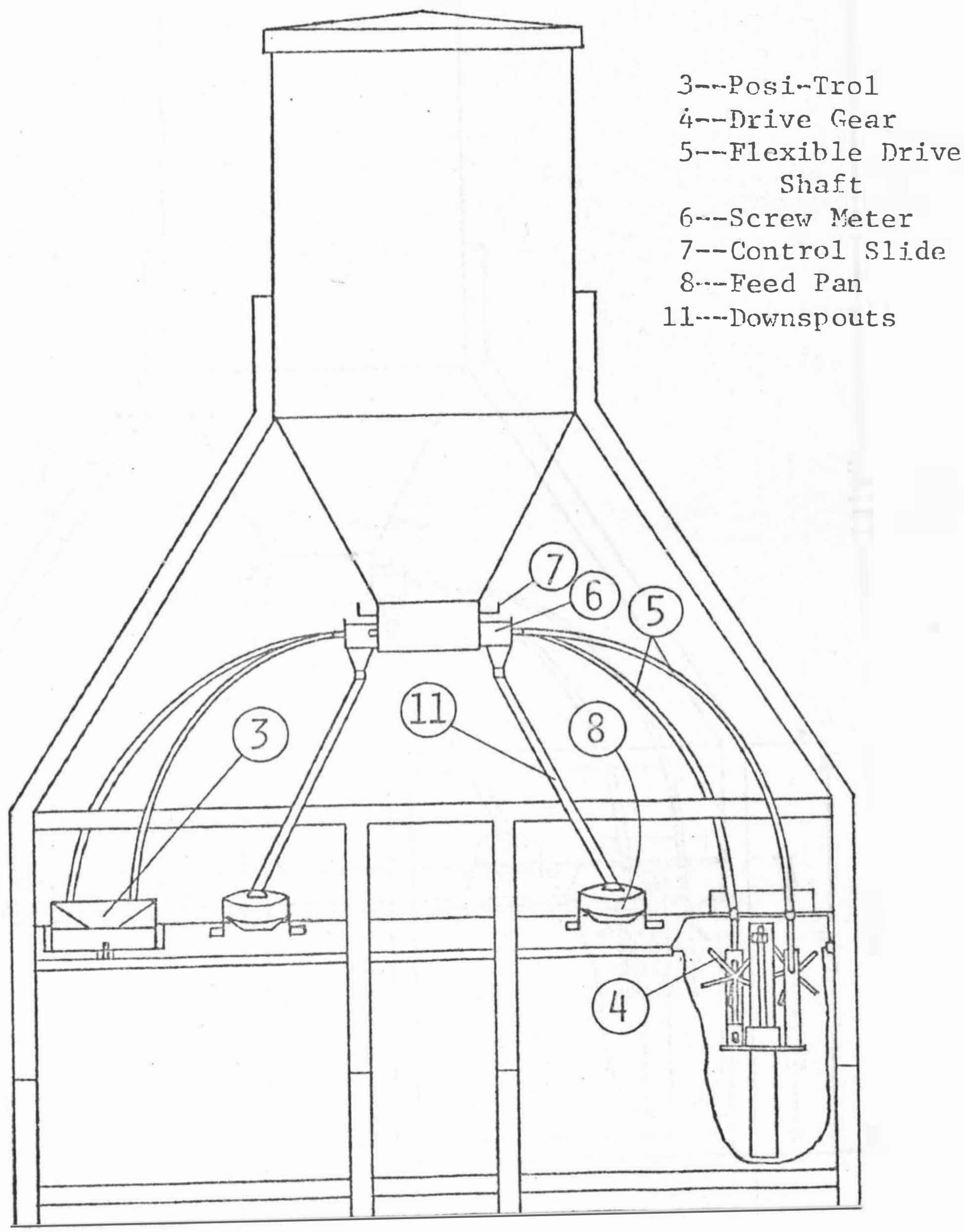

Figure 8. Liquid-Grain Feeding Unit--Front View

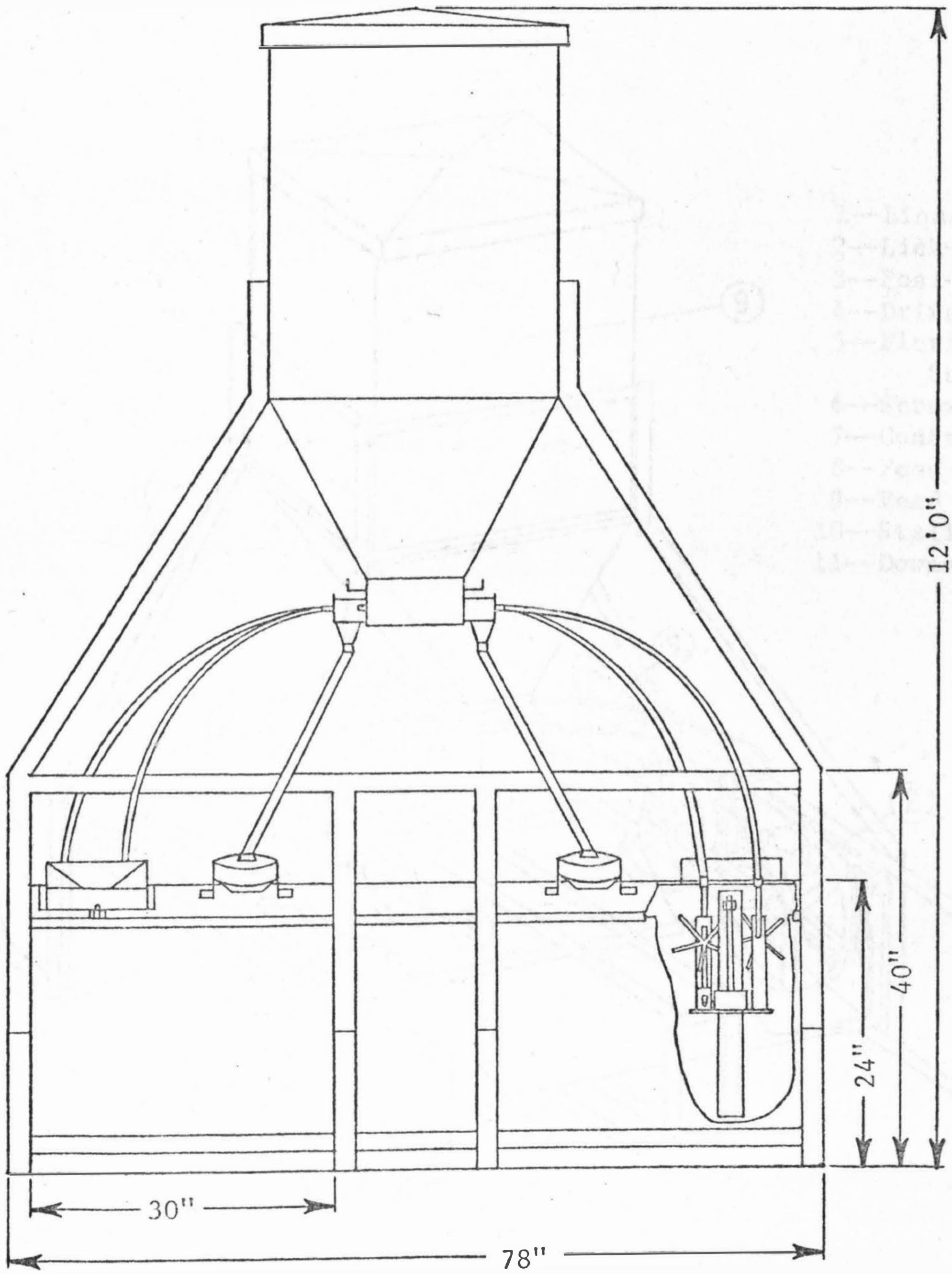

Figure 9. Front View Dimensions of the Model Feeding Unit

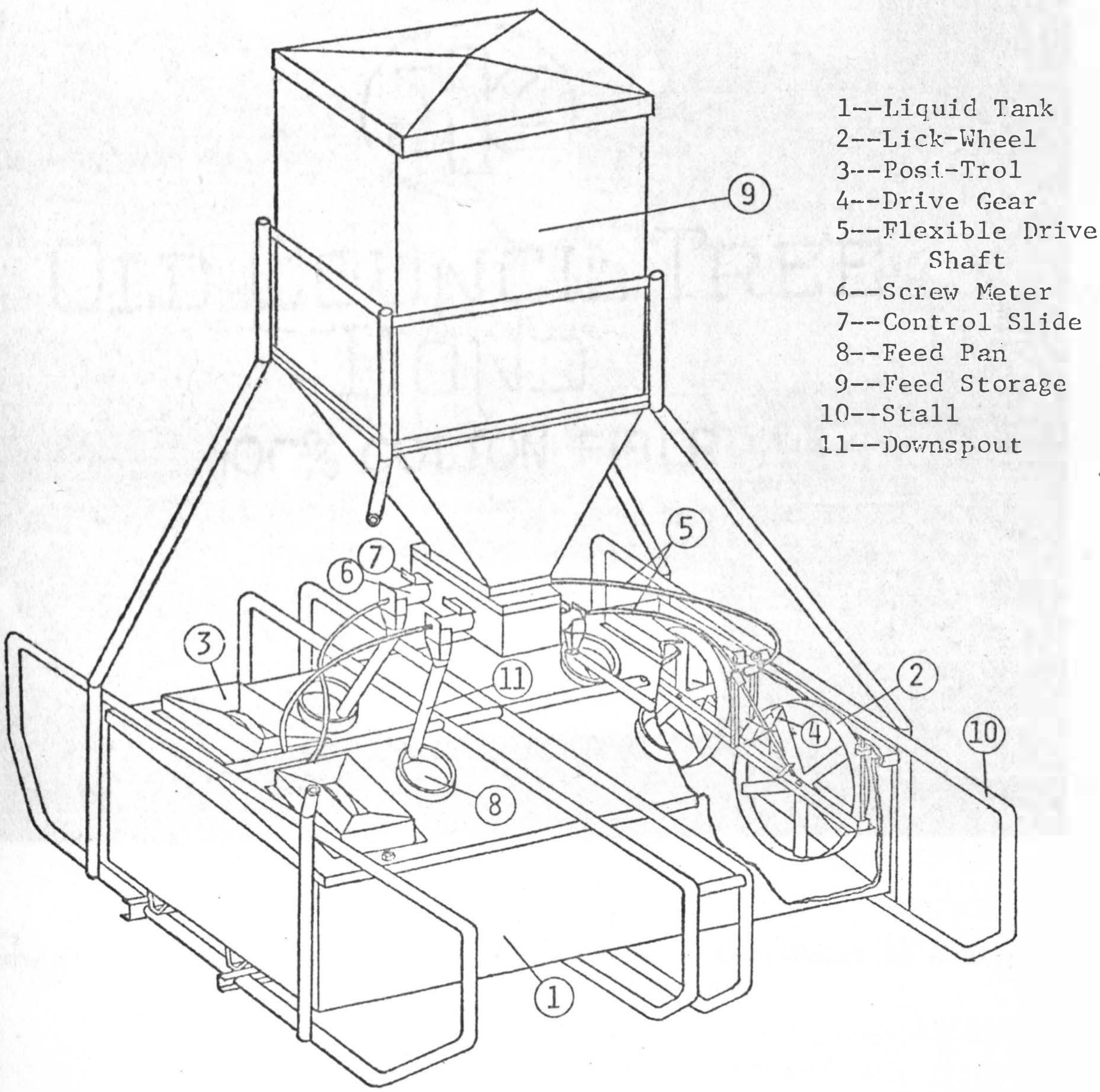

Figure 10. Liquid-Grain Feeding Unit--Perspective

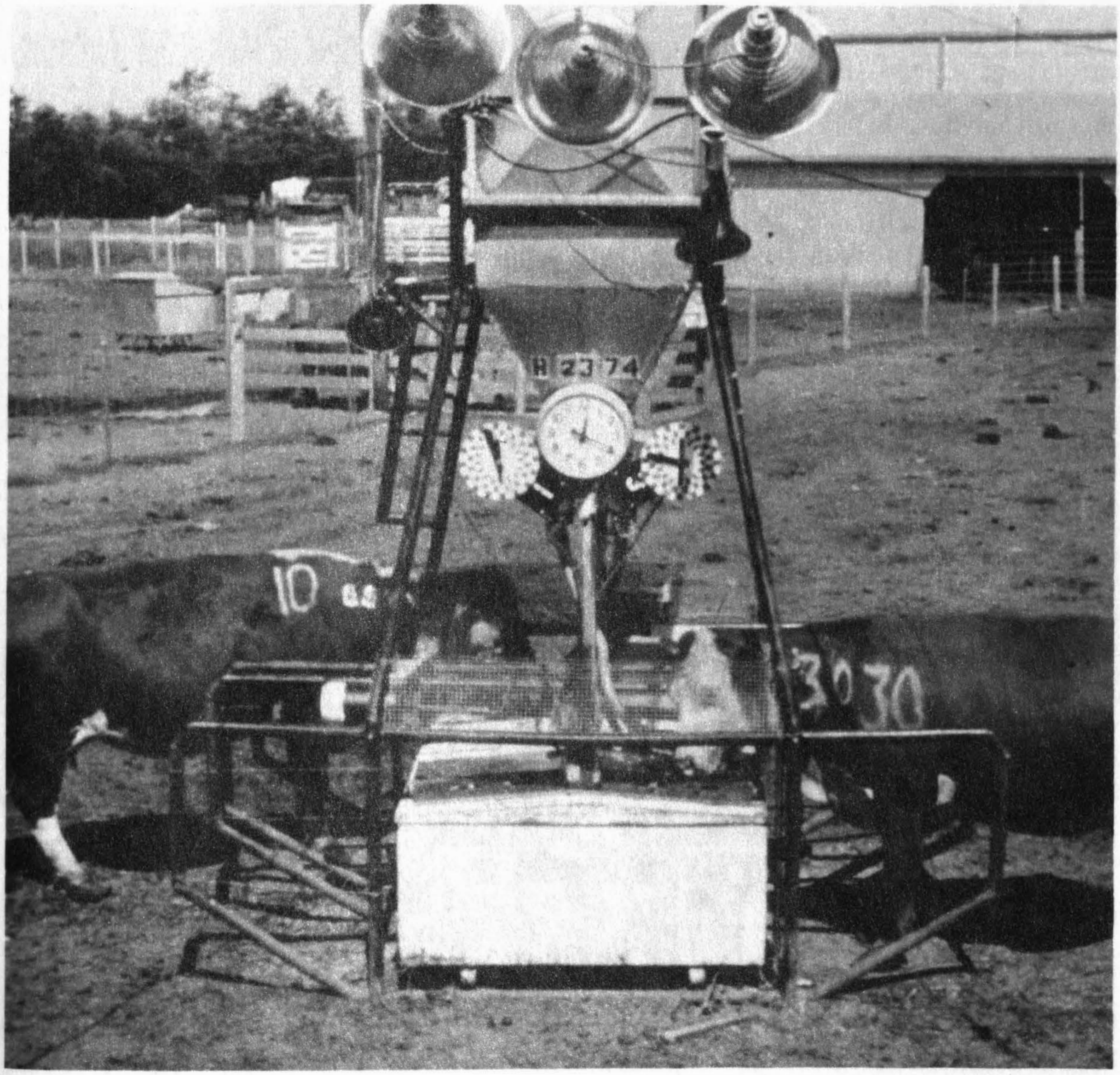

Figure 11. Animals Shown Using the Model Feeding Unit Which is Equipped With the Time Lapse Photography Apparatus.

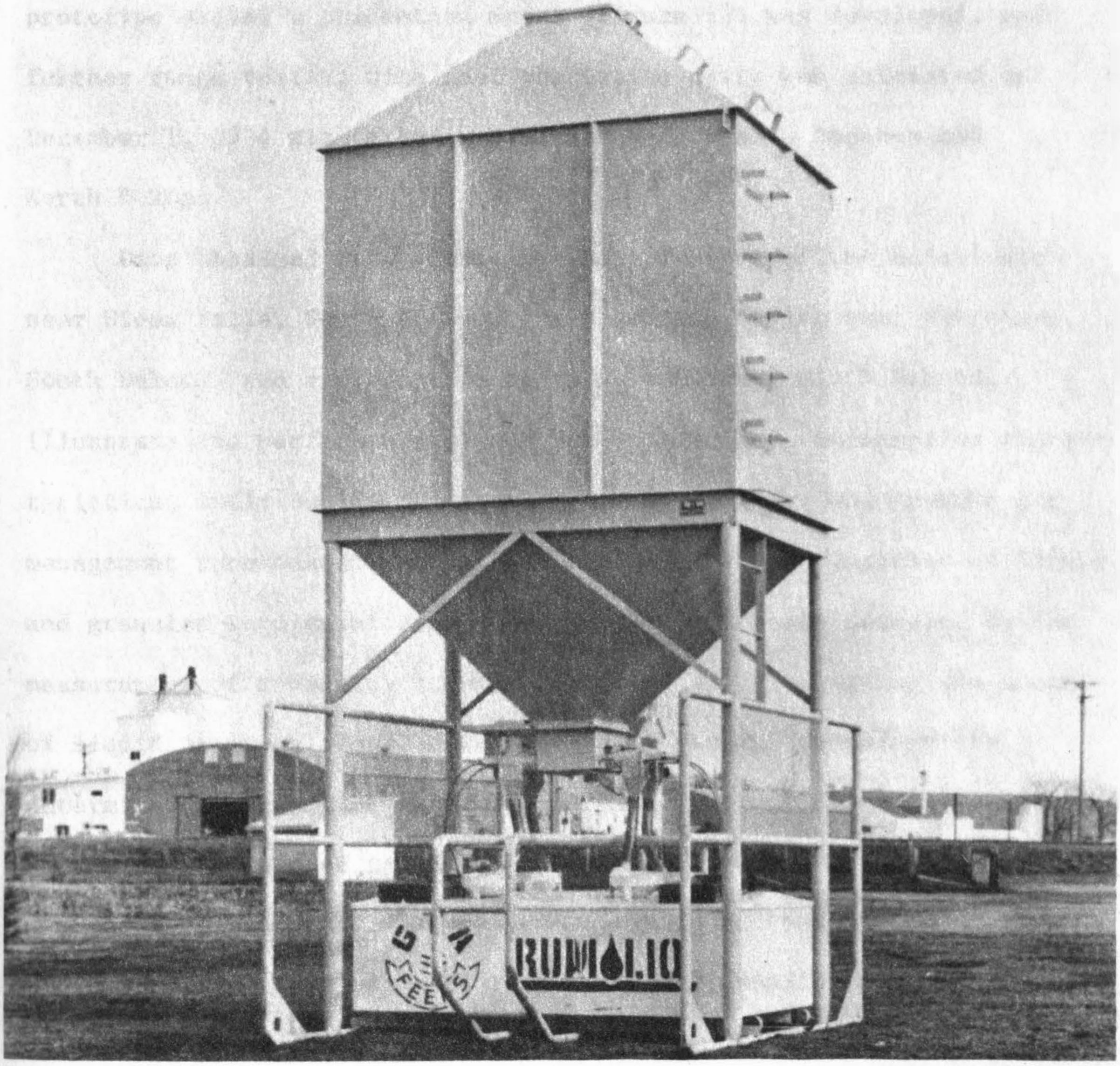

Figure 12. Front View of the Prototype Liquid-Grain Cattle Feeder.

prototype units, a production model (Figure 13) was developed, and further range testing with four production units was initiated on December 1, 1974 with grazing beef herds in Idaho, Montana and North Dakota.

Data obtained from observing the operation of the model unit near Sioux Falls, South Dakota, the prototype feeder near Garretson, South Dakota, and a production model near Medora, North Dakota, illustrate the performance of the feeding devices, consumption characteristics, individual participation of the animals, and reasons for management recommendations for the feeding system. Quantity of liquid and granular supplement consumed per time period was assessed by the measurement of remaining amounts contained or by recording the amount of liquid or grain required to refill the storage containers to a determined level. Lick-wheel and screw meter revolutions were recorded by counters connected to the axle of each of the feed metering units. A stage level recorder was mounted on the liquid tank cover of the prototype feeder and was used to continuously monitor the reduction in liquid depth, which is convertible to pounds consumed.

Time lapse photography techniques were used to evaluate individual animal use of the model feeder. Through the use of photoelectric switching equipment, a movie camera, positioned 30 feet south of the feeder, photographed with singular picture frames the animal identification number, time and the relative position of the lick-wheels. The camera was activated only when the animals were in the process of

Figure 13. Front View of the Production Model Liquid-Grain Cattle Feeder.

entering or exiting the feeder stalls. By comparing animal entrance and exit pictures, the number and time of the entrances to and exits from the feeder were recorded, yielding the amount of time the feeder was occupied by the individual animals. The pictures, when compared, also illustrate the number of lick-wheel revolutions compiled by the animals as shown by dial indicators which were driven by the rotation of the lick-wheels. Figure 11 illustrates the experimental arrangement as seen by the movie camera during the time study. Note the lights positioned for night photography, the clock mounted on the feeder, the lick-wheel rotation dial indicators and the animals in the feeder stalls with their individual identification numbers.

A comparison of the costs incurred with different pasture supplementation methods was made by relating the daily expense of owning, operating and maintaining the liquid-grain feeder to the costs of providing a comparative pasture supplement by commonly practiced methods. Hourly charges were calculated for the use of a tractor and self-unloading wagon, and of a pickup truck, since the cost of supplement distribution by these methods is dependent upon the amount of time that is required to deliver the feed to the animals.

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RESULTS AND DISCUSSION

Model feeder system testing from August 14 to December 13, 1973 in the GTA Feeds 2.84-acre dry-lot research facilities with 30 Hereford beef cows revealed that the cows were able to provide sufficient physical energy to operate the feeding device. The cows, having had previous experience in operating lick-wheel type liquid feeders, learned within several days to turn the wheels to receive liquid and grain supplements. During this period the cows were fed alfalfa or prairie hay ad libitum, and 33% protein equivalent (molasses-urea based) liquid supplement and whole oats were provided by the model unit.

Before this period, the amount of liquid supplement consumed per lick-wheel revolution was unperceived, therefore, the delivery rate of the granular feed meters required to provide desired ratios of granular feed to liquid supplement was also uncertain. Delivery rate of the screw meters was found to be insufficient, and was increased by replacing the 2.5-inch pitch meter screws with 3.5-inch pitch screws. The meters then delivered grain at an acceptable rate, but plugging and restricted flow through the feed meters, due to the presence of foreign material in the granular feed supply, still occurred. Shielding of the orifice of each delivery tube at the feed pan was installed to prevent blockage with saliva and feed dust, and it was noted that subsequent feeder designs should include deeper feed pans with concave bottoms to reduce feed loss due to wind and animal feeding actions.

Operation of the model feeder, with the modifications mentioned, was observed during three test periods from December 13, 1973 to June 20, 1974 (Table 1) at the GTA research facilities, with from 15 to 30 Hereford beef cows. The dry-lot confined animals were fed alfalfa

Table 1. Feeder Performance--Sioux Falls, South Dakota--December 13, 1973 to June 20, 1974

	Trial Dates		
	December 13 to March 3	March 4 to April 25	April 26 to June 20
Liquid Consumed (Lb)	1955	1800	2000
Oats Consumed (Lb)	3189	4925	6640
Grain to Liquid Ratio (Lb/Lb)	1.63:1	2.74:1	3.32:1
Total Lick-Wheel Revolutions	37,287	46,503	76,689
Liquid Consumption Rate (Lb/Rev)	0.052	0.039	0.026

or prairie hay ad libitum, with liquid supplement (33% protein equivalent) and oats provided by the feeder. A ratio of 3.0 lb. of oats dispensed per 1.0 lb. of liquid supplement consumed was desired. During the first test period, December 13, 1973 to March 3, 1974, 1955 lb. of liquid supplement and 3189 lb. of whole oats were consumed, establishing a 1.63 to 1.0 grain to liquid ratio. The two lick-wheels were rotated a total of 37,287 revolutions and liquid consumption per lick-wheel revolution averaged 0.052 lb. Freezing of the liquid supplement prevented operation of the feeder from December 30, 1973 to January 13, 1974. This was due to an inadequate amount of phosphoric acid in the liquid mixture (0.5% rather than 1.0%), resulting from an insufficient supply of phosphoric acid available to the liquid feed manufacturer at the time of supplement formulation.

A total of 1800 lb. of liquid and 4925 lb. of oats were consumed during the second trial (March 4 to April 25, 1974), the machine delivered an average grain to liquid ratio of 2.74 to 1.0. There were 46,503 lick-wheel revolutions and liquid consumption per lick-wheel revolution was found to average 0.039 lb. for this period.

In the third trial period (April 26 to June 20, 1974), the animals consumed 2000 lb. of liquid and 6640 lb. of oats. The grain to liquid ratio averaged 3.32 to 1.0 and lick-wheel revolutions totaled 76,689 with average liquid consumption rate being 0.026 lb. per lick-wheel revolution. The difference in liquid provided per wheel revolution between the three trials was related to viscosity of the liquid and temperature, which averaged 16.5° F for trial 1, 37.9° F for trial 2 and 57.8° F for trial 3.

The feeding device operated properly under typical South Dakota winter conditions, provided that the proper liquid formulation to prevent supplement freezing was used. However, difficulty was encountered in maintaining grain flow and machine operation when granular feeds containing straw or fine particle matter were fed, due to the small diameter (2.25 inch) screws and the restricted port area of the feed meters. Therefore, because of interruptions in machine operation and since the number of cattle having access to the feeder was not constant during the three periods cited, daily liquid and grain consumption per animal were not calculated.

Data are presented for the fourth feeding period, September 22 to September 29, 1974 in Table 2. The 30 animals in the trial were

Table 2. Feeder Performance--Sioux Falls, South Dakota--September 22 to September 29, 1974

	Trial Date September 22 to September 29
Lick-Wheel Revolution Rate (Rev/Animal/Day)	86.2
Liquid Consumption Rate (Lb/Rev)	0.015
Daily Liquid Consumption Rate (Lb/Animal/Day)	1.27
Daily Grain Consumption Rate (Lb/Animal/Day)	11.28
Grain to Liquid Ratio (Lb/Lb)	8.9:1
Lick-Wheel Stocking Rate (Animals/Wheel)	15.0

confined to a 2.84 acre (4125 ft^2/ animal) dry-lot and were fed alfalfa-brome hay free choice. The liquid-grain supplement feeder provided 22% protein equivalent liquid and cleaned whole oats to the animals, which were allowed unrestricted access to the feeder with one lick-wheel per 15 head. Of the 30 animals in the group, there were 17 Hereford beef cows, 12 breeding heifers and one bull. The cows and the bull had four years previous lick-wheel feeder experience, but the heifers had only 17 days previous experience. The animals consumed an average of 1.27 lb. of liquid and 11.3 lb. of oats per animal per day, establishing a grain to liquid ratio of 8.9 to 1.0, with the lick-wheels turned at a rate of 86.2 revolutions per animal daily. The increased grain to liquid ratio of 8.9 to 1.0 occurred because cleaned oats, which had better flow characteristics through the grain meters, were fed during this trial and because the liquid consumption rate per lick-wheel revolution declined to 0.015 lb. at an average temperature of 57.0° F for the period. The reduction in liquid consumption rate follows the previously noted trend that liquid consumption rate per lick-wheel revolution varies inversely with average ambient temperature.

Consumption rate of liquid per lick-wheel revolution for the 12 month period varied from 0.015 to 0.063 lb. Figure 14 illustrates the approximate liquid consumption rates observed for different periods of the year and average monthly temperature. In order that desired grain to liquid ratios may be established and maintained, the calibration of the granular feed meters should be based upon such data. Both 22%

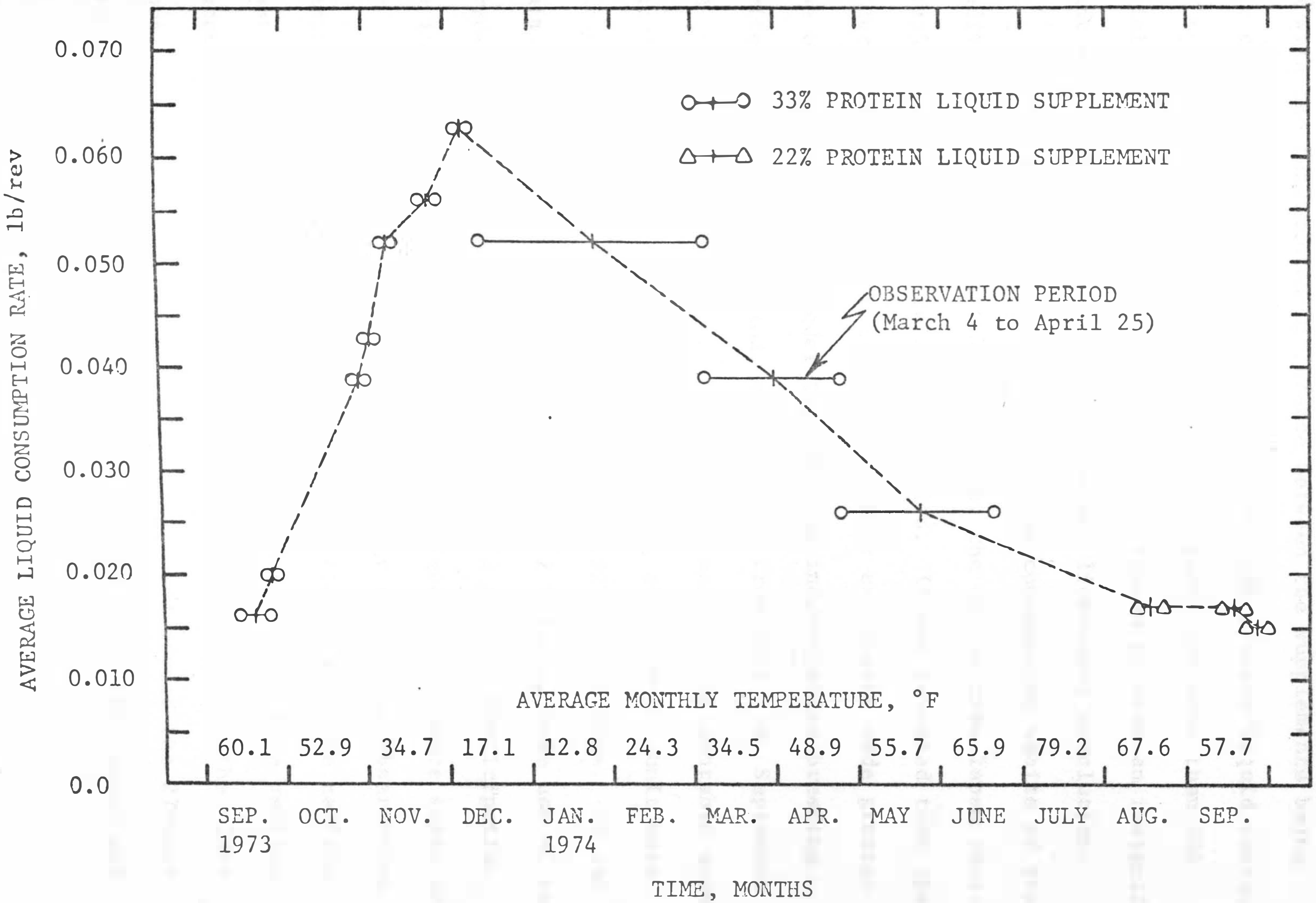

Figure 14. Average Liquid Consumption per Lick-Wheel Revolution Related to Time of Year and Average Monthly Temperature for the Model Feeder at Sioux Falls, S.D.

and 33% protein equivalent liquid supplements are included in Figure 14 with the fundamental difference between the supplements being the comparative urea content and that the 22% protein liquid contains up to 46% moisture and the 33% protein liquid, not more than 42% moisture, when formulated. This was considered to have an insignificant effect on the liquid consumption per lick-wheel revolution.

During the fourth study period, the consumption habits of the individual animals were investigated by the use of time lapse photography techniques for one 27-hour period. It was revealed that the older animals with prior lick-wheel feeder experience made greater use of the supplement feeder than did the inexperienced breeding heifers. Within the period, which lasted from 2:09 p.m. September 28 to 5:24 p.m. September 29, 1974, there were 306 accountable animal entries into the feeder and the two stalls of the model unit were occupied approximately 3049 minutes or 97.82% of the time. Of the 30 animals, 18 or 60% (15 cows, the bull and 2 heifers) made use of the feeder, while 40% did not (10 heifers and 2 cows). Participation is indicated to increase with lick-wheel feeder experience since 88.8% of the older animals made use of the feeder during the observation period while 83.3% of the heifers did not (Table 3). The heifers that did use the feeder tended to participate during idle periods because they were usually forced to leave the feeder by the older cows. However, as the study period progressed beyond the 27-hour period, the heifers became more adept at operating the feeder and

Table 3. Individual Animal Use of the Model Unit from 2:09 p.m. September 28 to 5:24 p.m. September 29, 1974

Animal Identification	Entries	Active Entries	Time of Occupation Minutes	Lick-Wheel Revolutions	Time per Active Entry Minutes	Lick-Wheel Revolution Rate Rev/Min
30 C*	22	19	317	290	16.68	0.99
10 C	39	24	192	281	8.00	1.46
16 C	34	21	214	163	10.19	0.76
17 C	25	11	146	211	13.27	1.45
15 C	24	14	257	295	18.36	1.15
5 C	20	14	155	159	11.07	1.03
9 C	48	34	327	295	9.62	0.90
24 C	30	19	497	365	26.16	0.73
3 C	4	4	91	159	22.75	1.75
14 C	25	19	331	303	17.42	0.92
11 C	9	7	79	37	11.29	0.47
31 B	10	10	128	158	12.80	1.23
26 C	4	4	159	175	39.79	1.11
29 C	3	2	8	10	4.00	1.25
21 C	1	1	5	2	5.00	0.40
25 H	2	2	22	24	11.00	1.09
12 H	1	1	2	1	2.00	0.50
19 C	5	4	119	137	29.75	1.15

* Denotes a Cow, Bull or Heifer

more aggressive in their feeding habits.

In comparing the consumption habits of the animals, it was found, that while cow #9 entered the feeder the greatest number of times (48 entries in the 27-hour period) cow #24 compiled the highest occupation time and greatest number of lick-wheel revolutions (365 revolutions in 497 minutes and 30 feeder entries). Two cows had an equal number of lick-wheel revolutions, but cow #5 took 20 entries and 155 minutes to complete 159 revolutions while it required cow #3 only 4 entries and 91 minutes to accomplish an equal number of wheel revolutions.

These observations illustrate the importance of managing the use of the feeder so as to feed animals of similar age, weight and feeder experience during the first approximate three weeks of feeder usage. They also illustrate the individuality of the animals in relation to their consumption characteristics and proficiencies of feeder operation and serve to indicate that the number of entries by the animal to the feeder and the time spent in the feeder by an animal are not accurate indicators of lick-wheel rotation and feed consumption. It was also shown that not enough animals of similar experience and proficiency were present to create ample competition for use of the feeder to reduce consumption to an acceptable and economical level. When initially using the feeder it may be necessary to remove the Posi-Trol units temporarily, exposing more of the lick-wheels so that the inexperienced animals may learn more easily to operate the feeder, but experienced animals should not have access to the feeder when the consumption limiting devices are removed.

A pasture feeding study employing a prototype feeder, designed to provide 300 ft^3 of granular feed storage capacity, to use feed meters with 3.5-inch diameter tapered screws and expanded port areas and to have improved feed pans, was conducted from April 15 to June 10, 1974, near Garretson, South Dakota. Data (Table 4) reflect system performance for 120 lactating beef cows, that had had previous

Table 4. Prototype Performance--Garretson, South Dakota--May 31 to June 7, 1974

	Trial Results
Lick-Wheel Revolution Rate (Rev/Animal/Day)	26.1
Liquid Consumption Rate (Lb/Rev)	0.023
Daily Liquid Consumption Rate (Lb/Animal/Day)	0.59
Daily Grain Consumption Rate (Lb/Animal/Day)	2.3
Grain to Liquid Ratio (Lb/Lb)	3.9:1
Lick-Wheel Stocking Rate (Animals/Wheel)	30.0

experience with lick-wheel liquid feeders, as they grazed a 70-acre, alfalfa pasture. The seven day study period was chosen as being representative of system performance after the animals had become accustomed to the operation of this feeder. It was noted that initially, the animals were apprehensive toward entering the stalls of the feeder, and that the Posi-Trol units had to be removed for several days to enact feeder usage. Commercial, 22% protein equivalent liquid supplement and a granular energy supplement consisting of 2/3 rolled yellow corn and 1/3 whole oats, were provided by the prototype unit. The grain meters were calibrated to deliver 4.0 lb. of grain for every pound of liquid supplement consumed, with 1.0 lb. of liquid per head daily the desired intake.

During the seven day period, the animals turned the four lick-wheels at a rate of 26.1 revolutions per head daily, consumed liquid at a rate of 0.023 lb. per lick-wheel revolution (65° F the average temperature) and received 0.59 lb. of liquid and 2.3 lb. of grain per head per day. This established a grain to liquid ratio of 3.9 to 1.0 which indicated adequate performance of the granular feed meters in delivering a desired grain to liquid ratio. Figure 15 represents the liquid consumption pattern observed for the period. The consistency with which liquid supplement was consumed from the feeder indicates the animals had developed a consistent consumption pattern and uniform consumption rate of liquid and grain. However, daily liquid consumption per animal was lower than had been anticipated (0.59 lb. compared to 1.0 lb/day desired) and this may have been due to excessive restriction

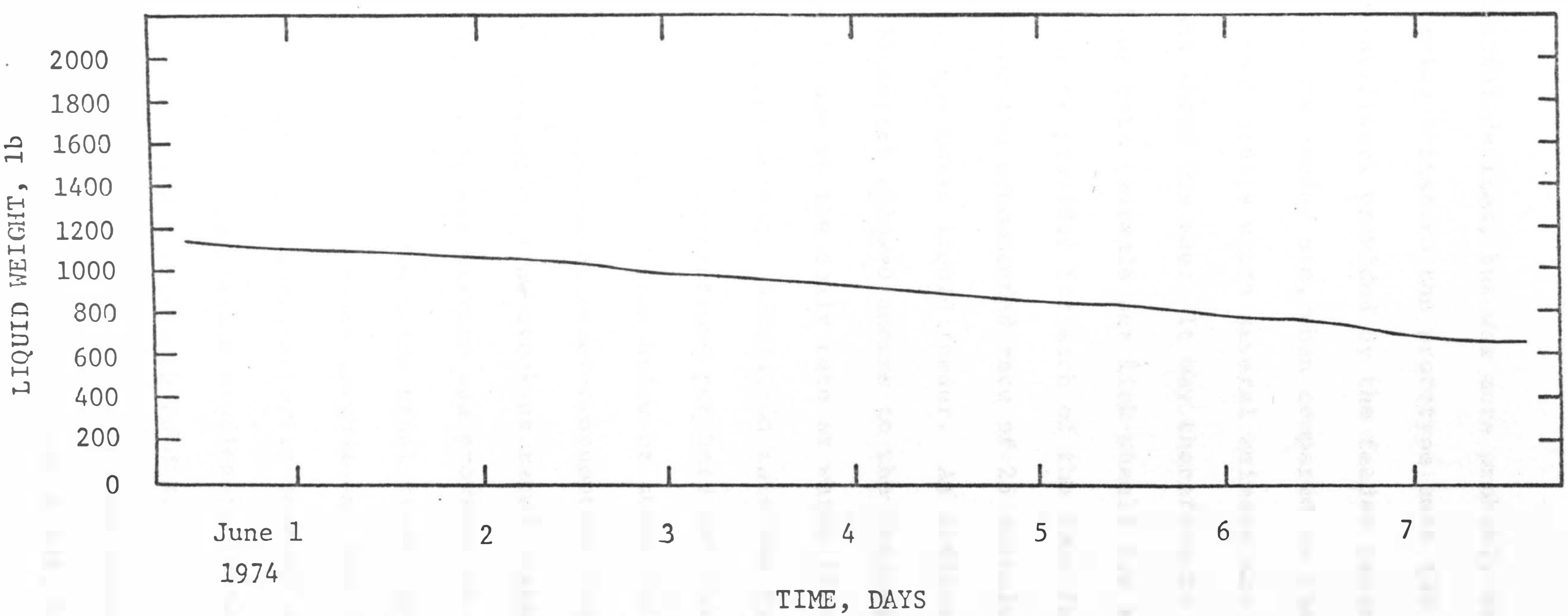

Figure 15. Consumption of Liquid from the Prototype Feeder Related to Time; 120 Cattle on Pasture Near Garretson, S.D.

by the consumption control devices, but was more probably the result of too many animals having access to the prototype unit (30 animals per lick-wheel). The stallwork provided by the feeder tended to suppress animal traffic and feeder use, when compared to that observed for liquid feeders without stalls where several animals may approach the same lick-wheel and share its use. It may therefore be assumed that lick-wheel stocking rate (animals per lick-wheel) for such a feeding unit with stallwork provided for each of the four feeding positions should be below the recommended rate of 25 animals per lick-wheel, Witmer (36), for the basic liquid feeder. An indication of the proper number of livestock allowed access to the feeding unit (animals per lick-wheel) may be the daily rate at which lick-wheel revolutions are compiled per animal. Revolution rate was typically observed to vary from 25 to 100 revolutions per head per day with the model and prototype units, with rates below or above this typical range usually indicative of supplement under-consumption (excessive stocking rate) or over-consumption (low stocking rate), respectively.

While a rolled corn-whole oat mixture was provided by the prototype unit during the pasture supplementation trial cited, granular feed products ranging from a finely ground sorghum-oat mix to a pelleted barley supplement were fed satisfactorily through the other prototype unit during range supplementation studies conducted in 1974 with beef cows and heifers near Winner, South Dakota.

In December, 1974, the testing of four production model liquid-grain feeders to be used for winter range supplementation, was initiated with units located in Idaho, Montana and North Dakota. One feeder was located near Medora, North Dakota, for use with 48 heifers, and its operation was observed as the 450 lb. animals grazed 200 acres of winter pasture. The animals were also fed 10 to 12 lb. of hay per head daily and had access to salt and mineral. The feeding unit contained whole oats and 33% protein equivalent supplement, and was stocked at a rate of 12 animals per lick-wheel with the grain meters calibrated to deliver a 3.0 to 1.0 grain to liquid ratio (assuming a liquid consumption rate of 0.05 lb. per lick-wheel revolution).

The heifers, which had no previous lick-wheel feeder experience, hesitated initially to use the feeding device, compiling only 56 total lick-wheel revolutions from December 16, 1974 to January 13, 1975. The Posi-Trol units were removed from the liquid feeder cover on January 13, exposing more of the lick-wheels to the heifers, then reinstalled on January 23. The information in Table 5 illustrates how rapidly the animals learned to operate the production model feeder as daily liquid consumption and lick-wheel revolution rates increased and as liquid consumption per lick-wheel revolution decreased over the study period to a rate similar to those observed during previously cited studies for that period of the year.

From January 13 to February 16, 1975, approximately 4260 lb. of oats and 2068 lb. of liquid supplement were consumed by the 48 heifers, but because the grain meters were readjusted on February 4 to reduce the delivery rate, an accurate assessment of the average grain to

Table 5. Production Model Performance--Medora, North Dakota--December 30, 1974 to February 16, 1975

Date	Lick-Wheel Revolutions	Ave. Lick-Wheel Revolution Rate (Rev/Animal/Day)	Ave. Liquid Consumption Rate (Lb/Rev)	Ave. Daily Liquid Consumption (Lb/Animal/Day)	Lick-Wheel Stocking Rate (Animals/Wheel)
Dec. 30-Jan. 13	9				
Jan. 14-Jan. 23	6,139	12.8	0.084	1.08	12
Jan. 24-Feb. 3	13,222	27.5	0.043	1.18	12
Feb. 4-Feb. 10	8,656	25.8	0.054	1.40	12
Feb. 11-Feb. 16	14,189	49.3	0.036	1.80	12

liquid ratio provided by the feeder can not be ascertained for the period. On March 1, the heifers were weighed and sold with average daily gain for the period (December 30, 1974 to March 1, 1975) found to be 2.125 lb. per head per day. Once the animals learned to operate the liquid-grain feeder, no problems were encountered in either animal participation or machine performance.

Pasture or forage supplements are commonly provided to grazing beef animals with a tractor and feed wagon, pickup truck or with a self-feeder. The daily expenses associated with each method may be ascertained to formulate a cost comparison for feed delivery methods with expenses required to own, operate and maintain a tractor, feed wagon and pickup truck calculated as a cost per hour of daily use and with costs attributable to the liquid-grain feeder expressed as a cost per day of use. The three methods of delivery are assumed to provide comparable pasture supplements with the feed supplement fed in wooden feed bunks and on the ground for the tractor-feed wagon and pickup truck delivery methods, respectively. Each liquid-grain feeder will accommodate 80 head of cattle, so cost comparisons are presented for the three feed delivery methods providing supplement for 80 and 240 cattle.

Purchase price of the tractor, feed wagon and pickup is assumed to be 90% of list price. The derived machine cost information (Tables 6 and 7) is based on methods used by Bowers (4), Allen (1) and Curly, Dobie and Parsons (10) with the adjustment of annual repair rate to

Table 6. Summary of Machine Costs, February 22, 1975

Implement	List Price ($)	Purchase Price ($)	Hours Used Per Year	Years Owned	Hours Life	Total Accumulated Repairs ($)	Remaining Farm Value ($)	Annual Deprecia- tion ($)	Fuel Con- sumption (Gal/Hour)
Oliver 1555 Gas, 53 Hp*	8273	7445	600	10	12000	6618.40	2456.85	498.815	3.657
Grainovator Feed Wagon*	2400	2160	1000	10	10000	1920.00	540.00	162.000	2.070
Chevrolet 3/4 Ton Pickup**	4900	4410	500	8	4000	3136.00	1102.50	413.437	2.000

* Skarloken Implement Company, Estelline, South Dakota
** Kjellsen Chevrolet & Cadillac Inc., Brookings, South Dakota

Table 7. Summary of Machine Costs per Hour, February 22, 1975

Implement	Fuel and Lubrication Cost ($/Hour)	Repair Cost ($/Hour)	Taxes, Housing, Insurance and Interest Cost ($/Hour)	Depreciation Cost ($/Hour)	Total Cost ($/Hour)
Oliver 1555 Gas, 53 Hp	1.95137	1.10306	0.82515	0.83135	4.71093
Grainovator Feed Wagon	1.10455	0.19200	0.13500	0.16200	1.59355
Chevrolet 3/4 Ton Pickup	1.06720	0.78400	0.55125	0.82687	3.22932

8% of list price per year of ownership. Machine costs per hour of annual use (Table 7) were calculated using formulas and cost coefficients shown in Tables 8 and 9.

The total cost per hour to own, operate and maintain the tractor and feed wagon plus a fixed daily expense (Table 10) to own and maintain five wooden feed bunks (80 head capacity) is illustrated in Figure 16 with labor wage rates for the tractor operator included. Pickup truck operating cost per hour is shown in Figure 17. The daily expense incurred in providing the supplement by these methods will depend on the time required to load, deliver and distribute the supplement, and return to the feed loading point. Delivery distance and weather conditions will influence the amount of time invested daily and will therefore affect the feed delivery costs.

The annual cost for the ownership and maintenance of one and three liquid-grain feeding units (Tables 11 and 12, respectively) is calculated assuming 10 years of machine use with an annual repair cost per feeder of 5% of list price. The production model feeder considered in this analysis (Figure 13) has storage capacity for 3000 lb. of liquid supplement and 185 cubic feet of granular feed, which will accommodate 80 animals for an average of 18.6 days per fill depending upon daily liquid consumption, the grain to liquid ratio and the type of grain fed. Retail feed dealers with delivery trucks equipped to haul both liquid and granular feeds receive a fee of $0.30 per mile (one-way) with a $5.00 minimum delivery charge

Table 8. Cost Summary Formulas

Average Value	$= \dfrac{\text{Purchase Price} + \text{Remaining Farm Value}}{2}$
Annual Depreciation	$= \dfrac{\text{Purchase Price} - \text{Remaining Farm Value}}{\text{Years Owned}}$
Total Accumulated Repairs	= (Annual Repair Expense)(Years Owned)
Repair Cost per Hour	$= \dfrac{\text{Total Accumulated Repairs}}{\text{(Hours Annual Use)(Years Owned)}}$
Fuel and Lubrication Cost per Hour	= (Gallons Fuel/Hour)(1.15)(Fuel Price)
Lubrication Cost	= 15% of Fuel Cost
Fuel Price (Gasoline)	= $0.464/Gallon*
Tractor Fuel Consumption per Hour	= (53 Hp)(0.069)** = 3.657 Gallons/Hour
Feed Wagon Fuel Consumption per Hour	= (30 Hp)(0.069) = 2.070 Gallons/Hour
Pickup Truck Fuel Consumption per Hour	$= \dfrac{\text{(20 Miles per Hour)}}{\text{(10 Miles per Gallon)}}$ = 2.0 Gallons/Hour

* Community Oil, Estelline, South Dakota, February 22, 1975
** Fuel Consumption Factor, Allen (1)

Table 9. Equipment Annual Expense Information

Item	Remaining Farm Value % Purchase Price	Taxes Housing Insurance % Average Value	Interest % Average Value	Repairs % List Price
Oliver 1555 Tractor	33	2	8	8
Grainovator Feed Wagon	25	2	8	8
Chevrolet 3/4 Ton Pickup	25	2	8	8
Feed Bunks	25	2	8	5
Liquid-Grain Feeder	25	2	8	5

Table 10. Summary of Costs for Five, 16' Wooden Feed Bunks, February 22, 1975

Purchase (List) Price ($)	Years Owned	Annual Repairs ($)	Annual Interest ($)	Remaining Farm Value ($)	Taxes Housing Insurance ($/Year)	Annual Deprecia-tion ($)	Total Annual Cost ($)	Total Cost per Day ($)
400.00*	20	20	20	100	8	15	63	0.1726

* Great Plains Supply, Brookings, South Dakota

Table 11. Annual Cost Summary for One Liquid-Grain Feeder

Purchase (List) Price ($)	Years Owned	Total Accumulated Repairs ($)	Annual Repairs ($)	Annual Interest ($)	Taxes Housing Insurance ($)	Remaining Farm Value ($)	Annual Depreciation ($)	Total Annual Cost ($)
2000.00*	10	1000	100	100	40	500	150	390

* GTA Feeds, Sioux Falls, South Dakota

Table 12. Annual Cost Summary for Three Liquid-Grain Feeders

Purchase (List) Price ($)	Years Owned	Total Accumulated Repairs ($)	Annual Repairs ($)	Annual Interest ($)	Taxes Housing Insurance ($)	Remaining Farm Value ($)	Annual Depreciation ($)	Total Annual Cost ($)
6000.00	10	3000	300	300	120	1500	450	1170

to fill the pasture self-feeders with one fee charged to fill several feeders in a pasture during one delivery. Therefore, if the feeders must be refilled every 18.6 days, 9.7 and 18.8 fills will be required per feeder in 180 or 350 day feed periods, respectively. One hour of labor (at $3.00 per hour) per feeder fill is included to provide for periodic machine inspection between feed deliveries. The annual machine cost with the addition of the feed delivery fees and machine inspection labor charges yields the cost to deliver the pasture supplement for the feed period (180 or 350 days) with the liquid-grain self-feeder. Tables 13, 14 and 15 summarize the costs involved in operating one feeder (80 head) for 180 and 350 days per year and three feeding units (240 head) for 350 days per year, respectively. The cost per operating day of the liquid-grain self feeding system may then be compared to those costs derived from feed distribution by other methods. Figures 16, 17, 18 and 19 illustrate cost comparisons for one liquid-grain feeder and a tractor-feed wagon delivery system, one feeder and a pickup truck, three feeders with a tractor and feed wagon, and three feeders with a pickup truck delivery method, respectively. A $0 hourly labor wage rate implies no cost for labor and only machine cost is included. For those cost comparisons using the tractor-feed wagon delivery method, a fixed cost per day of $0.1726 and $0.5178 for 80 and 240 cattle, respectively, is included to provide for owning and maintaining feed bunks.

Daily supplement delivery costs may therefore be compared in a

Table 13. Summary of Costs for One Liquid-Grain Feeder Including Feed Delivery Charges for 180 Days of Machine Use per Year

Feed Delivery Distance and Cost/Fill	Average Days/Fill	Fills per Use Period	Fill Service Charge ($)	Labor Cost for Machine Inspection ($)	Total Annual Machine Cost (Table 11) ($)	Total Cost for the Operating Period ($)	Cost per Operating Day ($)
16.7 Mi. $5/Fill	18.6	9.7	48.30	28.98	390.00	467.28	2.5960
33.3 Mi. $10/Fill	18.6	9.7	96.60	28.98	390.00	515.58	2.8643
50.0 Mi. $15/Fill	18.6	9.7	144.90	28.98	390.00	563.88	3.1326

Table 14. Summary of Costs for One Liquid-Grain Feeder Including Feed Delivery Charges for 350 Days of Machine Use per Year

Feed Delivery Distance and Cost/Fill	Average Days/Fill	Fills per Use Period	Fill Service Charge ($)	Labor Cost for Machine Inspection ($)	Total Annual Machine Cost (Table 11) ($)	Total Cost for the Operating Period ($)	Cost per Operating Day ($)
16.7 Mi. $5/Fill	18.6	18.8	93.95	56.37	390.00	540.32	1.5437
33.3 Mi. $10/Fill	18.6	18.8	187.90	56.37	390.00	634.27	1.8122
50.0 Mi. $15/Fill	18.6	18.8	281.85	56.37	390.00	728.22	2.0806

Table 15. Cost Summary for Three Liquid-Grain Feeders Including Feed Delivery Charges for 350 Days of Use per Machine Yearly

Feed Delivery Distance and Cost/Delivery	Average Days/Fill	Deliveries per Use Period	Delivery Service Charge ($)	Labor Cost for Machine Inspection ($)	Total Annual Machine Cost (Table 12) ($)	Total Cost for the Operating Period ($)	Cost per Operating Day ($)
16.7 Mi. $5/Delivery	18.6	18.8	93.95	169.20	1170.00	1433.15	4.0947
33.3 Mi. $10/Delivery	18.6	18.8	187.90	169.20	1170.00	1527.10	4.3631
50.0 Mi. $15/Delivery	18.6	18.8	281.85	169.20	1170.00	1621.05	4.6315

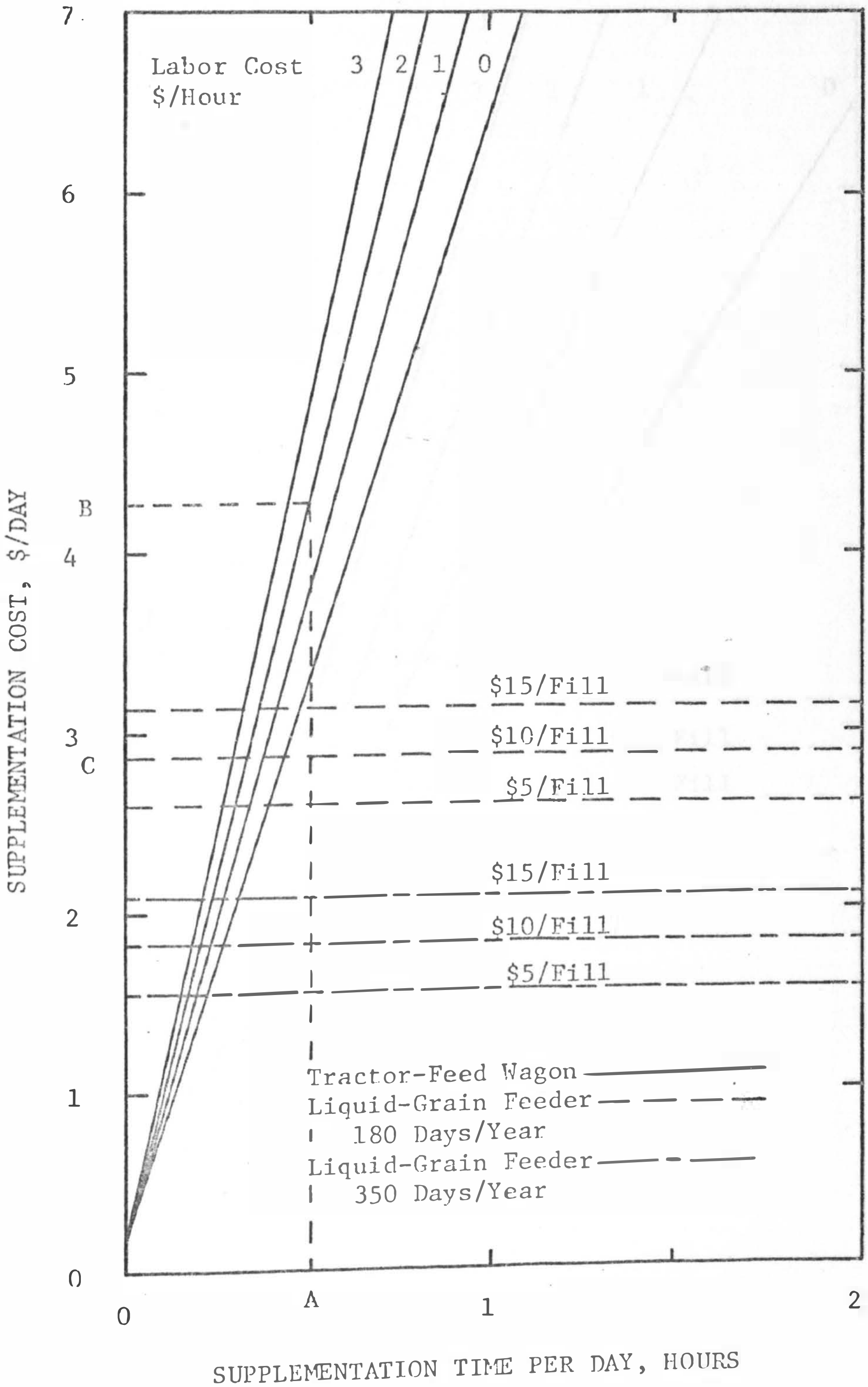

Figure 16. Supplementation Costs as Affected by Labor and Feeding Method; 1) Tractor and Feed Wagon, 2) Liquid-Grain Feeder Used 180 or 350 Days per Year.

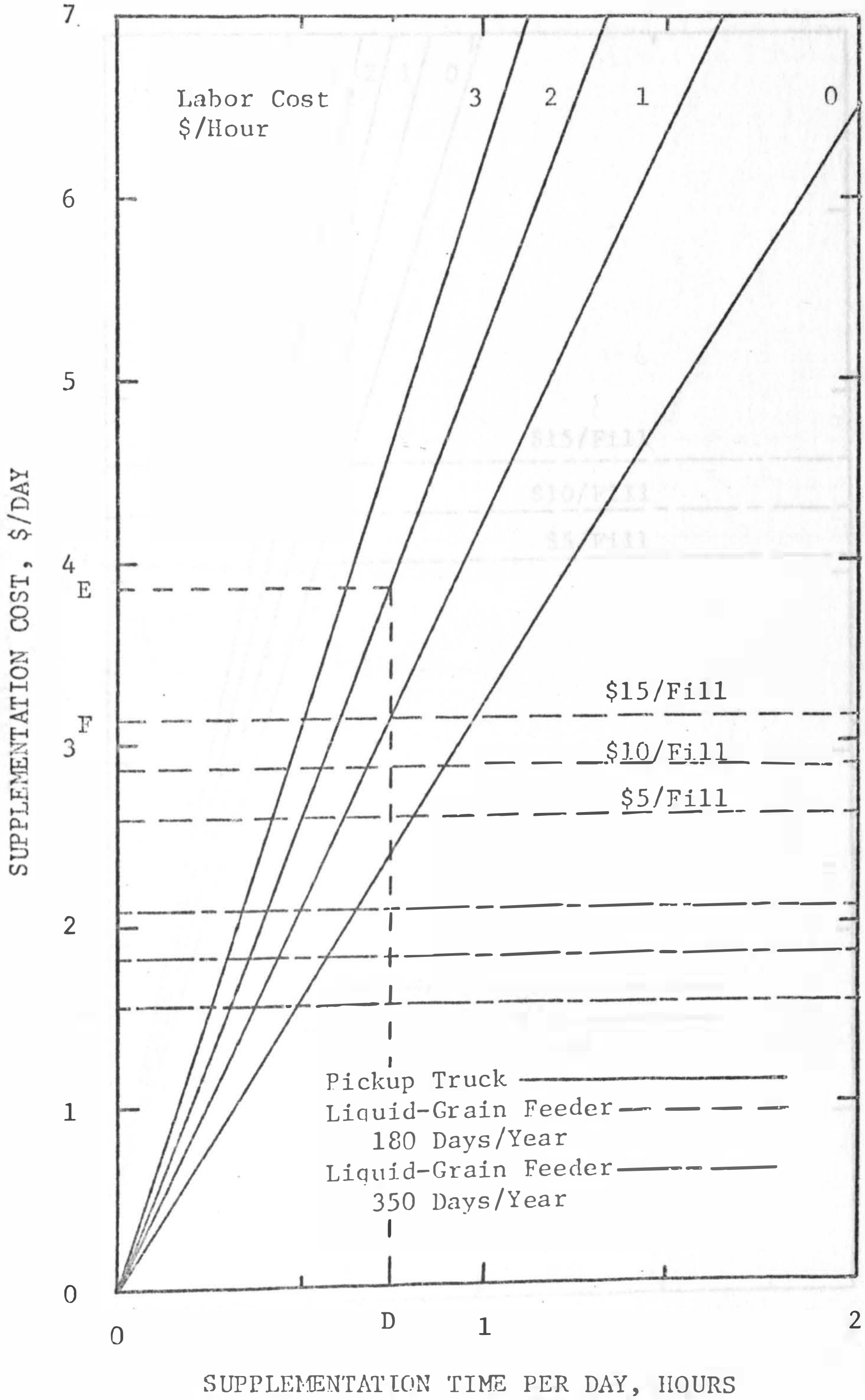

Figure 17. Supplementation Costs as Affected by Labor and Feeding Method; 1) Pickup Truck, 2) Liquid-Grain Feeder Used 180 or 350 Days per Year.

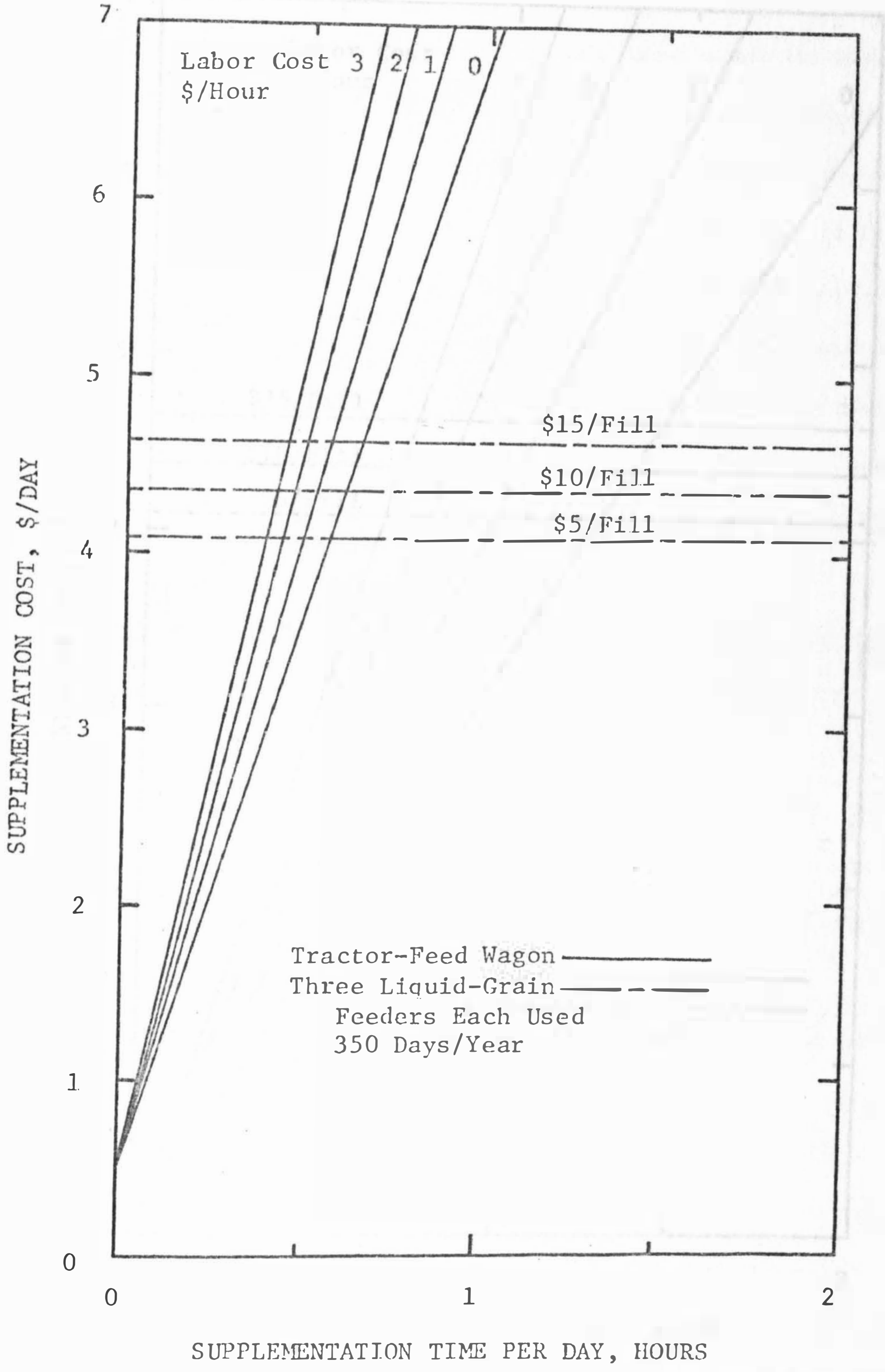

Figure 18. Supplementation Costs as Affected by Labor and Feeding Method; 1) Tractor and Feed Wagon, 2) Three Liquid-Grain Feeders, Each Used 350 Days per Year.

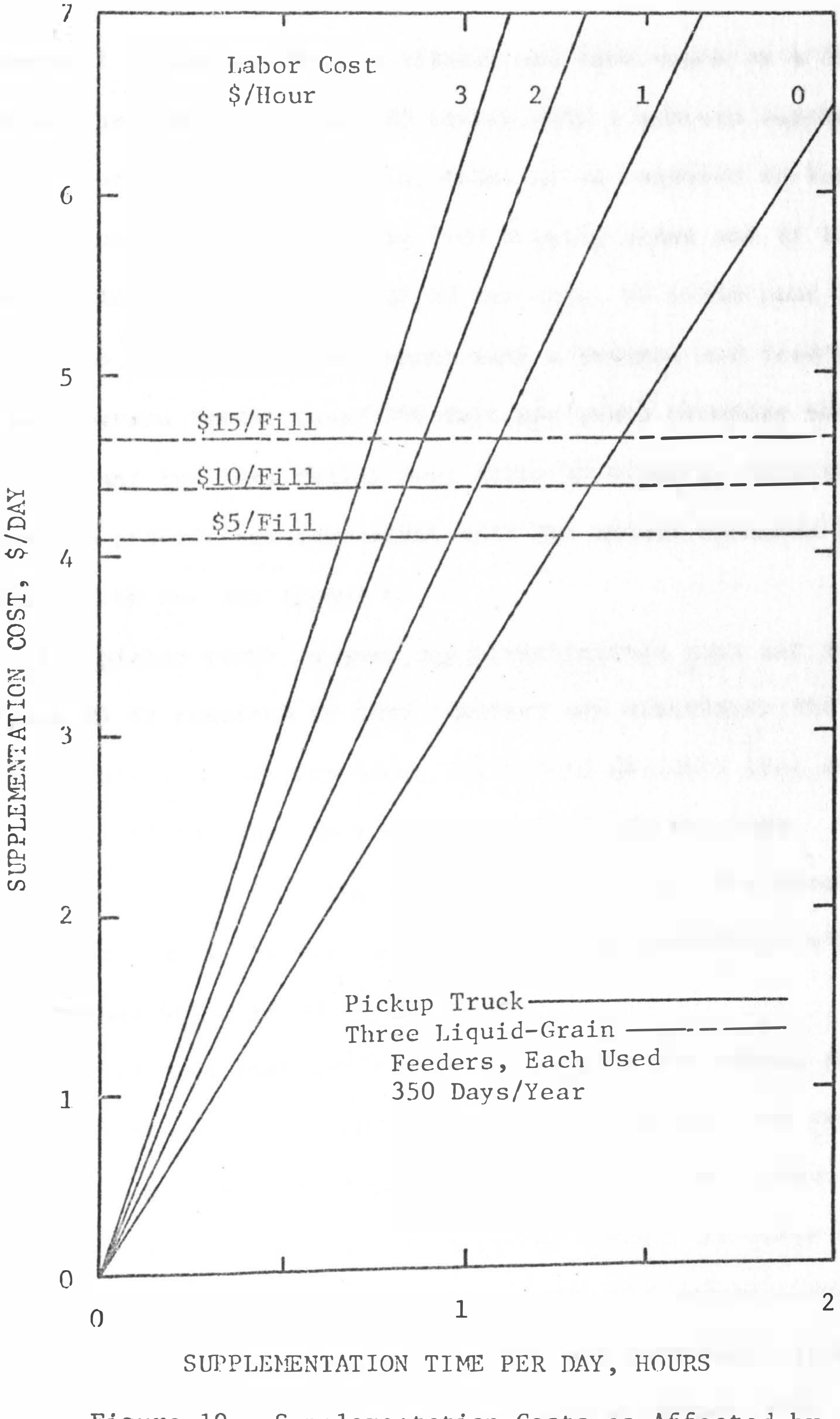

Figure 19. Supplementation Costs as Affected by Labor and Feeding Method; 1) Pickup Truck, 2) Three Liquid-Grain Feeders, Each Used 350 Days per Year.

hypothetical situation where a tractor and feed wagon or a liquid-grain feeder may be used to provide 80 cattle with a pasture supplement. If one-half hour per day (Figure 16, Point A) is required to load, deliver the supplement and return to the feed loading point and if the tractor operator's labor is valued at $2.00 per hour, it would cost $4.32 daily (Point B) to deliver the supplement with a tractor and feed wagon. If the liquid-grain feeder (used 180 days per year) provides the pasture supplement and the feed dealer must drive 33 miles to fill the unit, the cost to provide the supplement with the animal operated feeder would be $2.86 per day (Point C).

If a pickup truck is used and three-fourths hour per day (Figure 17, Point D) is required to load, deliver and distribute the supplement to the 80 cattle and return home, daily feed delivery cost would be $3.92 (Point E), if the labor wage rate is $2.00 per hour. Assuming the feed dealer must haul the feed 50 miles to fill the feeder (used 180 days per year), the cost per operating day associated with this feeding method would be $3.13 (Point F).

Theorize next that 240 cattle are grazing dry winter pasture found deficient in protein and available feed energy, and one hour per day would be required to provide the animals with a diet supplement using a tractor and feed wagon or a pickup truck. If labor cost is $2.00 per hour, the daily expense to provide the animals with the supplement would be $8.82 for the tractor and feed wagon (Figure 18), and $5.23 for the pickup truck delivery method (Figure 19). If instead, three liquid-grain feeders were used to distribute the supplement, the daily cost would be $4.36 to operate the three self-feeders assuming each feeder is used 350 days per year and the feed supplier must haul the supplement 33 miles to fill the units.

The daily time requirements for supplement delivery cost with a pickup truck (including selected labor wage rates) to equal daily cost for supplement distribution with three liquid-grain feeders (used 350 days per year) are shown in Table 16. Both delivery methods are assumed to provide 240 cattle with supplement. Liquid-grain feeder fill costs are included and time required for equal daily

Table 16. Time Required per Day for Supplement Delivery Cost with a Pickup Truck to Equal Daily Cost for Supplement Distribution with Three Liquid-Grain Feeders--240 Cattle

Supplement Delivery Cost		Hourly Labor Wage Rates			
		$3	$2	$1	$0
$15/Fill	(hr)	0.74	0.89	1.10	1.43
	(min)	44	53	66	86
$10/Fill	(hr)	0.70	0.83	1.03	1.35
	(min)	42	50	62	81
$5/Fill	(hr)	0.65	0.78	0.97	1.26
	(min)	39	47	58	76

feed delivery cost between methods are shown in hours and minutes. Calculated break even-cost time requirements for pickup truck feed delivery are illustrated by the intersection of the cost curves in

Figure 19. Therefore, if, for example, more than 50 minutes per day is required to deliver the supplement to the 240 animals with a pickup truck (assuming labor at $2/hour and a delivery cost of $10/fill for the feeders), less feed delivery expense would be incurred by using the three liquid-grain feeders.

Certain benefits or utility may be realized by each of the pasture supplementation methods, but an important consideration to make in deciding upon which delivery method to employ should be the relative value of labor and machinery for use in alternative enterprises. One of the periods of greatest nutritional demands by the beef cow is the time from calving through breeding, Fox (14), which usually coincides with the planting season for cereal and feed grains. During this period, greater returns may possibly be realized for labor and machinery use in crop production. Even if livestock production is the principal concern, these cost analyses demonstrate that pasture supplementation with the liquid-grain feeding system is quite competitive in daily delivery cost with provision methods employing a tractor and feed wagon or a pickup truck, and that a cost advantage may often be realized because of the time required daily to provide the supplement by conventional methods.

CONCLUSIONS

The following conclusions were reached in this study:

1. An animal operated device developed to provide predetermined quantities of liquid and granular feed to livestock operated satisfactorily over a wide range of feeding conditions using only energy supplied by the cattle.
2. Most granular feed materials (pelleted to finely ground) can be provided at determinable rates using a tapered screw type meter.
3. The amount of liquid supplement consumed per lick-wheel revolution varies inversely with temperature and was found to range from 0.015 lb. to 0.063 lb. per lick-wheel revolution (57.0° and 19.7° F the respective average daily temperatures) with grain meter calibration based upon this liquid consumption rate.
4. Twenty animals per lick-wheel is the maximum number of animals that should have access to the liquid-grain feeding device for optimum feeder utilization.
5. Individual animal use of the feeding device varies directly with feeder use experience. Animals of similar age, weight and feeder experience should be fed together during approximately the first three weeks of feeder use.
6. Lick-wheel revolution rate typically varies from 25 to 100

revolutions per head per day with rates below or above this range usually indicative of supplement underconsumption or overconsumption, respectively.

7. Satisfactory performance results were obtained with the improved design feeders constructed and tested under actual conditions during winter and summer feeding studies in South Dakota, North Dakota, Montana and Idaho.
8. The daily cost associated with providing a pasture diet supplement with the animal operated liquid-grain cattle feeder was found to be competitive and may exhibit a cost advantage when contrasted to feeding a pasture supplement in bunks with a tractor and feed wagon or when delivered with a pickup truck and fed on the ground.

SUMMARY

There are periods when existing vegetation alone can not supply sufficient protein and energy to meet the nutritional demands of the grazing beef animal. Liquid feeds containing a source of non-protein nitrogen (urea), when fed from lick-wheel feeders, have met limited success in fulfilling the protein needs of animals consuming a poor quality roughage due to poor nitrogen utilization. A readily available carbohydrate energy source (grain starch) when fed in conjunction with the liquid supplement should increase nitrogen utilization by the rumen microorganisms, help to prevent undue wastage of protein in metabolism and supply additional feed energy. However, a method by which liquid protein and granular energy supplements can be self-fed to cattle has not been available. Therefore, a research project was initiated to design, develop, and test an animal operated device to coordinate the feeding of liquid protein supplement and grain to cattle.

The animal operated feeder was developed to provide predetermined ratios of liquid and granular feed using only the energy provided by the cattle licking the circumference of a wheel partly submerged in liquid feed to operate the mechanism. A tapered screw type grain meter was developed to allow a wide range of granular materials (pelleted to finely ground) to be fed with the liquid supplement.

In investigating the use of the feeding device under actual

conditions, it was discovered that the amount of liquid consumed per lick-wheel revolution varies inversely with temperature, that lick-wheel revolution rate typically varies from 25 to 100 revolutions per head per day and that 20 animals per lick-wheel is the maximum number of animals that should have access to the feeder. Time lapse photography was used to investigate consumption characteristics of individual animals and revealed that use of the feeder varies directly with feeder use experience and that animals of similar age, weight and feeder experience should be fed together for an adaptation period of approximately three weeks. The animals were also shown to be very individualistic in their consumption characteristics and feeder use proficiencies.

Improved design feeders were constructed and testing was conducted during winter and summer feeding studies in South Dakota, North Dakota, Montana and Idaho with satisfactory performance results obtained.

The daily cost to provide 80 and 240 cattle with pasture supplement using the liquid-grain self-feeder was evaluated and was found to be very competitive and often offered a cost advantage when compared to commonly practiced supplementation methods.

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