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The Effect of Harvesting and Storage Methods on Chemical Composition and in Vitro Digestibility of First Cutting Alfalfa Hay

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THE EFFECT OF HARVESTING AND STORAGE METHODS ON CHEMICAL COMPOSITION AND IN VITRO DIGESTIBILITY OF FIRST CUTTING ALFALFA HAY

BY

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THE EFFECT OF HARVESTING AND STORAGE METHODS ON

CHEMICAL COMPOSITION AND IN VITRO

DIGESTIBILITY OF FIRST CUTTING

ALFALFA HAY

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor — Date

Head, Dairy Science Department — Date

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INTRODUCTION

The importance of alfalfa hay in dairy cattle feeding is generally acknowledged. The reasons why alfalfa is used so extensively in dairy cattle rations are due to its high protein content, high acceptability by cattle, its wide area of adaptation, and high yields. A popular way of handling the forage is to put it up as hay. South Dakota produced 3,261,000 tons of alfalfa hay in 1968. There were 73 million tons of alfalfa hay produced in the United States during 1968 (10) making it a crop of major importance.

Farming practices have changed considerably the last ten years. Among these changes has been the replacement of machinery for labor because of the difficulty of securing farm workers. Farm operators have attempted to reduce the labor involved in the haying operation by stacking the hay loose or as bales in the field, to be hauled to the farmstead later for feeding. Stack frames, stack movers, bale collectors, and mechanical bale stackers have all reduced the man hours of labor required to harvest hay.

With the increased use of these mechanical devices to reduce labor, increasing amounts of alfalfa hay are being stored out of doors and exposed to the weather rather than being protected in the hay loft of the stanchion barn. It appeared beneficial to examine the losses in alfalfa hay that was stored exposed to the weather. The economy of storing alfalfa hay under a temporary or permanent type cover may be advantageous to conserve more nutrients in the hay and still take advantage of the labor-saving methods of handling hay.

The objectives of this study were to determine the cost of making hay by various methods, to determine the change in chemical composition of the hay as affected by methods of harvesting and storage, and to determine the influence of harvesting and storage methods on nutrient utilization.

LITERATURE REVIEW

Research work on alfalfa hay first considered the effects of stage of maturity at harvest on nutrient composition (11, 18, 21), the moisture content of the hay at storage, and losses caused by moisture (2, 5, 13, 29). Losses during the harvesting procedure were studied (2, 5, 13, 41). Harvesting and storage losses were compared between field-cured and barn-cured hay (2, 3, 8) as well as among alfalfa hay, alfalfa silage, and wilted alfalfa silage (25, 27).

Hay quality

Marble (20) attempted to determine hay quality on a quantitative basis rather than a visual observation. He tested five lots of Federal Grade #1 hay and found the moisture to vary from 11.1 to 19.3%, the protein to vary from 11.7 to 19.7%, and the ash to vary from 8.1 to 12.0%. Novasod (25) used a point system to evaluate alfalfa hay visually considering maturity, texture, leafiness, freedom from non-injurious foreign material, and color, giving each characteristic a maximum of 20, 10, 35, 20, and 15 points, respectively. Hueg (17) indicated stage of growth is used heavily to evaluate forage quality and suggested that leafiness, color, and texture are also important considerations.

Hall et al. (12) found a highly significant difference in the speed of digestion and gas production by rumen microorganisms when comparing alfalfa hay to orchard grass hay. The alfalfa hay also produced higher rates of gain when fed to fattening steers. Hi Kon Oh et al. (14) evaluated different digestibility methods in the laboratory and found the two stage in vitro digestion procedure of Tilley and Terry (33) to be the best for all forage species and mixtures of species. There is a high correlation between forage intake and stage of maturity (17). Feeds that are high in fiber are less digestible and therefore less nutritious than those lower in fiber, according to Morrison (23). Bohsted (5) considers carotene as the best indicator of quality because it is too easily lost. If large amounts of carotene are saved, the other nutrients necessary to have good quality hay are also saved.

Bartle et al. (4) indicated that feeding hay of low quality limited milk production of dairy cows by lowering the hay consumption which decreased the content of digestible nutrients in the total ration from hay and increased feed costs. The quantity, quality, and feed value of hay varies, depending on the stage of maturity, weather conditions, handling methods, moisture content when stored, and amount of nutrients preserved for feeding. Hay quality was about equal for loose hay stored in field stacks and baled hay stored in the barn. Each showed a bright color, pleasing aroma, and retained enough leaves to qualify as U. S. #2 market grade hay. The baled hay stored outdoors had a musty odor, dark brown color, high leaf loss, and moldy spots throughout the bales.

Ross et al. (27) noted that windrowed hay tended to have a slightly higher protein content and lower crude fiber content than mown hay, primarily because of the longer low quality stubble left by the windrower adjacent to levees. Under reasonably good mowing and raking conditions there should be little or no difference between windrowed and mown hay yields in a flat field that has no levees.

Nutrient changes

During harvest. Archibald et al. (3) found that carotene and sugar are the most subject to loss during the curing process by sampling hay at the time of cutting, storage, and several times during storage. Losses in protein, crude fat, and ash were relatively unimportant unless exposed to repeated and excessive rainfall.

Wolff (41) in 1895 found that 20% of the dry substance of hay may be lost by simply soaking in cold water. Clover hay was damaged more by rain than meadow hay. Bartle et al. (4) reported that dry matter losses during harvesting of alfalfa hay averaged 12.3%. Barn-cured hay lost 9% and field-cured hay lost 17% of its dry matter from the time it was cut until it was stored (9). Truninger (34) followed seven lots of hay in detail from the time of cutting to the time of storing and found changes in dry matter ranging from a maximum loss of 11.3% to a maximum gain of 1.3%.

Bartle et al. (4) reported that the per cent change in nutrients during harvest was ether extract, -7.03; crude protein, -6.06; ash, -6.82; nitrogen free extract (NFE), -4.41; and crude fiber, +18.58. Archibald et al. (3) found that losses of crude protein, ether extract NFE and carotene were 0.9, 15.4, 0.9, and 63.1%, respectively.

<u>During storage</u>. Barn-cured hay lost 6% and field-cured hay lost 7% of its dry matter while stored in a barn mow (9). Shepherd et al. (29) reported dry matter losses of three to five per cent during storage of well cured long hay with less than 30% moisture. Truninger (34) studied seven lots of hay that were stored in small stacks with a moisture content range of 23.4 to 39.1%. Dry matter losses ranged from 2 to 11% with an average of 6% for the seven lots. Huffman and Bradshaw (15) reported organic matter losses ranging from 4 to 22% with an average of 13% loss in hay stored at 28 to 79% moisture. Woodward and Shepherd (42) studied the chemical changes in two lots of hay stored three months at 27 and 25% moisture. The moisture content of the hay after three months was 9.5 and 8.5%, respectively, and total dry weight losses were 4.1 and 5.3%, respectively. Similar losses, 3 to 8%, in total dry weight of eight different hays stored at 12 to 28% moisture were found by Camburn et al. (7).

Archibald et al. (2), reporting on field cured hay stored in a barn, found that crude protein, NFE and carotene had losses of 9.3, 4.6, and 81.2%, respectively. They noted a gain in ether extract, crude fiber, and ash composition of 4.3, 7.3, and 3.3%, respectively. The largest losses occurred during the first week of storage.

Nutrient loss was greatest for NFE, which ranged from a loss of 40% to a slight gain in two cases (34). Swanson et al. (32) reported losses of protein, crude fiber, NFE, and ether extract of 32.7, 46.5, 45.4, and 63.6%, respectively, for hay stored in stacks at 40% moisture. Crude fat loss ranged from 6 to 47% with a complete loss of carotene (15). Sugar loss of 59.1 to 93.7% was caused by fermentation. Cellulose loss ranged from 6.7 to 21.1%. Woodward and Shepherd (42) found the losses consisted principally of NFE with small losses of crude protein and ash and no loss of crude fiber or fat. Camburn et al. (7) found losses of crude protein, NFE, and ether extract of 3.3, 16.8, and 8.9%, respectively, and a gain in crude fiber of 3.1%.

Streeter et al. (31) found little difference in the chemical composition of upland meadow hay stored in small bunches, in windrows, or in round bales. The change in chemical composition of standing forage was considerably different from that of the hay during storage. The influence of storage time on nutritive value was only important for a few months after harvesting. Shepherd et al. (29) reported NFE and ether extract were the two nutrients most readily lost in storage.

Bartle et al. (4) noted that alfalfa stored as loose hay exposed to the weather showed losses in ether extract, crude protein, and NFE (-3.85, -4.10, and -1.69%, respectively) and gains in crude fiber and ash (+7.11 and +1.22%, respectively). Baled hay stored in field stacks exposed to the weather had losses in crude protein and NFE (-11.00 and -1.89%, respectively) and gains in ether extract, crude fiber, and ash (+3.70, +9.52, and +5.15%, respectively). Baled hay stored in a barn had losses of ether extract and NFE (-3.45 and -1.30%, respectively) and gains in crude fiber, crude protein, and ash (+1.65, +1.06, and +1.27%, respectively).

Effect on utiliztion

Even though the amount of crude protein remained practically unchanged, Truninger (34) reported a marked decrease in the coefficient of digestibility of the pure protein. Mohanty et al. (22) reported a 23.9 and 10% decreased in the digestion coeeficent for protein and dry matter, respectively, for moldy hay. The average daily gain of dairy steers fed good hay was 20.15% higher and they consumed 8.53% more hay than the steers fed moldy hay. Browning of hay resulted in a marked decrease in the digestibility of protein (16).

Five years of investigation with 63 cows showed no appreciable advantage in feeding value of barn-dried hay over field-cured hay stored inside as measured by hay consumption and milk production (9). Cows consumed an average of 30.1 pounds of barn-dried hay and 30.5 pounds of field-cured hay daily. Average daily production of 4% Fat Corrected milk (FCM) was 31.5 pounds for the barn-dried hay and 31.1 pounds for the field-cured hay. During three of the five years, comparisons were made of barn-dried hay, field-cured hay stored loose and field-cured hay windrow baled stored in a barn. No significant differences were measured in hay composition or in milk production.

Bartle et al. (4) compared loose hay stored in field stacks, baled hay stored in a barn, and baled hay stored in field stacks exposed to the weather. They found that dairy-yearling heifers showed a slight preference for the loose hay stored in field stacks over baled hay stored in the barn, and a definite preference over baled hay stored in field stacks (1.65, 1.55, and 1.27 pounds of hay consumption per 100 pounds of body weight, respectively). Morrison (23) reported dairy heifers wintered on good alfalfa hay, U. S. No. 1 or 2, gained 28% more and required 12% less hay per 100 pounds of gain than other dairy heifers fed poor hay, U. S. No. 3. He also reported 0.3 pounds more gain per head daily from steers fed good hay and the difference in actual value between the good and poor hay was far greater than the $7.50 per ton difference in cost.

Cost of harvesting

Mowing and raking. Purdue studies (38) in 1959, estimated the cost of mowing and raking at $1.20 per ton, crushing increased the cost to $2.10 per ton. Kepner et al. (19) in 1961 calculated the average acres per hour for mowing, mowing and conditioning, and raking and found them to be 3.15, 2.65, and 8.70 acres per hour, respectively. They also estimated the average annual investment per operation and found it to be 47.50, 110.00, and 67.50 dollars for mowing, mowing and conditioning, and raking, respectively. In an Arkansas study conducted in 1960, Capstick (8) reported the labor requirement on a per ton basis and found it to be 23 and 19 minutes for mowing and raking, respectively. Ross et al. (27) reported mowing, conditioning, and raking to be cheaper than windrowing with a swather equipped with a conditioner if used to harvest less than 1,500 acres annually.

Swathing. Kepner et al. (19) reported swathing averaged 5.35 acres per hour with an average annual investment of $500 without a conditioner and $600 with a conditioner, based on 1961 prices. Ross et al. (27) reported that the annual use must exceed 1,500 acres for the swather to be more economical than the mower and rake.

<u>Stacking loose</u>. A Purdue study (37) estimated that stacking hay loose was the cheapest method of harvesting up to 100 tons of hay per year when compared to baling or chopping hay using 1962 prices. Vary (35) reported in 1954 that the hay loader and buck rake methods required as many man-hours per ton of hay harvested as did baling, but the baler could handle twice as much hay per hour. Handling the hay loose had total costs of $1 to $2 less per ton for hay moved from the windrow to storage when compared to bales.

<u>Baling</u>. Baling and picking up the bales cost $2.50 per ton and hauling and storing the bales added another $1.50 per ton according to a 1959 Purdue study (38). They estimated that the total cost of harvesting a ton of hay was $10 to $12. An Indiana study (39) reported that farmers baling hay had an average investment in hay harvesting equipment of $2,616 in 1958. Michigan research workers (39) reported an average labor requirement of 2.2 man-hours per ton to bale and place hay in storage, but by using the most efficient handling methods, the time could be reduced to 1.2 man-hours per ton.

Myles and Wallace (24) estimated the machine and labor costs of harvesting a ton of hay to be $7.50. The cost was based on a 3.4 tons average yield per acre from two cuttings and the harvesting of 420 tons per year in northern Nevada in 1960. Vary (35) reported the cost per ton from windrow to storage to be $5.71 with an automatic baler harvesting 300 tons annually and $6.71 with a hay conditioner and baler harvesting 175 tons annually. The study conducted in 1954 indicated an average of 2.2 man-hours per ton were required to move the hay from windrow to storage.

In 1962, Capstick (8) reported the baling time per ton of hay and the cost per bale excluding labor as being respectively: 32 minutes and 7.6¢ for a small power-take-off (PTO) baler, 33 minutes and 8.6¢ for a small auxiliary-engine baler, 22 minutes and 6.2¢ for a large PTO baler, and 24 minutes and 7.1¢ for a large auxiliary-engine baler. He reported labor requirements of 3.52 man-hours to harvest hay and the harvesting cost including labor and machine costs ranged from 18.6 to 20.0 cents per bale.

Walker and Beven (36) reported that owning the hay equipment was more economical than having the hay custom harvested when harvesting 125 tons or more per year. They reported the variable cost per ton was $0.94 for a twine tie PTO baler and the fixed cost excluding labor ranged from $1.93 to $0.57 per ton when the tons of hay harvested annually ranged from 132 to 450 tons.

EXPERIMENTAL PROCEDURE

The study was conducted during the summers of 1968 and 1969. Four farmers participated in the study in 1968 and six farmers participated in 1969. The average size of the alfalfa fields was 20.9 acres. Only the first cutting from each field was used in this study.

Harvesting methods. Each participant harvested his hay by the method with which he was most familiar. Five of the ten farmers baled hay and the other five stored loose hay. One farmer in the baled group and two that stored loose hay used swathers rather than a mower and rake. Each participant kept records of the machines used, machine-time, and man-hours involved in harvesting the hay.

Storage. The hay was placed in two stacks in each field, either loose or baled. One stack was covered with a 4-mill, black, polyethylene-plastic sheet and the other was left exposed to the weather. The covers were held in place with weighted, commercially-produced fasteners the first year and with weighted, nylon netting the second year. The storage period was four to four and one-half months.

Yields. Yields for the baled hay were determined by weighing every 30th bale in each field. The bale weights were averaged and this average was used to calculate the yield in tons per acre.

Yields for the loose-stored hay were determined at the time of stacking by weighing representative six-foot lengths of the windrows from 10 different areas in each field. Unusual areas, such as a small ravine or a sandy knoll, were not included in the yield determination unless they represented at least 10% of the field. The weights were averaged and this average was used to calculate the yield in tons per acre.

Field hay losses. Field hay losses were determined for both harvesting methods by collecting the leaves and stems from 10 representative three-foot square areas where the windrow had laid in each field. The samples were weighed and the loss was reported as pounds per acre for each field.

Sampling time and method. The hay in each field was sampled for laboratory analysis three times during harvesting and storage. Samples were collected as the hay was being mown, as the dried loose-stored or baled hay was placed in the stacks, and at the end of the storage period. At the end of the storage period, one sample from the covered stack and one sample from the uncovered stack were collected.

The mown samples were collected from 20 representative areas and composited into one sample from each field. The baled and loose-stacked hay were sampled by different methods. Core samples were collected from every 30th bale and were composited into one sample from each field of the baled group. Samples were collected for the loose-stacked hay from 10 representative areas in each field and the samples were composited into one sample. The samples taken at the end of the storage period were collected by taking one core sample from each side and six from the top of each stack. The core samples were taken from approximately the same location in each stack. The core samples were composited into one sample from each stack.

Chemical analysis. The collected samples were analyzed chemically and the proximate analysis and carotene content were determined according to standard AOAC methods (1). The digestible dry matter (DDM) was determined by the Tilley and Terry two stage in vitro digestion procedure (33).

Statistical analysis. Comparisons in chemical composition were made between the two harvesting methods (baled and loose) and between the two storage methods (covered and uncovered).

The mown to stacked differences were compared between farms to measure the affect of harvesting methods. The stacked to feed differences were compared within farms to measure the affect of storage method. Least squares of analysis of variance computations were obtained using an IBM 360 computer.

RESULTS AND DISCUSSION

Harvested yields and field hay losses. The yield and field hay loss are reported in Appendix Table 1. The size of field, yield, field hay loss in pounds and as a per cent of the total for the two methods studied, and the average of the two methods is reported in Table 1. The yields varied from 0.68 to 2.24 tons per acre. The average yield for the baled method was the lowest because the three lowest yields occurred in the baled group. The average yield is representative of the hay yields for the area studied. The stand, fertility, and weather conditions during the study are reflected in the yield.

Table 1. Average field size, yield, and field hay loss for two harvesting methods studied.

Method	Size of field	Yield	Field hay loss	Field hay loss
	(acres)	(tons/acre)	(pounds/acre)	(%of total)
Baled	24.00	0.96	82.22	4.13
Loose	17.80	1.56	91.81	3.27
Average	20.90	1.26	87.01	3.65

The field hay loss figure represents the leaves and stems that were left after the hay had been stacked. It may not represent all the losses that occurred since it was impossible to measure the leaching and fermentation losses that may have taken place. Two farmers had hay in the windrow during a three week rainy period. The hay was in the windrow for nearly a month which resulted in a large loss of nutrients and a lowering of the digestibility.

Chemical composition of the hay. The chemical composition of the hay was analyzed three times, as mown, as stacked, and at the end of storage, both covered and uncovered. The data in Appendix Tables 2 through 5 are the laboratory analysis of the hay studied. The actual dry matter loss that may have occurred during harvesting and storage, due to leaching and fermentation, was not measured.

The crude protein per cent did not change significantly ($P<0.05$) during harvesting or storage; however, the covered hay was 0.20 to 0.50% higher than the uncovered. Truninger's (34) data indicated there was very little change in the amount of crude protein, although there was a marked decrease in the digestibility coefficient. Mohanty et al. (22) also reported a 23.9% decrease in the digestion coefficient for protein in moldy hay. A visual observation revealed that the uncovered hay had from slight to excessive mold, depending on how well the top was put on the stack.

Crude fiber per cent increased significantly ($P<0.05$) in the uncovered hay (Table 2). The covered hay was variable in regard to fiber during storage. The fiber in the baled hay increased less than in the loose hay regardless of cover (+1.52 to +18.87% change for baled and loose hay uncovered, respectively).

Table 2. The effect of method of storage and a four month storage period on the chemical composition[a] of first cutting alfalfa hay studied in 1968 and 1969, expressed as the per cent change on a dry matter basis

		Crude protein	Crude fiber	Ash	Ether extract	N-free extract	Digestible dry matter	Carotene
		% Change						
S-F[b]	Covered	+5.39	+0.86	+4.78	+2.84	-3.86	-4.50	-47.52
S-F[b]	Uncovered	+3.57	+10.98	+11.38	+7.07	-24.66	-14.56	-68.40
Level of significance[c]		N.S.	*	**	N.S.	**	**	*

[a] Average for the two methods of storage.
[b] S-F = change in composition from stacking to time of feeding.
[c] N.S. = not significant; * and **, values in the same column significantly different, $P<0.05$ and $P<0.01$, respectively.

Ash content of the uncovered hay increased significantly ($P<0.01$) during storage. The per cent change during storage for covered baled and loose-stored hay was +1.88 and -7.80%, respectively, and for uncovered baled and loose-stored hay was +10.50 and +12.38%, respectively.

NFE decreased significantly ($P<0.01$) in the uncovered hay, showing a 9.04% drop during storage. The covered hay lost 1.70% of its NFE content during storage.

Ether extract content did not vary significantly during storage when the covered and uncovered hay were compared. The covered hay had a 2.84% increase, while the uncovered hay increased 7.07%.

The digestible dry matter was significantly higher ($P<0.01$) for the covered hay than the uncovered. During storage the covered hay decreased 4.50% while the uncovered hay decreased 14.56%.

The carotene content decreased significantly ($P<.05$) from the time of mowing to the end of the storage period (27.33 to 4.08 mg/lb. for baled hay and 23.43 to 3.19 mg/lb. for loose-stored hay, respectively). The method of harvesting or the type of storage did not alter the carotene content of the hay significantly. The covered and uncovered hay averaged 4.21 and 3.05 mg/lb. (Table 3), respectively, at the end of the storage period. This represents a loss of 83.41 and 87.9% for covered and uncovered hay, respectively, from mowing through storage.

Table 3. The chemical composition[a] of first cutting alfalfa hay studied in 1968 and 1969 as affected by method of storage, reported on a dry matter basis, after four months of storage

	Crude protein	Crude fiber	Ash	Ether extract	N-free extract	Digestible dry matter	Carotene
	%						mg/lb.
Covered	18.58	26.67	9.01	1.77	44.00	62.74	4.21
Uncovered	18.23	29.70	9.68	1.84	36.67	57.27	3.05

[a] Average for the two methods of storage.

The nutrients most easily lost during storage were NFE and carotene. Crude protein remained relatively constant, while crude fiber and ash increased significantly.

Covered versus uncovered. The covered hay when compared to uncovered was slightly higher in crude protein, about equal in ether extract and carotene, and significantly lower in crude fiber ($P<0.05$) and ash ($P<0.01$) (Tables 2 and 3). The covered hay was significantly higher ($P<0.01$) in digestible dry matter and NFE.

The covered hay, when visually observed, had a much brighter color on the outer surface and less mold throughout the stack. The uncovered, loose-stored hay, unless properly topped, had pockets of spoilage two to four feet into the stack. The uncovered, baled hay, if not tightly stacked, had spoilage in the top row and parts of the second, third, and fourth rows of bales.

Baled versus loose hay. The chemical composition of the baled and loose hay is reported in Table 4. There was no significant difference between the methods of harvesting for any of the nutrients.

Harvesting costs. The hay harvesting equipment and the costs are reported in Appendix Tables 6, 7, and 8 and in Table 5. Harvesting costs were composed of fixed and variable machine costs and labor charges. An estimate of repairs, fuel costs, housing, insurance, and taxes was used as suggested by Bowers (6).

Table 4. The chemical composition[a] of first cutting alfalfa hay studied in 1968 and 1969 as affected by the harvesting method, reported on a dry matter basis.

Method	Time	Crude protein	Crude fiber	Ash	Ether extract	N-free extract	Digestible dry matter	Carotene
		%						mg/lb.
Baled	Mown	18.89	23.75	8.40	2.68	46.28	70.97	27.33
	Stacked	18.23	26.60	8.87	1.80	44.50	64.86	11.80
	Fed[b]	19.48	25.09	9.48	1.68	40.30	61.15	4.08
Loose	Mown	17.69	24.67	8.49	2.55	46.59	68.28	23.43
	Stacked	16.91	26.27	8.28	1.63	46.92	66.24	14.84
	Fed[b]	17.32	31.28	9.22	1.92	40.37	58.82	3.19

[a] Average for the two harvesting methods.
[b] At the end of a four-month storage period.

Harvesting costs per acre averaged one dollar less for the loose hay when compared to baled hay. The cost per ton is misleading because the loose-stored hay yielded 1.56 tons per acre, while the baled hay yielded only 0.96 ton per acre. As a result, the cost of harvesting a ton of baled hay was almost twice that of the loose-stored hay. The method of harvesting should not affect the yield of hay per acre. Had both methods yielded the same, there would still be a slight advantage for the loose-stored hay.

Table 5. The cost of harvesting first cutting alfalfa hay by two different methods during 1968 and 1969.

	Machine[b]		Labor[b]		Total costs[b]	
Method[a]	hr./a	cost/a	hr./a	cost/a	per acre	per ton
Baled	0.99	$4.11	1.44	$2.16	$6.27	$6.81
Loose	1.09	3.79	0.98	1.47	5.26	3.45

a. See Appendix Table 7 for data included in each method.
b. costs in Appendix Table 8 were averaged for method.

The average mowing, raking, and swathing time per acre was 19.4, 25.4, and 9.8 minutes per acre, respectively, or 3.10, 2.36, and 6.10 acres per hour, respectively. The machine time from mowing to storage was 0.1 hour per acre less for baled than loose-stacked hay, but machine cost per acre was 32¢ more for the baled hay because more expensive equipment was used. Baled hay required almost one-half hour more labor per acre than loose-stacked hay. Total harvesting costs were one dollar less for the loose-stacked hay than the baled hay.

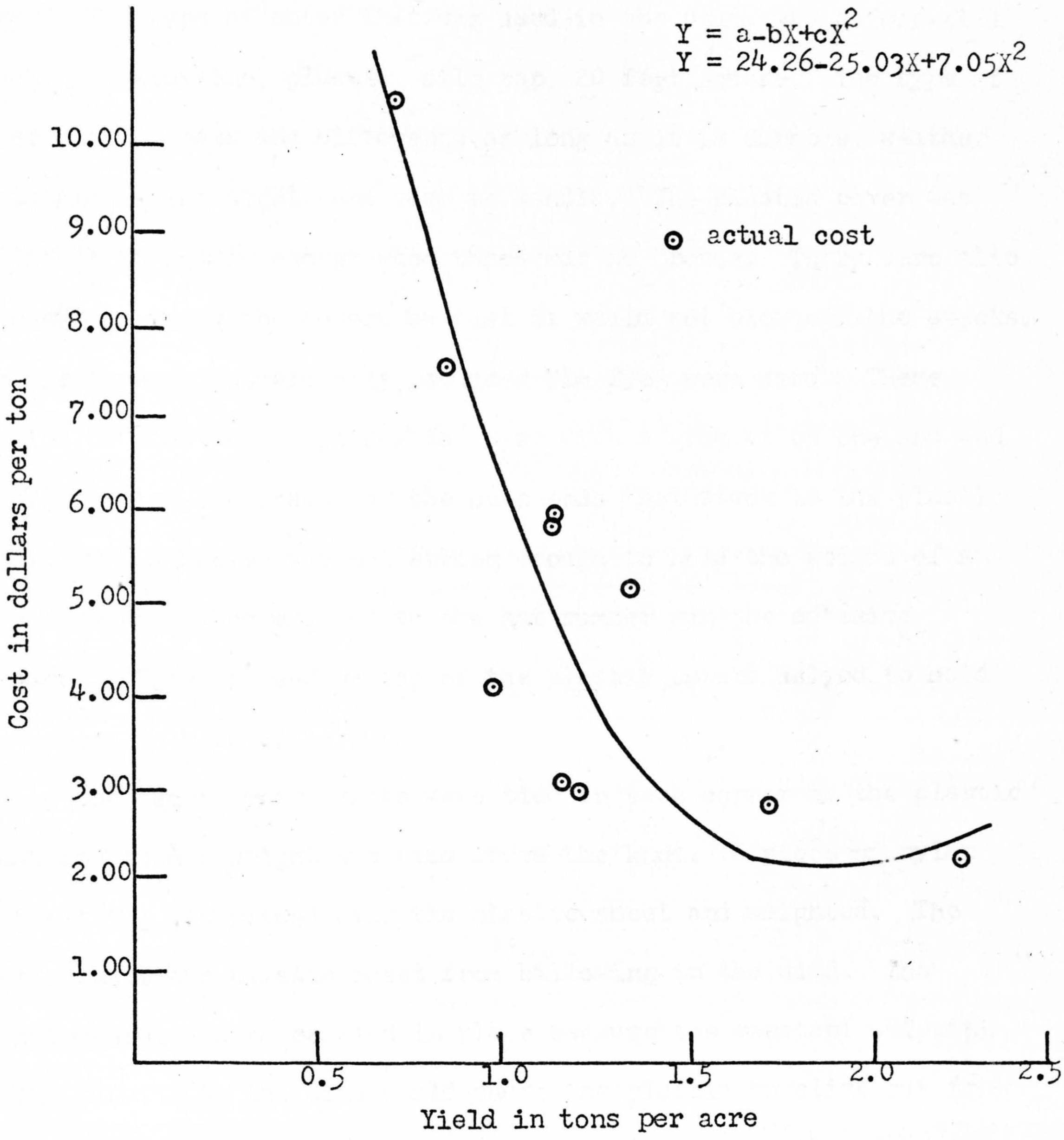

Figure 1. Estimated and actual cost per ton relationship to yield per acre for first cutting alfalfa hay on 10 northeastern South Dakota farms in 1968 and 1969.

Cover. The type of cover that was used in the study was a four-mill black, polyethylene, plastic, silo cap, 20 feet square. The type of cover did not make any difference as long as it is durable, weather resistant, water tight, and easy to handle. The plastic cover was difficult to handle except when there was no breeze. There were also problems in tying the covers so that it would not blow off the stacks. The first year, commercially produced Tie Eye[1] were used. These consist of plastic strips doubled over with a grommet on one end and an adhesive on the inside of the open ends that stuck to the plastic sheet. The adhesive was not strong enough to hold the weight of an auto tire, and when exposed to the hot summer sun the adhesive released. Tires placed on top of the plastic covers helped to hold the covers in place.

The second year, knots were tied in each corner of the plastic sheet and then a weight was tied above the knot. A piece of nylon bird netting was placed over the plastic sheet and weighted. The netting kept the plastic sheet from billowing in the wind. The plastic sheet had to be tied in place because the constant whipping of the plastic by the wind would cause the plastic to slide out from under the netting and off the stack. When tires were placed on top of the covers, the covers remained in place during the storage period. Return trips to the other stacks were required to retie or replace the cover.

[1]The Vis Queen Tie Eye, Visqueen Division, P. O. Box 2422, Baton Rouge, Louisiana 70821

<u>Cost of storage and savings</u>. The plastic covers cost $[illegible].91 and the nylon netting cost $11.49 per stack. This resulted in an average storage cost per ton for the loose-stored hay and baled hay of $2.20 and $1.10, respectively.

The value of the covered hay as affected by digestible dry matter saved is calculated below.

Covered	Uncovered
2,000 pounds of hay	2,000 pounds of hay
62.74% DDM	57.27% DDM
1,254.8 pounds DDM/ton	1,145.4 pounds DDM/ton

If the value of the covered hay is $20.00 per ton, the value of each pound of DDM is $0.016.

1,254.8	1,145.4
.016	.016
$20.00 value per ton	$18.32 value per ton

The amount saved per ton by covering is $1.68 and the annual storage cost per ton is $2.20 and $1.10 for loose-stored hay and baled hay, respectively.

The amount of crude protein did not vary significantly when the two storage methods were compared. The digestion coefficient of crude protein, according to earlier work done by Mohanty (22), dropped 23.9% in the moldy hay when compared to good hay. Truninger (34) reported a marked decrease in the digestion coefficient of crude protein but did not report a figure. Honcamp (16) indicated that browning of hay resulted in a marked decrease in the digestion of protein. The value of hay as affected by the crude protein digestibility is calculated below.

Covered	Uncovered
2,000 pounds of hay	2,000 pounds of hay
18.58% C.P.	18.23% C.P.
371.6 pounds C.P./ton	364.6 pounds C.P./ton

Using Mohanty's (22) digestion coefficient figures, the crude protein in the covered hay is 76.9% digestible and in the uncovered hay is 53.0% digestible.

371.6	364.6
76.9%	53.0%
285.8 pounds D.P./ton	193.2 pounds D.P./ton

Again valuing the covered hay at $20.00 per ton, each pound of digestible protein is worth $0.07.

285.8	193.2
.07	.07
$20.00 value per ton	$13.52 value per ton

This amounts to a savings of $6.48 per ton for covered hay with an annual storage cost of $2.20 and $1.10 for loose-stored hay and baled hay, respectively.

In this study, a plastic sheet was used to cover the hay stacks. An alternative cover would be a pole type hay shed. A 25' x 40' hay shed 12 foot high will cost about $1 per square foot, or $1,000. A ton of baled hay occupies 200 cubic feet so the hay shed will hold 60 ton of baled hay. The annual cost per ton of storage is reported in Table 6.

Table 6. The estimated annual storage costs per ton in a 25' x 40' x 12' pole hay shed used to store 60 ton of alfalfa hay annually.

Building cost	$1,000	
Depreciation	(5% x new cost - $100 salvage)	$ 45.00
Interest	$(8\% \times \frac{\text{new cost + salvage}}{2})$	44.00
Repairs	(1% x new cost)	10.00
Taxes	(2% x new cost)	20.00
Insurance	(0.25% x new cost)	2.50
	Total annual cost	$121.50
	Total annual cost per ton	$ 2.03

The annual cost of storing a ton of hay, the savings per ton and the net savings per ton by covering are reported in Table 7.

Table 7. The expected annual storage cost, value of two nutrients saved by covering, and net savings per ton per year of first cutting alfalfa hay stored in 1968 and 1969.

Method	Cover	Annual cost/ton	Savings/ton[b] DDM	Savings/ton[b] C.P.	Net savings/ton[c] DDM	Net savings/ton[c] C.P.
Loose	plastic/netting[a]	$2.20	$1.68	$6.48	$-.52	$4.28
Baled	plastic/netting[a]	1.10	1.68	6.48	.58	5.38
Baled	hay shed[d]	2.03	1.68	6.48	-.35	4.45

[a] Four-mill black polyethylene plastic sheet covered with a weighted nylon netting.
[b] Estimated from the value of nutrients saved.
[c] Computed from storage cost and value of nutrients saved.
[d] From Table 6.

The plastic cover more than paid for itself on the basis of the crude protein that was digestible at the end of the four month storage period. The cover conserved enough DDM to pay the annual storage cost of the baled hay but not the loose-stored hay. If a hay shed were used and the same amounts of DDM and crude protein were conserved for feeding, it would more than pay for itself on the basis of crude protein but not DDM.

SUMMARY AND CONCLUSIONS

The chemical composition of hay at the time of mowing, when baled or stored loose, and at the end of the storage period was studied on ten northeastern South Dakota farms. Only the first cutting of the hay was compared in this study. All hay was stored outside in field stacks. One-half of the hay studied on each farm was covered with a plastic sheet and the other half was left exposed to the weather. The hay was analyzed for proximate analysis, carotene content, and digestible dry matter. Comparisons were made between the harvesting methods (baled and loose) between farms and the storage methods (covered and uncovered) within farms.

The nutrients and digestible dry matter composition of the hay at the end of the storage period were essentially the same for baled and loose-stored hay. Loose-stored hay cost one dollar less per acre to harvest than the baled hay, because the loose-stored hay required less expensive harvesting machinery and almost one-half hour less labor per acre.

The covered hay retained more of its nutrients during storage than the uncovered hay. The uncovered hay gained significantly in per cent crude fiber ($P<0.05$) and ash ($P<0.01$) during storage, primarily because of significant ($P<0.01$) loss of NFE. The covered and uncovered hay were about equal in crude protein, ether extract, and carotene. The covered hay was significantly ($P<0.01$) higher in digestible dry matter.

The savings which resulted from covering the hay during storage were more than enough to pay for the cost of the cover on the basis of the digestible crude protein conserved for feeding. The amount of digestible dry matter saved was enough to pay the annual storage costs of the baled hay but not the loose-stored hay.

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APPENDIX

Appendix table 1. The size of field, method of harvesting, yields per acre[a,b], and field hay losses on 10 northeastern South Dakota farms studied in 1968 and 1969.

Farmer	Size of field acre	Method	Yield tons/acre	Field hay loss pounds/acre	Field hay loss % of total yield
1	22	Baled	1.15	92.36	3.85
2	17	Loose	2.24	26.45	0.59
3	28	Baled	0.86	101.89	5.62
4	11	Loose	1.22	118.24	3.32
5	17	Loose	1.33	50.59	1.86
6	15	Loose	1.27	145.39	5.42
7	20	Baled	0.98	88.34	4.31
8	28	Baled	1.15	77.83	3.28
9	29	Loose	1.72	118.40	4.63
10	22	Baled	0.68	50.67	3.61

[a] Only the first cutting is reported.
[b] All hay was alfalfa or alfalfa-grass mixtures.

Appendix table 2. The chemical composition of first cutting alfalfa hay as mown[a] on 10 northeastern South Dakota farms in 1968 and 1969.

Farmer	Dry matter	Dry Matter Composition						
		Crude protein	Crude fiber	Ether extract	Ash	N-free extract	Digestible dry matter	Carotene
	%	%	%	%	%	%	%	mg/lb.
1	28.45	18.31	27.30	2.21	9.09	43.09	69.92	26.59
2	24.56	16.41	28.37	2.13	8.32	44.77	67.45	19.06
3	30.19	20.25	24.81	2.75	8.66	43.53	70.06	30.25
4	31.85	16.06	27.32	2.41	8.82	45.39	65.67	15.07
5	34.20	17.80	23.63	2.65	7.78	48.14	70.83	42.00
6	29.50	20.00	21.80	3.02	9.31	45.87	67.92	22.22
7	25.10	19.84	20.75	3.17	7.86	48.38	69.90	16.79
8	34.10	18.52	21.39	2.90	9.10	48.18	72.88	34.39
9	39.90	18.18	22.26	2.52	8.24	48.80	69.54	18.80
10	31.90	17.52	24.52	2.35	7.38	48.23	72.10	28.65

[a] Stage of maturity when mown ranged from early bud to 3/4 bloom.

Appendix table 3. The chemical composition of first cutting alfalfa as harvested[a] on 10 northeastern South Dakota farms in 1968 and 1969.

Farmer	Dry matter	Dry Matter Composition						
		Crude protein	Crude fiber	Ether extract	Ash	N-free extract	Digestible dry matter	Carotene
	%	%	%	%	%	%	%	mg/lb.
1	87.80	17.00	28.72	1.20	9.18	43.90	65.46	12.87
2	77.92	15.87	33.70	1.08	8.66	40.69	63.84	4.86
3	76.90	19.16	27.04	1.58	8.10	44.12	68.40	8.97
4	84.70	16.38	25.70	1.44	8.66	47.82	65.05	17.48
5	82.70	16.22	28.80	1.46	6.80	46.72	64.52	5.30
6	81.10	20.30	17.34	2.40	9.88	50.08	70.98	34.66
7	81.20	20.75	20.84	2.32	7.81	48.28	70.41	17.89
8	76.20	17.18	23.62	2.42	10.58	46.20	66.39	16.94
9	84.50	15.78	25.80	1.76	7.39	49.27	66.79	11.91
10	87.30	17.06	32.79	1.46	8.70	39.98	53.64	2.33

[a] Harvesting methods for each farmer is reported in Appendix table 1.

Appendix table 4. The chemical composition of first cutting alfalfa hay that was covered[a] during a four-month storage period[b] on 10 northeastern South Dakota farms in 1968 and 1969

		Dry Matter Composition						
Farmer	Dry matter	Crude protein	Crude fiber	Ether extract	Ash	N-free extract	Digestible dry matter	Carotene
	%							mg/lb.
1	88.20	20.14	25.36	1.10	8.14	45.26	67.13	5.87
2	85.90	18.08	31.13	2.37	8.84	39.58	64.05	4.06
3	86.90	20.50	22.61	2.82	6.83	47.24	69.41	4.08
4	87.40	14.29	31.24	2.99	6.90	44.58	64.63	12.51
5	86.50	16.59	32.51	0.94	12.30	37.66	57.73	0.79
6	83.50	22.44	29.04	1.44	9.10	37.98	62.03	0.89
7	84.20	21.72	24.59	1.44	7.64	44.61	66.34	1.58
8	87.35	18.74	22.40	1.59	11.71	45.56	62.56	7.55
9	89.30	15.70	27.00	1.42	7.76	48.12	59.75	0.49
10	80.70	17.56	20.71	1.45	10.86	49.42	53.70	4.31

[a] The cover was a 4-mill, black, polyethylene-plastic sheet covered with a weighted nylon netting.
[b] Storage period was from July to October each year.

Appendix table 5. The chemical composition of first cutting alfalfa hay exposed to the weather during a four-month storage period[a] on 10 northeastern South Dakota farms in 1968 and 1969.

		Dry Matter Composition						
Farmer	Dry matter	Crude protein	Crude fiber	Ether extract	Ash	N-free extract	Digestible dry matter	Carotene
	%	%	%	%	%	%	%	mg/lb.
1	84.05	15.96	29.19	1.48	12.04	41.33	63.37	5.02
2	84.50	15.84	36.30	2.19	9.56	36.11	60.96	3.23
3	83.90	20.90	22.50	3.30	6.74	46.56	61.92	5.11
4	84.80	15.48	37.78	2.73	9.18	34.83	60.14	7.36
5	82.40	17.52	29.08	1.34	8.86	43.20	43.55	0.31
6	83.30	20.48	25.30	1.55	10.25	42.42	61.89	1.19
7	81.20	23.34	25.42	1.34	8.39	41.51	63.95	6.20
8	82.40	20.05	24.11	1.21	12.35	42.28	58.75	0.39
9	88.80	16.76	33.43	1.23	9.38	39.20	53.46	1.04
10	78.60	15.88	33.84	1.06	10.01	39.21	44.30	0.66

[a] Storage period was from July to October each year.

Appendix table 6. Machine costs computed on a per hour basis for normal use.

Machine	New cost	Salvage value	Value to depreciate	Useful life in hours	Hrs./yr	Annual costs Fixed[a]	Annual costs Variable[b]	Annual costs Total	Cost per hour
Tractor 2-3 plow	$5,000	$500	$4,500	6,000	600	$711	$395	$1,106	$1.84
Mower 7 ft. semi-mounted	675	68	607	500	100	156	59	215	2.15
Swather 15 ft.	3,338	334	3,004	1,000	100	473	50	523	5.23
Rake side delivery	750	75	675	500	100	173	62	235	2.35
Baler PTO	2,500	250	2,250	1,000	200	579	103	682	3.41
Tractor 3-4 plow	6,000	600	5,400	6,000	600	815	442	1,293	2.15
Loader	1,450	145	1,305	6,000	600	207	66	274	0.46

[a] Fixed costs include depreciation (straight line), interest (7% of ½ the new cost), taxes (2% of ½ the new cost), housing (1% of ½ the new cost), insurance (.50% of ½ the new cost).

[b] Variable costs include fuel, oil, grease and repairs as suggested by Bowers (6).

Appendix table 7. Machine cost per acre based on computed per hour rates[a] and machine time per acre[b].

Farmer	Mowing		Raking		Baling		Stacking		Swathing		Machine totals	
	Hrs.	Cost	Hrs.	Cost	Hrs.	Cost	Hrs.	Cost	Hrs.	Cost	Hrs.	Cost
1	0.33	$1.32	0.25	$1.05	0.36	$2.00					0.94	$4.37
2	0.33	1.32	0.56	2.35			0.53	$1.38			1.42	5.05
3	0.32	1.28	0.53	2.22	0.16	0.89					1.01	4.39
4							0.65	1.70	0.13	$0.68	0.78	2.38
5	0.30	1.20	0.59	2.47			0.53	1.38			1.42	5.05
6			0.16	0.67			0.40	1.04	0.20	1.05	0.76	2.76
7					0.21	1.17			0.17	0.89	0.38	2.06
8	0.32	1.28	0.59	2.47	0.18	1.00					1.09	4.75
9	0.29	1.16	0.34	1.42			0.44	1.15			1.07	3.73
10	0.34	1.37	0.38	1.59	0.36	2.00					1.08	4.96

[a] Per hour rates were taken from the last column in Appendix table 6.
[b] Time per acre is the actual time reported by 10 northeastern South Dakota farms in 1968 and 1969.

Appendix table 8. Total hay harvesting cost based on machine and labor charges.

Farmer	Machine[a]		Labor[b]		Total cost	
	Hrs/acre	Cost/acre	Hrs/acre	Cost/acre	Per acre	Per ton
1	0.94	$4.37	1.67	$2.51	$6.88	$5.98
2	1.42	5.05	1.18	1.77	6.82	3.05
3	1.01	4.39	1.43	2.15	6.54	7.60
4	0.78	2.38	0.88	1.32	3.70	3.03
5	1.42	5.05	1.27	1.91	6.96	5.23
6	0.76	2.76	0.80	1.20	3.96	3.12
7	0.83	2.06	1.33	2.00	4.06	4.14
8	1.09	4.75	1.32	1.98	6.73	5.85
9	1.07	3.73	0.75	1.13	4.86	2.83
10	1.08	4.96	1.45	2.18	7.14	10.50

[a] Hours per acre are based on time reported by 10 northeastern South Dakota farms in 1968 and 1969. Cost per acre was computed on a per-hour basis for normal use, Appendix tables 6 and 7.

[b] Labor charge based on $1.50 per hour wage rate and the man-hours reported by 10 northeastern South Dakota farms in 1968 and 1969.

Appendix table 9. The sources of variation, degrees of freedom, mean square values and levels of significance using the least squares analysis of variance to analyze each hay fraction.

Source	Degrees of freedom	Mean squares			
		Moisture	Crude protein	Crude fiber	Ash
Total	59				
time	1	49,857.725[a]	500.84159[a]	973.58009	2,516.6696 [a]
cover	1	1,718.8521	104.87831	1,450.4609	2,717.3895[a]
method	1	505.59212	73.95681	1,042.3385	171.35453
cover x method	1	83.60774	.18090	5.26349	480.31819
time x method	1	1,069.3627	38.76960	2,570.8917[a]	1,185.9208[b]
Error	54	586.95722	54.33352	320.98537	291.77611

[a] highly significant at $P < 0.01$
[b] significant at $P < 0.05$

E

Appendix table 9. Continued.

Source	N-free extract	Ether extract	Digestible dry matter	Carotene
time	1,302.3339[b]	23,031.372[b]	529.327[b]	10,067.923[a]
cover	906.96904[b]	248.90082	644.08525[b]	4,902.9007
method	178.54846	1,806.8732	5.73049	7.92988
cover x method	.18090	686.74345	1.65242	1,261.2409
time x method	663.73613[b]	588.13595	280.63505[a]	2,434.2241
Error	60.35352	2,836.2331	56.82056	1,963.7868

[a] highly significant at $P < 0.01$
[b] significant at $P < 0.05$