

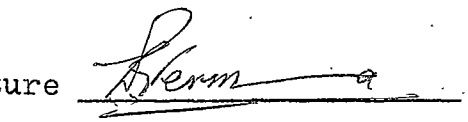
Storage properties of stacked alfalfa hay
by Lalit Raj Verma

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Agricultural Engineering
Montana State University
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Abstract:
Information is needed regarding the effect of hay-moisture content and stack density at harvest on protein and dry-matter losses during the storage period. An investigation was made to study the effect of hay moisture content at harvest on the losses in protein content and dry-matter yield during a storage period of 70 days. Two levels of stack density were obtained by using two compression pressures to form the haystack.

Tests were run with a Hesston StakHand-30 stack forming wagon using alfalfa hay. A wide range of moisture levels were tested, ranging from 6 percent to 45 percent (wet-basis). Final stack weights, moisture content and protein content ,were determined after 70 days of storage. Regression analysis was used to determine the effect of moisture content and initial stack density on the protein and dry-matter losses during storage. ¦

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STORAGE PROPERTIES OF STACKED ALFALFA HAY

by

LALIT RAJ VERMA

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

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Agricultural Engineering

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Thanks to my parents who could send me to Montana State University from India for this graduate experience.

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ABSTRACT

Information is needed regarding the effect of hay moisture content and stack density at harvest on protein and dry-matter losses during the storage period. An investigation was made to study the effect of hay moisture content at harvest on the losses in protein content and dry-matter yield during a storage period of 70 days. Two levels of stack density were obtained by using two compression pressures to form the haystack.

Tests were run with a Hesston StakHand-30 stack forming wagon using alfalfa hay. A wide range of moisture levels were tested, ranging from 6 percent to 45 percent (wet-basis). Final stack weights, moisture content and protein content were determined after 70 days of storage. Regression analysis was used to determine the effect of moisture content and initial stack density on the protein and dry-matter losses during storage.

Chapter 1

INTRODUCTION

Hay harvesting is gradually progressing towards complete mechanization. Farm and ranch economic conditions and labor problems have forced many of these changes. Improvements in the quality and quantity of hay grown have been of interest to each producer. Better varieties, irrigation, application of fertilizers and improved field methods have contributed to the improvement of both quality and quantity of hay. The quality of alfalfa is determined by its protein content and dry-matter yield determines the quantity. The highest possible level of quality and quantity should be maintained during storage. In this study, an attempt was made to measure the conditions which affect the protein and dry-matter losses during the storage period.

A knowledge of the effect of harvest moisture content and initial stack density on protein and dry-matter losses is essential for good management of a haying system. This knowledge will help to determine the optimum range of harvest conditions for minimum losses during storage.

Previous research has indicated that storage losses are lowest when hay dries to around 20 percent moisture content

or less*. In studies by Miller (17)** it was shown that dry-matter losses increase as the time required to achieve preservative conditions increases. Weeks (23) however has shown that if hay is stacked loose, there is a potential for maintaining its nutritive value even at moisture levels as high as 40 percent. His study also shows that nitro-digestibility results are good for hay stacked at moisture levels as high as 54 percent. Both of these studies indicate that there is a definite relationship between harvest parameters and storage losses. This project was designed to investigate this relationship.

---

*All moisture contents are calculated on a wet-basis.

**Numbers in parenthesis refer to appended reference.

Chapter 2

REVIEW OF RELATED LITERATURE

Alfalfa is a rich source of protein and can provide abundant and good protein for monogastric animals, including man; and the residue can be a good fibrous feed for ruminants. A study by Oliver (20) showed that 25 to 40 percent of the feeding value of alfalfa hay was lost due to weather damage during field curing. This loss was 15 to 30 percent when the hay was put up as grass silage. There are many different ways of handling hay; each method has its own advantages and disadvantages. In all cases there is a problem of minimizing the weather hazard which causes loss of feeding value. The likelihood of destruction of dry-matter increases with a delay in achieving the preservative conditions, as shown by Miller (17). Preservation is achieved by dehydrating the hay to a moisture level at which micro-organisms cannot carry on their life cycles.

The moisture content of alfalfa at the time of storage is one of the foremost factors affecting the maintenance of hay quality. Many research workers have investigated methods for improving the field drying rate for alfalfa hay. A study by Barrington et al. (2) has shown that the field drying rate of alfalfa can be satisfactorily increased by crushing treatments, with a minimum increase in subsequent field harvest

losses. The study by Boyd (5) also proved that crushing and other conditioning methods speed up field curing, reduce field damage and conserve color and feed value. Bruhn (7), in his study, showed that losses in hay vary with the effectiveness of crushing, the extent of delay from cutting time and the adequacy of drying conditions. His study also showed that crushing to increase the drying rate is desirable, but it also causes clipping losses of small leaves and stems. The increase in drying rate varies directly with the degree of crushing and clipping. Kepner et al. (12) in a similar study have shown that field losses are 1.1 percent greater for mowed and conditioned hay than for unconditioned hay. Also in the same study, crimped hay averaged 0.5 percent lower in protein and 1 percent higher in crude fibre than unconditioned hay. Pelleted hay, when fed to sheep, gave 65 percent greater gain per 100 lb of feed than baled hay. Hall (11) has shown in his studies that flail conditioning is an effective method of increasing the field drying rate of alfalfa. Losses due to this treatment are about 2 percent of the total yield, which exceeds the losses caused by crushing. This method of conditioning left a ragged end on the remaining stubble but had no effect on the plant's regrowth characteristics.

Most of the field losses during hay harvesting are associated with leaf loss. Vigyaraghvan et al. (22) have

shown in their study that leaf loss due to vibration, for all stages of maturity, increases with a decrease in moisture content of the plant. This loss was also affected by the difference in moisture content between the leaves and the stem. A maximum tumbling leaf loss of 27 percent occurred at 6 percent plant moisture in their study. This loss decreased quadratically as the plant moisture increased. In each stage of maturity, there was a linear increase in leaf loss as the difference between leaf and stem moisture content increased. Zimmerman et al. (25) have shown that leaves dry significantly faster than stems, and that crushing has significant effect on the drying rate of stems. The relative difference in the drying rates of stems and leaves were affected by weather conditions. The increase in drying rate for leaves by crushing was not significant in this study. Barre (1), in his study, has shown that drying of alfalfa is affected by the difference between vapor pressure of hay and the surrounding air.

There can be numerous combinations of operations in the hay-making process, but the important concepts as outlined by Lawton (15) from England are:

1. Aim for a dry spell
2. Cut quickly when crop is dry, condition immediately

3. Keep the crop on the move as long as possible to the point of leaf shatter
4. Bale quickly
5. Carry the bales immediately.

Mechanical crop moisture extraction, as a prelude to normal hot air dehydration could be a significant development in green crop drying. Lucas (16) has shown that squeezing a proportion of the juice out of grass or legume hay is cheaper than evaporating it out, and the resulting part-dried mass is less trouble to handle in a dehydrator than the untreated crop. In a different study, Kurtz (14) found that three crushing processes followed by turn-over rakings at four and six hours after cutting, gave the best combination of operations for accelerated drying. This treatment produced a 25 percent moisture product 10 hours after the 8.00 a.m. cutting under his conditions. This treatment also caused the highest leaf loss. These losses ranged from 4 to 28 percent. Fu-Ming-Lu (10) showed that saturation deficit, net radiation and wind velocity are important factors in determining hay moisture loss. These factors have the greatest effect on the drying rate when hay moisture is above 100 percent (dry-basis). The influence of net radiation and wind speed is roughly equal. Wetter hay absorbs more net radiation. A decrease in drying rate occurs at any time when there is a temperature inversion.

Duggal (9) showed that the rate of drying for crushed hay in the windrow increased with an increase in wind velocity and with a decrease in windrow density.

Respiration was a major source of heat energy for the drying of stored hay in a study by Wood et al. (24). The respiration rate was determined by the amount of carbon dioxide evolved per unit of time. The rate of respiration was shown to be a linear function of moisture content (wet-basis). The calculation of the respiration rate, in their simulation of barn hay drying, was made by the relationship:

$$R = 0.56m - 1.53$$

where R = m.g. of carbon dioxide/g d.m./h.

m = moisture content (wet-basis)

A study conducted by Bohstedt (4) showed that self-generated heat occurs at the expense of nutrient material, especially the easily digestible ones like sugars. Pressure or compaction during storage, once the hay is sufficiently dry, helps to preserve carotene. Dry matter losses, which were as high as 54 percent were reduced to levels as low as 7.5 percent with artificial drying. Damage from rain was least when the rain occurred soon after mowing of hay crop when the cells were still alive and metabolizing. Damage from rain increased as the plant cells died. Repeated showers caused more damage than one heavy rain. Twenty to 40

percent of the nutrients in hay can be soaked out by cold water, as indicated in this study. These are the most valuable nutrients, for they are soluble and therefore the most easily digested.

In a study by Nelson (18) it was found that the quantity of spontaneous heat generated per bale of alfalfa during storage increases with both increased moisture content of hay and increased density of bales. The increase is more for the former than the latter. Most of the spontaneous heating and the nutrient losses in baled hay occurred during the first few hours after baling. The retention of dry-matter, crude protein, etc. was independent of the density of bales but decreased with increased moisture content at the time of baling. Retention of carotene during storage decreased as both moisture content and bale density increased. The loss of nutrients during storage from hay baled at high moisture levels appeared to be less than the additional field losses that would occur for further field drying.

Brewer (6) studied the effect of pressure and moisture on the density of loose alfalfa hay. The following non-linear relationship was obtained:

$$Z = 13.64 + 0.032x - 7.5 \times 10^{-5} x^2 - 16.7y + 2.46y^2.$$

where Z = density of hay, lb/ft^3 (wet basis)

$$x = x_1 + c/2 + L$$

x_1 = applied force,

c = column weight of hay,

L = weight of compression chamber top;

y = (percent dry-matter) /100.

The following linear equation relating compressed and relaxed densities was also obtained in this study:

$$Z_1 = 0.99Z - 0.74$$

where Z_1 = relaxed density,

and Z = compressed density.

These relationships can help in determining the force and volume requirements of machines used to compress hay.

Chapter 3

OBJECTIVES AND METHOD

A. Objectives

The objectives of this research project were to study the effect of two variables: hay harvest moisture and initial stack density, on hay yield and hay storage properties. Yield was determined in terms of tons of 15 percent moisture (wet-basis) hay per acre. The storage properties were determined by changes in protein and dry-matter over the storage period of 70 days.

The information from this study may serve as a guide for determining the optimum range of harvest moisture content and stack densities for minimum losses in dry-matter, protein and yield of hay.

B. Method

The experimental field for this study was a sprinkler-irrigated alfalfa field with an average yield of 2.5 tons per acre. All the hay was cut at one time, then allowed to field dry to three different moisture intervals prior to stacking. A wide range of moisture levels was obtained, ranging from 44.9 to 6.4 percent (wet basis). The moisture level, initial density, protein content and dry-matter yield at harvest time were determined. The stacks

were then left in the field under prevailing natural conditions. All stacks were oriented alike with a spacing of 2 to 3 feet between stacks. Samples were taken from the stacks to determine the protein content and dry-matter yield after a period of storage of 70 days. The changes in protein and dry-matter content were then determined for the storage period. These changes were then related to their respective moisture content and the initial stack density at the time of harvest.

Three different moisture levels were to be studied. The three proposed moisture levels were 40, 30 and 20 percent (wet basis). Two stack densities at each moisture level were obtained by using hydraulic pressures of 2200 and 1500 pounds per square inch. The experiment was replicated four times to compensate for field variability. The test required two pressures, three moistures and four replications, giving a total of 24 stacks.

The field was cut with a self-propelled swather, starting at the South end and working towards the North. The field harvest pattern followed to minimize field variation at the time of harvest is shown in Figure 1. Every third windrow was harvested at a high moisture level. The hay was then allowed to dry to a lower level prior to harvesting the second windrow in each group of three. Additional field

drying was obtained before harvesting the third windrow in each group. In this manner field variations were distributed uniformly over all treatments.

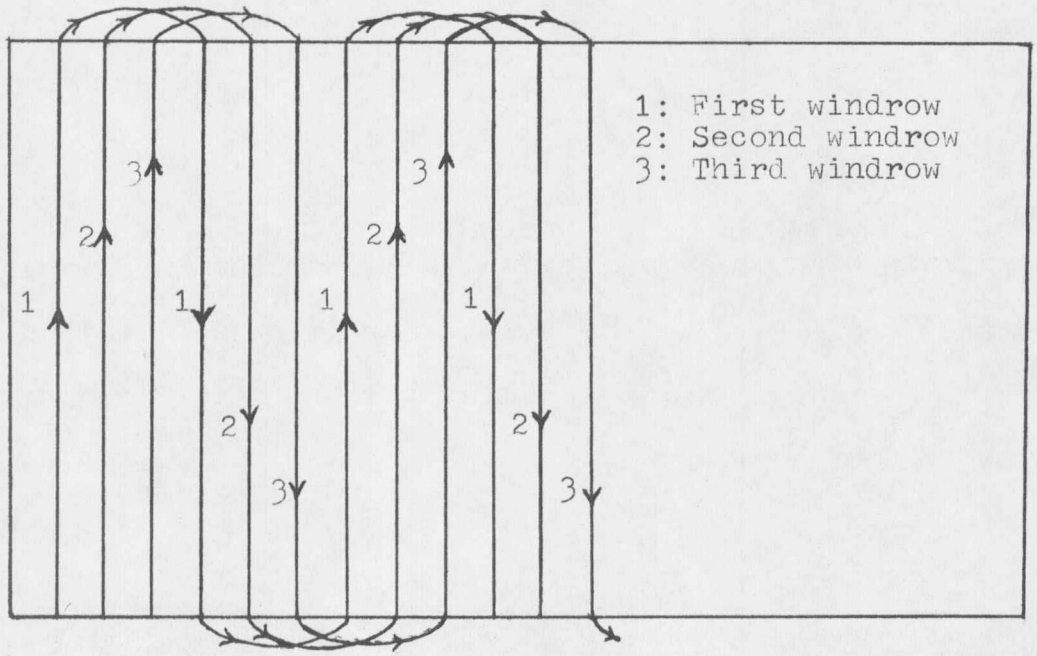


Figure 1. Field Harvest Pattern

Chapter 4

DESIGN OF THE EXPERIMENT

The different experimental factors and the response variables considered in this experiment are given below. The independent variables and the description for each variable are shown in the following list. Models relating response variables to the independent variables and experimental factors are considered and are presented thereafter in this chapter.

Experimental Factors:

Factors	Qualitative/ Quantitative	Random/Fixed
M- Initial Moisture Content	Quantitative	Fixed (approx)
M_1 = 40 percent w.b.		
M_2 = 30 percent w.b.		
M_3 = 20 percent w.b.		
P- Compression Pressure	Quantitative	Fixed
P_1 = 2200 psi		
P_2 = 1500 psi		

The response variables were:

1. Dry-matter loss of hay during the storage period, percent.
2. Protein loss of hay during the storage period, percent.

Hypothesis Statement: The significance of the main and interaction effects of moisture content and compression pressure on the loss in dry-matter and protein content of hay over a storage period of 70 days was studied.

The general structural model of the experiment was:

$$N = k_1 . k_2 . k_3 \ldots . k_p$$

where N = number of cells in the experiment

k_i = number of levels of the ith factor or the independent variables.

p = total number of k_i factors.

For each of the four replications, R, the matrix layout of the experiment was as follows:

	M_1	M_2	M_3
P_1	x	x	x
P_2	x	x	x

Here M_1 = 1st level of moisture = 40 percent (w.b.)
M_2 = 2nd level of moisture = 30 percent (w.b.)
M_3 = 3rd level of moisture = 20 percent (w.b.)
P_1 = 1st level of pressure = 2200 psi
P_2 = 2nd level of pressure = 1500 psi
x = cell observation

In this experiment: p = 2 factors
k_1 = 3 moisture levels
k_2 = 2 pressure levels

Therefore, N = 3 x 2 = 6

The independent variables in this experiment were:

Independent Variables		Qualitative/ Quantitative	Units
1.	Time after harvest	Quantitative	Days
2.	Initial moisture content	Quantitative	%(wet basis)
3.	Crop density in field	Quantitative	lb/ft^2 of area
4.	Crop maturity (age)	Qualitative	% bloom
5.	Humidity at harvest	Quantitative	% R.H. or vap. press
6.	Temperature at harvest	Quantitative	^oF
7.	Atmospheric pressure at harvest	Quantitative	in-Hg
8.	Rainfall during drying period	Quantitative	in & frequency
9.	Soil type	Qualitative	distribution
10.	Recorder	Qualitative	-----
11.	Elapsed time for recording	Quantitative	hrs.
12.	Amount of fertilizers used	Quantitative	nutrients-lb/ac
13.	Amount of irrigation	Quantitative	Ac. in./Ac
14.	Machine used to harvest	Qualitative	-----
15.	Pattern of harvest	Qualitative	-----
16.	Speed of harvest	Quantitative	M.P.H. or tons/hr.
17.	Soil moisture content	Quantitative	% of f.c.
18.	Soil density	Quantitative	lb/ft^3
19.	Type (variety) of crop	Qualitative	-----
20.	Dew (amount)	Quantitative	%
21.	Temperature of stacks	Quantitative	^oF
22.	M.C. of stacks	Quantitative	%
23.	Yield of crop	Quantitative	tons/ac
24.	Time of year	Qualitative	-----
25.	Wind velocity and direction	Quantitative	M.P.H., Asmuth
26.	Solar radiation	Quantitative	Langley

Description of Categories for Each Factor

The categories for each factor are as follows:

A. A boundary condition (held constant in the experiment)

B. An unmeasured experimental factor contributing to experimental error

C. A measured factor in the experiment

	Factor	Category	Remarks
1.	Moisture content of hay	C	Measured factor
2.	Density of stack	C	Measured factor
3.	Protein and dry matter content	C	Measured factor
4.	Compression pressures	C	Measured factor
5.	Storage time in days for each stack	C	Measured factor
6.	Yield of hay	C	Measured factor
7.	Temperature of stack	B	Experimental error
8.	Density of crop in field	B	Experimental error
9.	Crop maturity(% bloom)	B	Experimental error
10.	Ambient humidity and temperature	B	Experimental error
11.	Atmospheric pressure	B	Experimental error
12.	Dew or/and rainfall on stacks	A	Same for all stacks
13.	Soil constituents	A	On one field
14.	Recorder (for data)	A	Same for whole experiment
15.	Irrigation on field	A	Same on whole field
16.	Fertilizers on field	A	Same on whole field
17.	Harvesting machine	A	Same for whole experiment
18.	Pattern of harvest	A	Same for whole experiment

(Description of categories - cont'd)

Factor	Category	Remarks
19. Speed of harvest	A	Same for the experiment
20. Type of crop	A	Same for the experiment
21. Time of year	B	Experimental error due to change
22. Wind velocity	B	Experimental error due to change

Two levels of compression pressure were studied. Therefore, only a linear relationship could be studied with respect to this variable. Three levels of hay moisture content were studied and therefore a quadratic relationship could also be studied for this variable.

Experimental Model: This experimental design formed a complete functional model and was also a balanced model. Its layout in matrix form was shown previously.

The analytical model is expressed by the following equation:

$$Y_{ijk} = Y + R_i + M_j + RM_{ij} + P_k + MP_{jk} + RMP_{ijk} + e_{ijk}.$$

where Y_{ijk} is the response measurement for (i)th level of replication, (j)th level of moisture and (k)th level of pressure.

Y is the common effect on Y_{ijk} in all cells of the experiment.

R_i is the true effect of the (i)th level of replication on Y_{ijk};

M_j is the true effect of the (j)th level of moisture on Y_{ijk}.

RM_{ij} is the true interaction effect of (i)th level of replication and (j)th level of moisture on Y_{ijk}.

P_k is the true effect of the (k)th level of pressure on Y_{ijk}.

RP_{ik} is the true interaction effect of (i)th level of replication and (k)th level of pressure on Y_{ijk}.

MP_{jk} is the true interaction effect on (j)th level of moisture and (k)th level of pressure on Y_{ijk}.

RMP_{ijk} is the true three-way interaction effect of the (i)th level of replication, (j)th level of moisture and (k)th level of pressure on Y_{ijk}.

e_{ijk} is the true effect of unmeasured parameters (contributing to the error term) in all cells of the experiment.

The degrees of freedom without considering replication are as follows:

Source	Degrees of Freedom
Moisture content (M)	2
Compression pressure (P)	1
MP (interaction)	2
Error	0
Total	5

as N = 6.

There were no degrees of freedom left for the error term since both the main and interaction effects of the experimental variables were studied, so the experiment was replicated to provide some degrees of freedom for the error

term. Due to the variability inherent in agricultural experiments, four replications were conducted.

This particular experimental design was dependent on natural field drying rates. It was therefore necessary to take all of the observations for one moisture level before working with the others. The plots and split plots layout was adopted to meet the requirements of the harvesting machine since complete randomization was impracticable. There were 6 treatments and 4 replications, and the number of split plots was 6 x 4 = 24.

The field harvest pattern is shown in Figure 1. The analysis of the experimental design revealed that the experimental whole plots had 2 factors (p), 3 moisture levels (k_1) and 4 replications (R). Therefore, the number of cells N = 3 x 4 = 12 (plots).

Any change in the level of moisture or replications was a change between plots. The two pressure levels were the split plots. The pressure levels were changed within each plot and so both pressure levels were run in each moisture and replication plot before moving to another plot. The mathematical model for the split plot design is as follows:

$$Y_{ijk} = Y + A + B; \text{ where,}$$

$$A = R_i + M_j + RM_{ij} \qquad \text{(whole plot) and}$$

$$B = P_k + RP_{ik} + MP_{jk} + RMP_{ijk} + e_{ijk}. \qquad \text{(split plot)}$$

The degrees of freedom with four replications are:

Source	Degrees of Freedom	
Replication (R)	3	Between plots
Moisture content (M)	2	
RM (interaction)	2	
Pressure (P)	1	Within plots
RP (interaction)	3	
MP (interaction)	2	
RMP (interaction)	6	
Error	0	
Total	23	as N = 24.

Replications (R) were considered as one of the factors in the whole plot and therefore there were no degrees of freedom left for the error term. The error terms were obtained as follows:

RM (interaction) with 6 degrees of freedom was considered as error for the whole plot, while RP + RMP (interactions) with 9 degrees of freedom was considered as error for the split plot.

Chapter 5

TEST EQUIPMENT AND PROCEDURE

A. Stack Forming Wagon

The hay was picked up from the windrow with a Hesston StakHand 30. This wagon had a flail type pickup. The hay from the windrow was blown into the wagon through a spout which had a deflector to distribute the hay in the wagon. After loading the hay in the wagon it was compressed by hydraulically pulling the lid of the wagon down on the hay. The compression cycle took 30 to 40 seconds. The number of pressure cycles per load varied from 2 to 6. The finished stack was pushed off the wagon by dropping the endgate of the wagon and activating the drag chains to carry the stack out while the wagon was moved forward (Figure 2). Each stack was 14 feet long, 8 feet wide and approximately 9 feet high. The wagon weighed 6800 pounds. An experienced operator operated the Hesston StakHand 30 in its normal manner. The length of windrow per compression and per load was obtained by counting and recording the number of wheel revolutions of the wagon while filling was in action, and multiplying by the travel distance per wheel revolution.

As soon as one stack was formed, it was unloaded in the field and the next stack started.



Figure 2. A Stack Being Unloaded in the Field

B. Stackmoving Wagon

The stacks were picked up in the field with a Hesston StakMover 30. After loading in the field they were moved to the scales and then to the nearby storage area.

(Figure 3). The StakMover was 8 feet wide and 14 feet long. The platform of the StakMover was tilted to the ground for loading and unloading. Chains on the platform moved the stack on or off the wagon. Stacks were reloaded and moved to the scales for weighing after 70 days of storage.



Figure 3. Hesston StakMover 30 Picking Up a Stack.

C. Windrow and Stack Moisture Measurements

Two small electric driers were used to observe the change of hay moisture in the windrows. Samples were taken at 30 minute intervals and the drying rate determined from these samples. The drying rate in the windrow was used to estimate the time when the hay approached the desired moisture level. Samples were taken from the windrows by cutting a narrow section across the entire width of the windrow. When the desired moisture level was achieved the stacking operation was started. Samples were again taken from the windrows for each stack. These samples were dried in a heated, circulating air oven to determine the moisture level by measuring the wet and dry weights of each sample. The moisture level in samples taken after 70 days of storage was determined in the same oven.

D. Compression Pressure Measurement

The hydraulic pressure used in a master slave system to pull down on the wagon lid and compress the hay was measured by a pressure transducer in the hydraulic line (Figure 4). This transducer was pre-calibrated by applying a known pressure over a range of 0 to 3000 psi. A pressure relief valve and a two-way control valve were also installed so that two pressure ranges could be selected. The control valve was set at high and low for alternate stacks giving pressures of

2200 and 1500 psi respectively on the compression system. These pressures were converted to pressures in pounds per square foot of the compression lid from the effective area of the hydraulic cylinder and the lid dimensions.

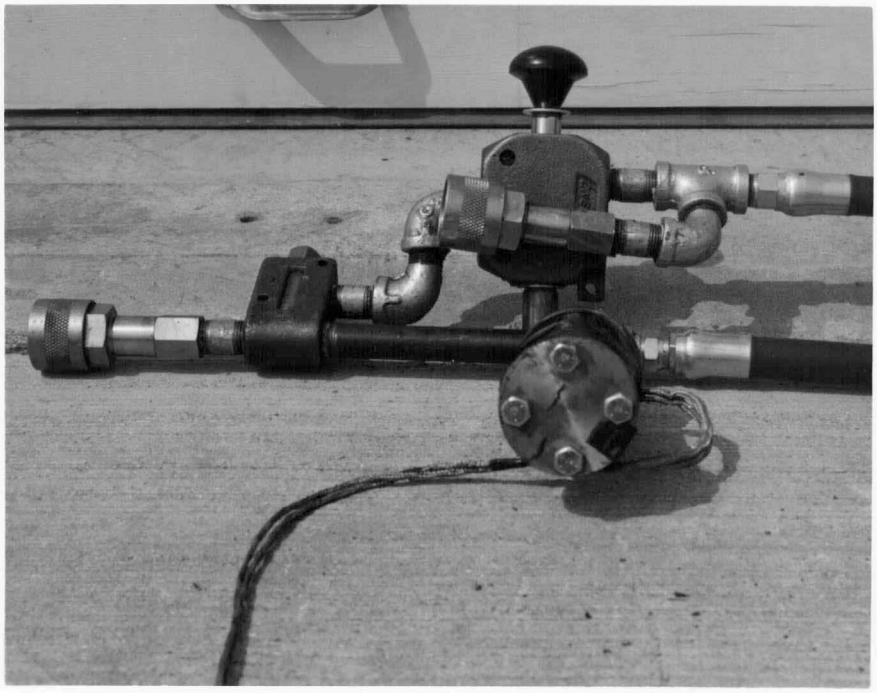


Figure 4. Hydraulic Pressure Transducer

E. Stack Volume Measurement

The movable top of the wagon was connected by a steel wire to a spring loaded wheel. Motion of the top was then directly proportional to rotation of the wheel. A torsion

spring was connected to the wheel and held in place by a torque arm resting on a ring transducer (Figure 5). Torque on the torsion spring due to the rotation of the wheel was therefore measured as a force on the ring transducer which was proportional to the lid position. The outputs from both the pressure and volume transducers were recorded simultaneously by a Sanborn strip chart recorder.

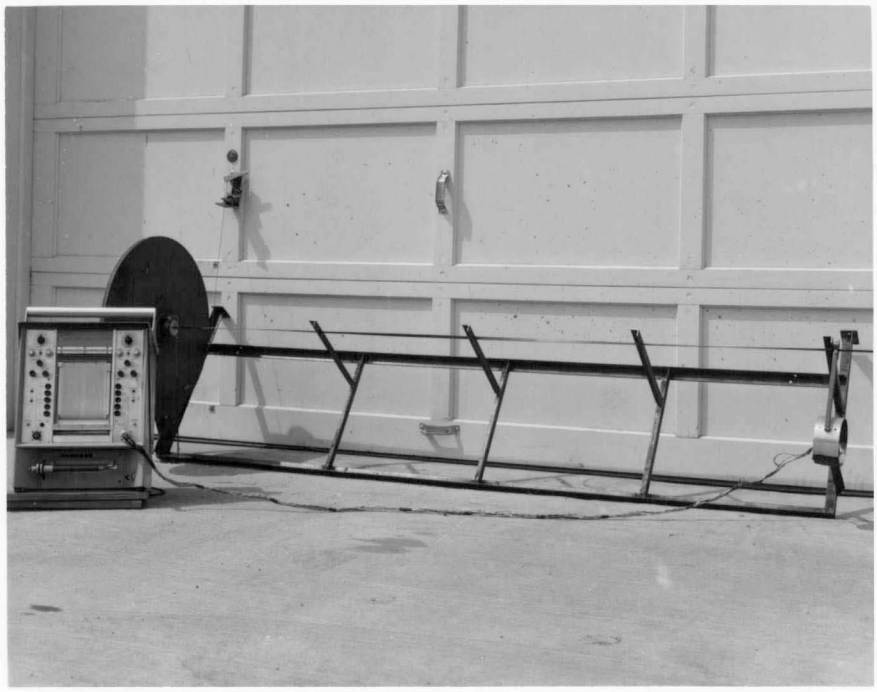


Figure 5. Sanborn Recorder and the Volume Transducer

The retracted position of the cylinder rod at the end of each compression was indicated by dust marks on the rod as the retracted portion of the rod was wiped clean each time. Each compression required less motion than the previous one; therefore a dust mark could be observed for each compression after the load was completed. The floor dimensions of the wagon were 14 feet by 8 feet and the position of the lid at final compression gave the height of the stack. In this manner the stack volume was calculated. (Figure 6)



Figure 6. Dust Marks on the Extended Cylinder Rod Used to Measure Stack Volume

The volume of each stack was also determined after 30 and 70 days of storage by measuring the length, width and distance over the center of the stack. The stack volume was calculated as:

$$V = \frac{1}{2} (O-W)WL$$

where V = volume of stack, ft^3

W = width, ft.

L = length, ft.

O = distance from the ground over the stack to the ground on the other side, measured over the center of the stack, ft.

F. Stack Weight Measurement

A weighing platform was constructed by placing a channel iron frame across two portable scales. The tractor and the StakMover were moved across this platform to determine the weight of each stack (Figure 7). Stacks were weighed when they were formed and again after 70 days of storage.

G. Protein Content Measurement

The protein content for each stack was determined from hay samples taken just before stacking and again after 70 days of storage. The protein tests were made by chemical analysis from the same samples used for the moisture tests.

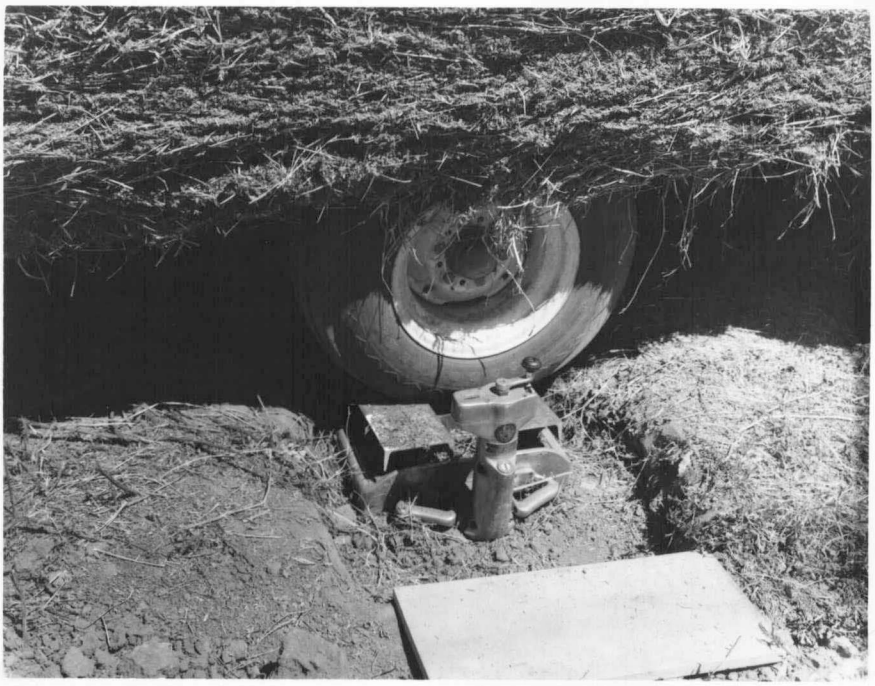


Figure 7. StakMover Wheel on the Scale Platform and Close-up of the Scale

H. Stack Temperature Measurement

The temperature of the stacks was measured twice a week during the first month of storage. This was a precaution to watch for possible spontaneous combustion. Stacks at high temperatures would have been moved to protect the remaining stacks. No fire hazard existed and the temperature measurements were reduced to once per week when the temperature stabilized.

I. Stack Sampler

A stack sampler shown in Figure 8 was constructed to cut 1½ inch by 48 inches core samples from each stack. Two samples per stack were taken after 70 days of storage. These samples were analysed for protein and moisture contents.



Figure 8. The Stack Sampler Starting to Cut a Core Sample

Chapter 6

ANALYSIS OF DATA

A. Effect of Initial Stack Moisture and Hour of the Day on On Yield

The windrow spacing in the field was uniform and approximately 11 feet on center. The length of windrow per load was obtained from the product of the number of wheel revolutions and the distance travelled per revolution of the wagon wheel. The land area used to form each stack was calculated from these dimensions. The initial moisture level of each of the stacks was determined from samples collected just before stacking. After the stack was weighed, the yield in tons per acre corrected to 15 percent moisture was calculated. The hour of the day when each stack was formed was also recorded. Regression analysis was used to determine the interaction between stacking moisture, time of day and the yield. This relation is shown by the following linear equation:

$$Y = 4.126 + 0.0003164M - 0.04032T$$

where

Y = yield, tons/acre (at 15 percent moisture)
M = initial stack moisture, percent (w.b.)
T = hour of the day when stack was formed

This linear relationship has a level of significance $(1-\alpha)$ of 0.95 and is shown graphically in Figure 9. There

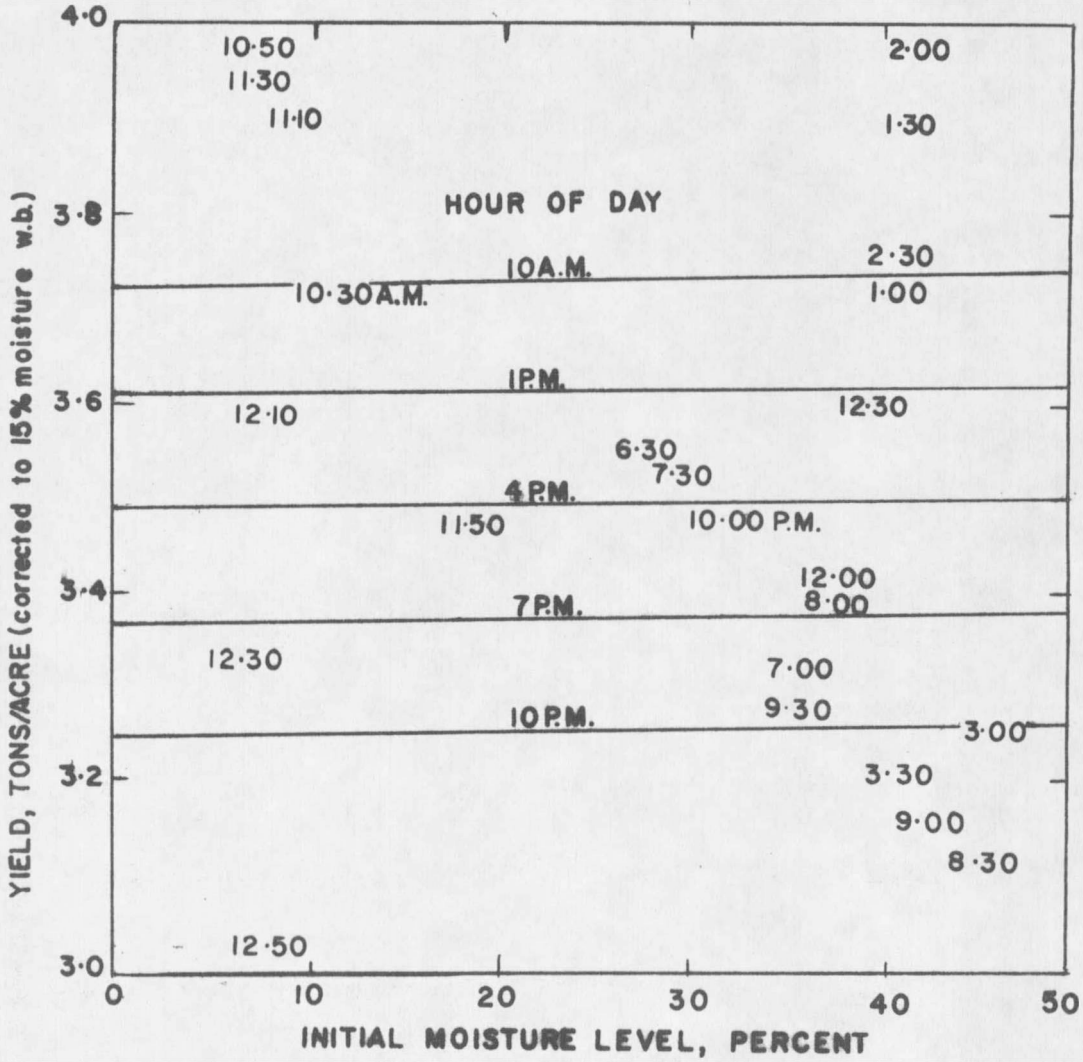


Figure 9. Effect of Initial Moisture and Hour of Day on the Yield

is a slight increase in yield with an increase in the hay moisture level at the time the stack is formed. The yield decreases rapidly as the stacking time during the day is delayed. This may be associated with the fact that the leaves dry faster than the stems and leaf loss during stacking may be more with a delay in the hour of stacking during

the day. The 8 stacks in lowest moisture range were formed 36 hours after the 16 stacks in two higher moisture ranges were formed.

B. Effect of Initial Stack Moisture and Compression Pressure on Stack Density

Stack density was determined from the compressed volume of the stack and its weight. The volume of each stack was determined from the wagon dimensions and the position of the compression lid at the end of final compression. There were two levels of hydraulic pressures, 2200 and 1500 psi used to pull the compression lid down on the load. The effective cylinder area in the master slave hydraulic system on the wagon was 5.841 square inches. Therefore, the total forces on the lid were 12850 and 8762 pounds respectively. The weight of the compression lid was found to be approximately 1622 pounds. Its dimensions were 14 feet by 8 feet. The total downward force in both compression levels was therefore the lid weight plus the hydraulic force or 14472 and 10384 pounds respectively. This gave compression pressures of 129.2 and 92.7 pounds per square foot on the hay. A very significant ($1-\alpha = 0.995$) linear relationship was found to exist between the density, applied pressure and the initial moisture level, and is shown in Figure 10. The relationship is expressed as follows:

$$D = 1.168 + 0.06825M + 0.03171P$$

where D = initial stack density, lb/ft^3

M = initial stack moisture, percent (w.b.)

P = applied compression pressure, lb/ft^2

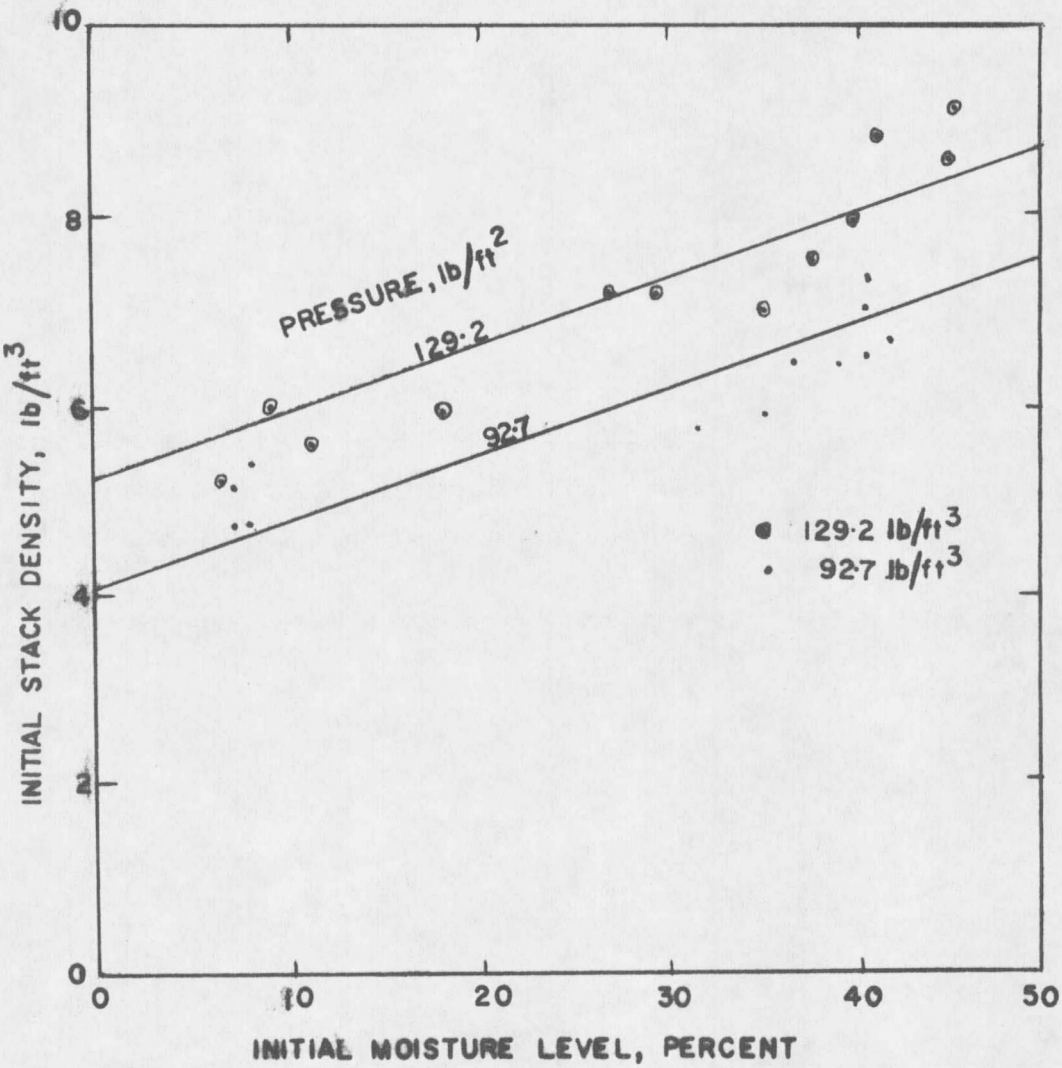


Figure 10. Effect of Initial Moisture and Pressure on Density

This relationship shows that the density increases

with an increase in both the moisture and pressure. The density is affected more by the moisture than by the pressure. The additional weight of wet hay would affect the total compression forces. Also wet hay is more flexible than dry hay.

C. Effect of Initial Stack Moisture and Initial Stack Density on Dry-Matter Loss

The weights of the stacks at the time they were formed and after 70 days of storage were compared. The weights at each condition were corrected to 15 percent moisture (w.b.) as this approximates the equilibrium moisture condition for hay exposed to air. Changes in stack weights were therefore related to changes in dry-matter and not changes in moisture. Regression analysis was used to study the relationship of initial moisture and stack density to the dry-matter loss. A very significant ($1-\alpha = 0.99$) linear relationship was found between these variables and is expressed by the following equation:

$$L = 8.254 - 0.4792M + 2.832D$$

where L = dry-matter loss in 70 days, percent

M = initial stack moisture, percent (w.b.)

D = initial stack density, lb/ft^3.

This relationship (Figure 11) shows that the dry-matter loss decreases as the initial stack moisture increases. At a particular moisture level, the loss increases with an increase in the initial stack density.

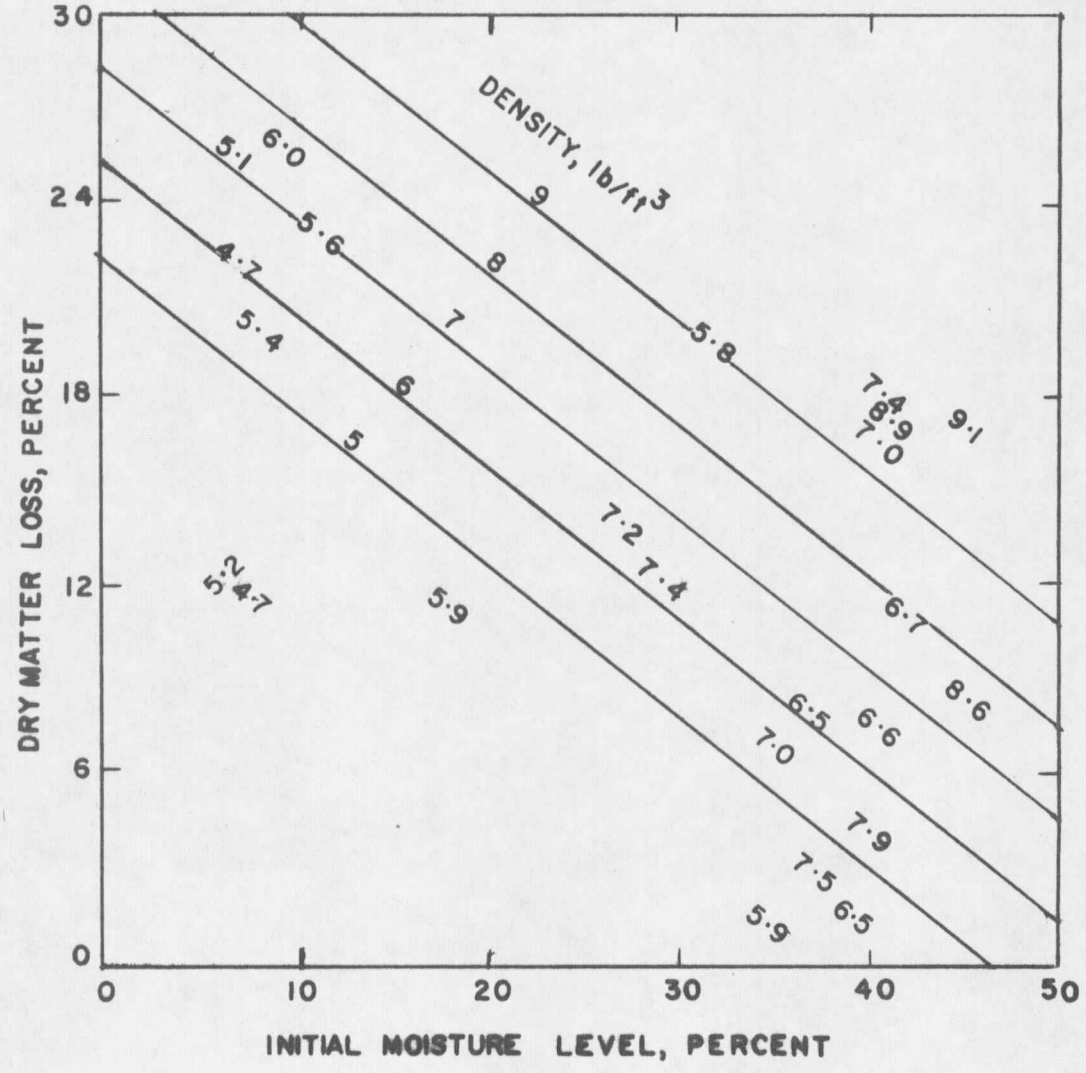


Figure 11. Effect of Stack Moisture and Density on Dry-matter Loss

D. Effect of Initial Stack Moisture and Initial Stack Density on Stack Settling

The amount of stack settling was determined by the change in stack volume. This change in volume was obtained by comparing the volume at the time the stack was formed, to the stack volume after 70 days. The correlation of stack settling to initial stack moisture and density was determined. This linear relationship was highly significant ($1-\alpha = 0.99$) and is expressed as:

$$S = 35.41 + 0.3201M - 1.572D$$

where S = reduction in stack volume (settling), percent

M = initial Stack moisture, percent (w.b.)

D = initial stack density, lb/ft^3

This relationship is shown in Figure 12, which shows that there is increased settling as the stack moisture increases and decreased settling with an increase in the initial stack density. The effect of initial density seems to be greater than that of initial moisture.

E. Effect of Initial Stack Moisture and Initial Stack Density on Protein Loss

The protein contents were determined when the stacks were formed and again after 70 days of storage. These two measurements were compared to obtain the protein loss during

storage. No significant relationship was established between this loss and either of the initial parameters. However, stacks with higher initial moisture levels tended to indicate a gain; whereas the drier stacks tended to decrease in protein. This may be related to dry-matter changes which are affected by initial stack moisture and initial stack density.

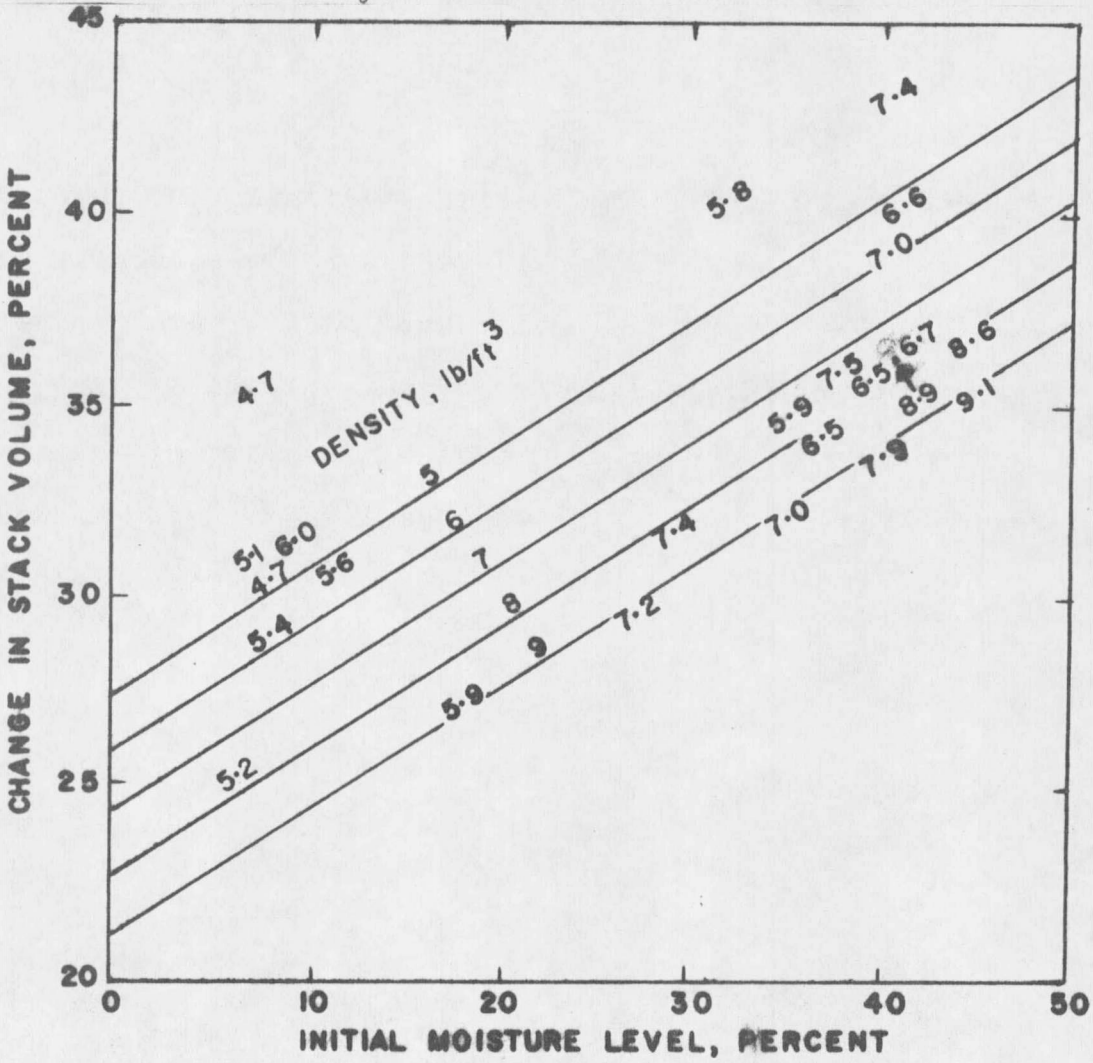


Figure 12. Effect of Stack Moisture and Density on Stack Settling

E. Hypothesis Testing of the Experimental Design

The experimental design consisted of 3 moisture levels, 2 pressure levels and 4 replications. Analysis of variance was conducted on this whole and split-plot design of experiment. The results of this analysis are given in Appendix B. According to the F test, neither the main nor the interaction effect of moisture and pressure were significant on dry-matter or protein losses. The lack of significance can be associated with the fact that there was considerable variation within each of the three moisture treatments. The initial stack moistures in each treatment varied from 37.8 to 44.9, 27.0 to 44.8 and 6.3 to 18.0 percent in each of the three levels respectively. There was an overlap of moisture ranges between the first and second treatments. The variability within the treatment therefore masked the effect of the treatments.

Regression analysis, however, showed a very significant linear relationship between initial stack moisture, stack density and dry-matter loss. In regression analysis, each of the initial stack moistures was considered as a level in itself and no variation within the moisture treatment occurred. The relationship between initial moisture, density and protein loss was not significant even when the moisture levels were considered independently.

The quadratic effect of initial stack moisture could not be studied because the three moisture levels were not equally spaced.

Chapter 7

SUMMARY AND CONCLUSION

This study involved the yield and storage properties of alfalfa hay. Hay was stacked at hay moistures ranging from 6 to 45 percent (w.b.) with two levels of pressure applied on the hay. These pressures were 92.7 and 129.2 pounds per square foot. The period of storage in the study was 70 days. The effect of the initial stack moisture and the pressure on stack density was investigated. Yield of hay while stacking, was studied as a function of initial stack moisture and time of day when stack was formed. The effects of initial stack moisture and initial stack density on dry-matter loss, protein loss, stack settling and crude fibre content were also studied.

A linear relationship was established between the initial moisture level, hour of the day when the stack was formed and the yield of hay in tons per acre corrected to 15 percent moisture (w.b.). This relationship is as follows:

$$Y = 4.136 + 0.0003164M - 0.04032T$$

where Y = yield, ton/acre (at 15 percent moisture)

M = initial stack moisture, percent (w.b.)

T = hour of the day when stack was formed

There was a slight increase in yield with an increase in the hay moisture level at the time the stack was formed. There was a rapid decrease in the yield as the stacking time during the day was delayed.

The following linear relationship was established for the effect of initial stack moisture and applied pressure on stack density:

$$D = 1.168 + 0.06825M + 0.03171P$$

where D = initial stack density, lb/ft^3

M = initial stack moisture, percent (w.b.)

P = applied compression pressure, lb/ft^2

The above equation confirmed that density increases with an increase in either the moisture or pressure. The effect of moisture was greater than that of the pressure.

A linear relationship was established between initial moisture, stack density and the dry-matter loss over a storage period of 70 days. This relationship is as follows:

$$L = 8.254 - 0.4792M + 2.832D$$

where L = dry-matter loss, percent

M = initial stack moisture, percent (w.b.)

D = initial stack density, lb/ft^3

According to the above equation, the dry-matter loss decreases as the initial stack moisture increases; whereas, the loss increases with an increase in stack density for a

particular moisture level.

The linear relationship which was obtained between initial stack moisture, stack density and stack settling is as follows:

$$S = 35.41 + 0.3201M - 1.572D$$

where S = reduction in stack volume (settling), percent

M = initial stack moisture, percent (w.b.)

D = initial stack density, lb/ft^3

This relationship indicated that there is increased settling with an increase in stack moisture. An increase in stack density caused a decrease in the settling. The effect of initial stack density was greater than that of initial moisture.

No significant relationship was obtained for protein loss and crude fibre content as related to initial harvest parameters. Stacks with higher initial moisture tended to increase in protein, while stacks with lower initial moisture tended to decrease in protein over the 70 days storage period.

The above equations can be used to predict the yield and density of stacks for known values of initial moisture and compression pressure. Changes in dry-matter and stack volume can also be predicted for given values of initial moisture and stack density.

As a result of this study, it seems that alfalfa hay can be stacked at higher moisture levels than is normally done. There is a slight increase in yield with increased moisture. High moisture stacks may look bad, due to excessive settling; however, the dry-matter loss is less in these high moisture stacks during storage period. The stacking operation should be done early in the morning whenever possible as there is a decrease in yield as the time of stacking during the day is delayed. This decrease was as much as $\frac{1}{2}$ ton per acre in this test.

Chapter 8

RECOMMENDATIONS FOR FURTHER STUDY

In this study, the compression pressure of 92.7 and 129.2 pounds per square foot were applied to the hay. A valuable area of further study would be to extend the pressure range. A range from 0 to 150 pounds per square foot might be desirable. The effect of initial stack moisture and compression pressure on the storage properties of stacked hay could then be studied with more details.

Detailed study regarding changes within a stack during the period of storage can also be useful. This may involve instrumentation to record the internal temperature, moisture content and weight of the stack during storage. Effect of the changes in stack temperature and moisture can be related to hay quality changes during storage.

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APPENDICES

APPENDIX A

Test Data for Moisture, Density, Dry-matter, Protein, Yield, Time of Day, Stack Volume and Compression Pressures

Stack No. 1: initial moisture of 37.8%, stacked at 12 noon with a compression pressure of 129.2 lb/ft^2.

Compression No.	Length of Windrow, ft	Compressed Volume, ft^3	Weight of Hay, lbs	Density of Hay, lb/ft^3
1	1829.2	751.9	3678.2	4.89
2	462.4	31.0	929.8	5.88
3	312.8	31.0	628.9	643
4	251.6	26.5	505.9	6.83
5	326.4	31.0	656.3	7.34
6	149.6	17.7	300.8	7.53
Total	2835.6	889.1	6700.0	7.53

Yield of 4.68 ton/acre at 37.8% and 3.42 ton/acre at 15% moisture. Dry-matter loss of 3.74%, Stack settling of 36.0%. Initial protein content of 15.1%, final protein content of 15.8% and Crude fibre 34.3%. Final stack moisture of 12.6%

Stack No. 2: initial moisture of 39.0% stacked at 12:30 p.m. with a compression pressure of 92.7 lb/ft^2.

1	1600.9	765.2	3277.2	4.28
2	510.5	39.8	1045.2	5.37
3	422.7	48.7	865.2	6.07
4	289.3	39.8	592.4	6.46
Total	2278.0	893.5	5780.0	6.46

Yield of 5.02 ton/acre at 39.0% and 3.60 ton/acre at 15% moisture. Dry-matter loss of 1.73%, Stack settling of 35.7%. Initial protein content of 14.3%, final protein content of 16.1% and crude fibre 36.4%. Final stack moisture of 15.9%.

Appendix A (cont'd)

Stack No. 3: Initial moisture of 40.0% stacked at 1.00 p.m. with a compression pressure of 129.2 lb/ft^2.

Compression No.	Length of Windrow, ft	Compressed Volume, ft^3	Weight of Hay, lbs	Density of Hay, lb/ft^3
1	1904.0	760.8	4044,8	5.31
2	462.4	22.1	982.2	6.42
3	340.0	39.8	722.2	6.98
4	374.0	31.0	794.4	7.66
5	224.4	31.0	476.8	7.93
Total	2638.4	884.7	7020.0	7.93

Yield of 5.26 ton/acre at 40.0% and 3.72 at 15% moisture. Dry-matter loss of 4.37%, stack settling of 33.9%. Initial protein content of 14.9%, final protein content of 14.7% and crude fibre 37.5%. Final stack moisture of 15.2%.

Stack No. 4: initial moisture of 40.6%, stacked at 1.30 p.m. with a compression pressure of 92.7 lb/ft^2.

1	1938.0	827.1	4017.1	4.85
2	442.0	39.8	916.2	5.69
3	476.0	35.4	986.7	6.56
Total	2101.2	902.3	5920.0	6.56

Yield of 5.58 ton/acre at 40.6% and 3.90 ton/acre at 15% moisture. Dry matter loss of 7.55%, stack settling of 40.3%. Initial protein content of 15.6%, final protein content of 15.3% and crude fibre 37.8%. Final stack moisture of 17.0%.

Stack No. 5: initial moisture of 40.8%, stacked at 2.00 p.m. with a compression pressure of 129.2 lb/ft^2.

1	1398.3	725.4	2969.3	4.09
2	729.4	48.6	1548.9	5.80
3	743.2	53.1	1578.1	7.33
4	543.6	39.8	1154.4	8.32
5	343.4	26.5	729.3	8.93
Total	2767.6	893.4	7980.0	8.93

Yield of 5.71 ton/acre at 40.8% and 3.98 ton/acre at 15% moisture. Dry-matter loss of 17.10%, stack settling of 36.3%. Initial protein content of 16.3%, final protein content of 16.3% and crude fibre 36.0%. Final stack moisture of 16.5%.

Appendix A (cont'd - 2)

Stack No. 6: initial moisture of 40.3%, stacked at 2.30 p.m. with a compression pressure of 92.7 lb/ft^2.

Compression No.	Length of Windrow, ft	Compressed Volume, ft^3	Weight of Hay, lbs	Density of Hay, lb/ft^3
1	1804.9	791.7	4683.0	5.91
2	366.9	44.2	952.1	6.74
3	337.2	44.2	874.9	7.40
Total	2409.8	880.1	6510.0	7.40

Yield of 5.35 ton/acre at 40.3% and 3.76 ton/acre at 15% moisture. Dry-matter loss of 18.11%, stack settling of 43.1%. Initial protein content of 14.4%, final protein content of 15.4% and crude fibre 34.7%. Final stack moisture of 16.9%

Stack No. 7: initial moisture of 44.9%, stacked at 3.00 p.m. with a compression pressure of 129.2 lb/ft^2.

1	2032.9	765.2	5156.8	6.74
2	376.9	26.5	955.9	7.72
3	297.5	13.3	754.6	8.53
4	257.9	48.6	654.1	8.81
5	228.0	35.4	578.6	9.11
Total	3193.2	889.0	8100.0	9.11

Yield of 5.02 ton/acre at 44.9% and 3.26 ton/acre at 15% moisture. Dry-matter loss of 17.26%, stack settling of 35.6%. Initial protein content of 14.1%, final protein content of 14.5% and crude fibre 37.9%. Final stack moisture of 15.5%.

Stack No. 8: initial moisture of 40.2%. stacked at 3:30 p.m. with a compression pressure of 92.7 lb/ft^2.

1	2052.8	818.3	4733.6	5.78
2	357.0	26.5	823.2	6.57
3	287.6	48.6	663.2	6.96
Total	2697.4	893.4	6220.0	6.96

Yield of 4.56 ton/acre at 40.2% and 3.21 ton/acre at 15% moisture. Dry-matter loss of 17.02%, stack settling of 39.1%. Initial protein content of 15.2%, final protein content of 15.0% and crude fibre 37.8%. Final stack moisture of 19.2%.

Appendix A (cont'd - 3)

Stack No. 9: initial moisture of 27.0%, stacked at 6.30 p.m. with a compression pressure of 129.2 lb/ft^2.

Compression No.	Length of Windrow, ft	Compressed Volume, ft^3	Weight of Hay, lbs	Density of Hay, lb/ft^3.
1	2003.3	769.6	4185.2	5.44
2	327.3	31.0	683.7	6.08
3	277.7	35.4	580.2	6.52
4	158.6	17.7	331.5	6.77
5	267.7	26.5	559.4	7.20
Total	3034.6	880.2	6340.0	7.20

Yield of 4.14 ton/acre at 27.0% and 3.55 ton/acre at 15% moisture. Dry-matter loss of 14.50%, stack settling of 29.6%. Initial protein content of 15.5%, final protein content of 16.0% and crude fibre 34.6%. Final stack moisture of 13.8%.

Stack No. 10: initial moisture of 35.2%, stacked at 7.00 p.m. with a compression pressure of 92.7 lb/ft^2.

1	1814.8	849.2	3988.1	4.70
2	99.2	8.8	217.9	4.90
3	257.8	26.5	566.6	5.40
4	317.4	48.6	697.4	5.86
Total	2489.2	933.1	5470.0	5.86

Yield of 4.35 ton/acre at 35.2% and 3.32 ton/acre at 15% moisture. Dry-matter loss of 1.33%, stack settling of 34.8%. Initial protein content of 15.3%, final protein content of 13.9% and crude fibre 37.2%. Final stack moisture of 13.0%.

Stack No. 11: initial moisture of 29.3%, stacked at 7.30 p.m. with a compression pressure of 129.2 lb/ft^2.

1	1993.3	769.6	4277.0	5.56
2	386.8	31.0	829.9	6.38
3	386.8	53.0	829.9	6.95
4	257.8	17.7	553.2	7.45
Total	3024.7	871.3	6490.0	7.45

Yield of 4.25 ton/acre at 29.3% and 3.53 ton/acre at 15% moisture. Dry-matter loss of 12.16%, stack settling of 31.9%. Initial protein content of 15.0%, final protein content of 14.9% and crude fibre 35.5% Final stack moisture of 13.7%.

Appendix A (cont'd - 4)

Stack No. 12: initial moisture of 36.7%, stacked at 8.00 p.m. with a compression pressure of 92.7 lb/ft^2.

Compression No.	Length of Windrow, ft	Compressed Volume, ft^3	Weight of Hay, lbs	Density of Hay, lb/ft^3
1	1874.3	866.9	4305.0	4.97
2	307.4	13.3	706.1	5.69
3	317.3	8.8	728.9	6.46
Total	2499.0	889.0	5740.0	6.46

Yield of 4.55 ton/acre at 36.7% and 3.39 ton/acre at 15% moisture. Dry-matter loss of 8.08%, stack settling of 34.2%. Initial protein content of 14.9%, final protein content of 15.0% and crude fibre 36.2%. Final stack moisture of 15.5%.

Stack No. 13: initial moisture of 44.8%, stacked at 8.30 p.m. with a compression pressure of 129.2 lb/ft^2.

1	1973.5	765.2	4916.1	6.42
2	376.8	31.0	938.8	7.35
3	327.3	35.4	815.2	8.02
4	297.5	39.8	741.1	8.50
5	208.2	26.5	518.8	8.61
Total	3183.3	897.9	7730.0	8.61

Yield of 4.81 ton/acre at 44.8% and 3.12 ton/acre at 15% moisture. Dry-matter loss of 8.44%, stack settling of 37.0%. Initial protein content of 14.8%, final protein content of 16.0% and crude fibre 35.4%. Final stack moisture of 14.7%.

Stack No. 14: initial moisture of 41.9%, stacked at 9.00 p.m. with a compression pressure of 92.7 lb/ft^2.

1	1973.5	862.5	4603.3	5.34
2	406.6	26.5	948.4	6.24
3	247.9	22.1	578.3	6.73
Total	2628.0	911.1	6130.0	6.73

Yield of 4.62 ton/acre at 41.9% and 3.16 ton/acre at 15% moisture. Dry-matter loss of 11.19%, stack settling of 36.9%. Initial protein content of 14.6%, final protein content of 15.3% and crude fibre 35.6%. Final stack moisture of 17.2%.

Appendix A (cont'd - 5)

Stack No. 15: initial moisture of 34.9%, stacked at 9.30 p.m. with a compression pressure of 129.2 lb/ft^2.

Compression No.	Length of Windrow, ft	Compressed Volume, ft^3	Weight of Hay, lbs	Density of Hay, lb/ft^3
1	1943.7	800.6	4205.7	5.25
2	406.6	44.2	879.8	6.02
3	337.1	35.4	729.6	6.61
4	238.0	17.7	514.9	7.05
Total	2925.4	897.9	6330.0	7.05

Yield of 4.28 ton/acre at 34.9 and 3.28 ton/acre at 15% moisture. Dry-matter loss of 7.08%, stack settling of 32.2%. Initial protein content of 13.5%, final protein content of 14.7% and crude fibre 37.0%. Final stack moisture of 15.1%.

Stack No. 16: initial moisture of 31.8%, stacked at 10.00 p.m. with a compression pressure of 92.7 lb/ft^2.

1	2072.6	906.7	4546.8	5.01
2	357.0	8.8	783.2	5.82
Total	2429.6	915.5	5330.0	5.82

Yield of 4.34 ton/acre at 31.8% and 3.48 ton/acre at 15% moisture. Dry-matter loss of 19.77%, stack settling of 40.4%. Initial protein content of 12.7%, final protein content of 15.2% and crude fibre 35.6%. Final stack moisture of 16.2%.

Stack No. 17: initial moisture of 11.1%, stacked at 10.30 a.m. with a compression pressure of 129.2 lb/ft^2.

1	1705.7	729.8	3064.7	4.20
2	446.3	70.8	801.8	4.83
3	277.7	35.4	498.9	5.22
4	297.5	35.4	534.6	5.62
Total	2727.5	871.4	4900.0	5.62

Yield of 3.56 ton/acre at 11.1% and 3.72 ton/acre at 15% moisture. Dry-matter loss of 23.13%, stack settling of 30.8%. Initial protein content of 14.8%, final protein content of 19.6% and crude fibre 33.5%. Final stack moisture of 16.5%.

Appendix A (cont'd - 6)

Stack No. 18: initial moisture of 7.2%, stacked at 10.50 a.m. with a compression pressure of 92.7 lb/ft^2.

Compression No.	Length of Windrow, ft	Compressed Volume, ft^3	Weight of Hay, lbs	Density of Hay, lb/ft^3.
1	1795.0	836.0	3429.1	4.10
2	387.0	39.8	663.1	4.67
3	342.0	39.8	577.8	5.10
Total	2524.0	915.6	4670.0	5.10

Yield of 3.65 ton/acre at 7.2% and 3.98 ton/acre at 15% moisture. Dry-matter loss of 25.56%, stack settling of 31.1%. Initial protein content of 15.1%, final protein content of 14.0% and crude fibre 37.3%. Final stack moisture of 12.7%.

Stack No. 19: initial moisture of 9.0%, stacked at 11.10 a.m. with a compression pressure of 129.1 lb/ft^2.

1	1735.5	725.4	3192.2	4.38
2	550.4	75.2	1012.4	5.22
3	332.2	48.6	611.1	5.64
4	257.8	31.0	474.3	6.05
Total	2875.9	880.2	5290.0	6.05

Yield of 3.64 ton/acre at 9.0% and 3.90 ton/acre at 15% moisture. Dry-matter loss of 25.90%, stack settling of 31.5%. Initial protein content of 12.7%, final protein content of 15.3% and crude fibre 34.1%. Final stack moisture of 13.0%.

Stack No. 20: initial moisture of 7.1%, stacked at 11.30 a.m. with a compression pressure of 92.7 lb/ft^2.

1	1938.8	871.4	3528.1	4.05
2	396.7	26.5	721.9	4.73
Total	2335.5	897.9	4250.0	4.73

Yield of 3.60 ton/acre at 7.1% and 3.94 ton/acre at 15% moisture. Dry-matter loss of 22.35%, stack settling of 35.5%. Initial protein content of 14.8%, final protein content of 14.2% and crude fibre 38.0%. Final stack moisture of 14.6%.

Appendix A (cont'd - 7)

Stack No. 21: initial moisture of 18.0%, stacked at 11.50 a.m. with a compression pressure of 129.2 lb/ft^2.

Compression No.	Length of Windrow, ft	Compressed Volume, ft^3	Weight of Hay, lbs	Density of Hay, lb/ft^3
1	1785.0	743.1	3239.4	4.36
2	545.4	74.2	989.8	5.17
3	302.5	39.8	548.9	5.57
4	238.0	22.1	431.9	5.92
Total	2870.9	880.2	5210.0	5.92

Yield of 3.59 ton/acre at 18.0% and 3.45 ton/acre at 15% moisture. Dry-matter loss of 11.45%, stack settling of 27.1%. Initial protein content of 14.5%, final protein content of 14.3% and crude fibre 37.4%. Final stack moisture of 14.8%.

Stack No. 22: initial moisture of 8.0%, stacked at 12.10 p.m. with a compression pressure of 92.7 lb ft^2.

1	1988.4	831.5	3334.8	4.01
2	520.6	22.1	873.2	4.93
3	576.8	35.4	632.0	5.44
Total	2885.8	889.0	4840.0	5.44

Yield of 3.22 ton/acre at 8.0 and 3.59 ton/acre at 15% moisture. Dry-matter loss of 20.32%, stack settling of 29.0%. Initial protein content of 14.8%, final protein content of 14.2% and crude fibre 35.9%. Final stack moisture of 14.3%.

Stack No. 23: initial moisture of 6.3%, stacked at 12.30 p.m. with a compression pressure of 129.2 lb ft^2.

1	2330.5	813.8	3558.8	4.37
2	456.2	39.8	696.6	4.98
3	317.3	48.7	484.6	5.25
Total	3104.0	902.3	4740.0	5.25

Yield of 3.02 ton/acre at 6.3% and 3.33 ton/acre at 15% moisture. Dry-matter loss of 12.32%, stack settling of 25.2%. Initial protein content of 15.8%, final protein content of 13.7% and crude fibre 35.6%. Final stack moisture of 12.1%.

Appendix A (cont'd - 8)

Stack No. 24: initial moisture of 8.0%, stacked at 12.50 p.m. with a compression pressure of 92.7 lb/ft^2.

Compression No.	Length of Windrow, ft	Compressed Volume, ft^3	Weight of Hay, lbs	Density of Hay, lb/ft^3
1	2429.7	844.8	3437.4	4.07
2	510.7	39.8	722.6	4.70
Total	2940.4	844.6	4160.0	4.70

Yield of 2.80 ton/acre at 8.0% and 3.03 ton/acre at 15% moisture. Dry-matter loss of 11.81%, stack settling of 30.5%. Initial protein content of 13.8%, final protein content of 13.6% and crude fibre 37.3%. Final stack moisture of 15.2%.

APPENDIX B

Analysis of Variance Results

A. Dry-matter Loss.

	Source	Degrees of Freedom	Sum of Squares	Mean Squares	'F' Statistic	Remarks
Whole plot	R	3	28.407	9.469	0.098	
	M	2	387.92	193.9	2.01	Not Significant
	RM(error)	6	578.13	96.35		
Split plot	P	1	2.263	2.263	0.089	
	MP	2	5.169	2.584	0.101	Not Significant
	RP + RMP (error)	9	228.2	25.36		

B. Protein Loss.

	Source	Degrees of Freedom	Sum of Squares	Mean Squares	'F' Statistic	Remarks
Whole plot	R	3	1.624	0.541	0.179	
	M	2	0.292	0.146	0.048	Not Significant
	RM(error)	6	18.12	3.021		
Split plot	P	1	2.100	2.100	0.903	
	MP	2	5.466	2.733	1.175	Not Significant
	RP + RMP (error)	9	20.93	2.325		

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