INNOVATIONS IN HAY HARVESTING AND STORING

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INTRODUCTION

Haymaking in the humid parts of the U.S. is the most risky operation that farmers engage in. Standing hay is extremely high in moisture and must be dried to at least 25% moisture or less before it can be stored without spoilage. Most farmers rely on natural field drying processes to cure their hay. Natural drying is often slowed by high relative humidity. Rainfall frequently occurs before the hay has dried which further slows the drying process and can result in serious nutrient and yield losses. Haymaking is also a labor-intensive farming operation and, until recently, involved a large amount of manual labor.

Most of the problems associated with haymaking could be solved if hay dried quickly in the field, or if it could be stored at high moisture without spoilage. A combination of both rapid drying and high moisture storage could revolutionize haymaking. These problem areas, as well as the labor problem, have attracted considerable research interest in recent years.

HAY DRYING

The weight of water that must be evaporated from a hay crop in order to dry it to a safe moisture percentage for storage is about four times the weight of the dry hay. While this is a large amount of water and normally requires two or three days to evaporate under field conditions, it represents only about six hundredths of an inch of water, if the hay crop yields 2 tons of dry matter per acre. This quantity of water could be evaporated from a free water surface or from a standing hay crop in 4 to 6 hours on a sunny day. Thus, the problem in hay drying is not the amount of water that must be evaporated but rather the resistance to evaporation afforded by the structure of the plant. Resistance to water loss is a highly desirable attribute for living plants because it allows the plants to withstand drought stress. However, the same phenomenon prevents cut hay from drying rapidly.

Enhanced Drying. Resistance to water loss results from a waxy layer (cuticle) on the surface of leaves and stems and from membranes and constituents within the plant cells. Water loss from cut forage plants has been experimentally increased by subjecting the plants to treatments that disrupt the cuticle and internal cells. Figure 1, adapted from Leshem et al. (1972), shows the water loss from untreated and petroleum ether treated orchardgrass under laboratory conditions at 43% relative humidity. Petroleum ether treatment disperses the cuticle and disrupts internal membranes. The initial rate of water loss (Figure 1) was about seven times faster when the hay was treated with petroleum ether than when the hay was untreated. The drying rate appears to have slowed considerably at about 50% moisture even when treated. This is presumably due to resistance to water loss caused by factors other than the cuticle.

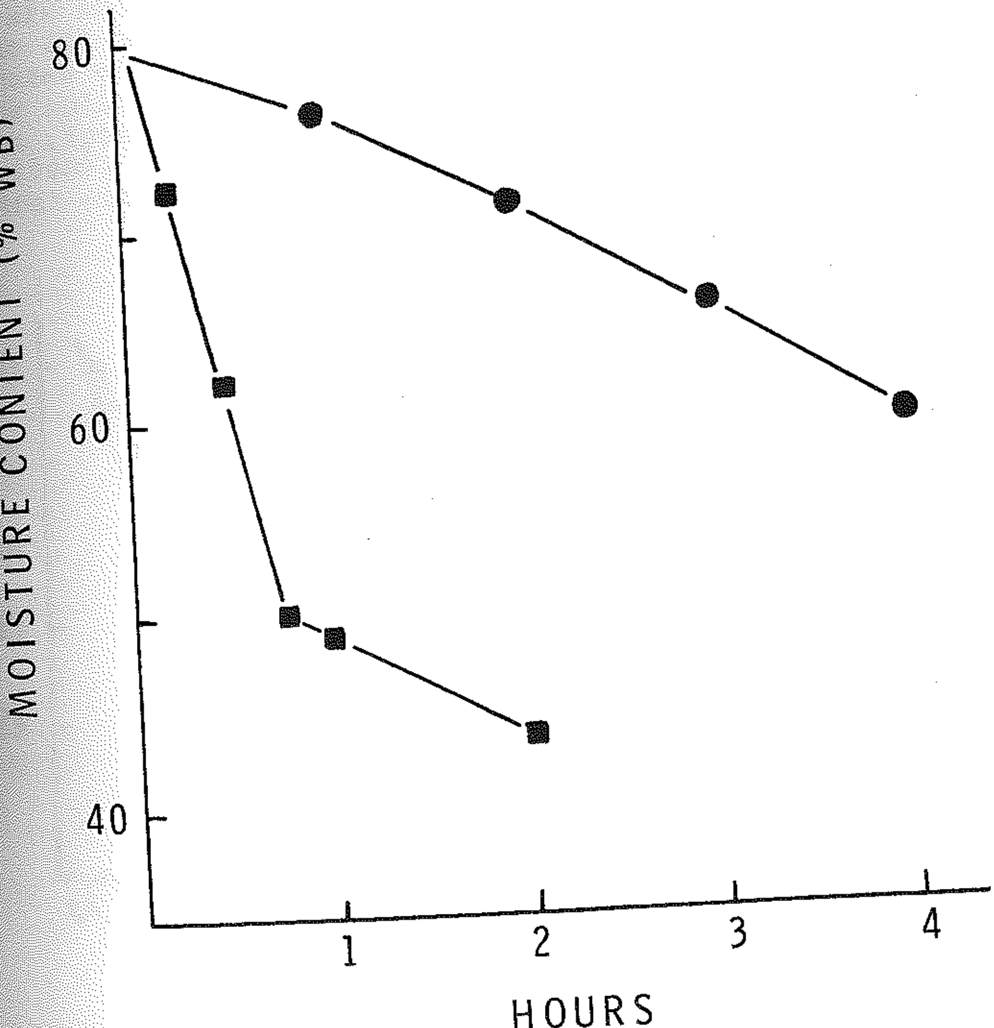

Figure 1. Moisture content of untreated (●) and petroleum ether (■) treated orchardgrass during drying at 43% relative humidity in the laboratory. (Adapted from Leshem et al. 1972.)

Similar increases in drying rate can be achieved by macerating tissue to disrupt cell structure. Figure 2 shows results of a study by Krutz et al. (1978) in which the drying rate of untreated and macerated alfalfa was compared. Macerated material dried to less than 20% moisture by 5 hours after harvest. Untreated material was approximately 61% moisture 5 hours after harvest.

Figures 1 and 2 clearly show that hay can be made to dry quickly if the resistance to evaporation is overcome. Neither of these treatment procedures have been developed for practical field applications. However, other treatment procedures aimed at increasing water loss from cut forage are being studied.

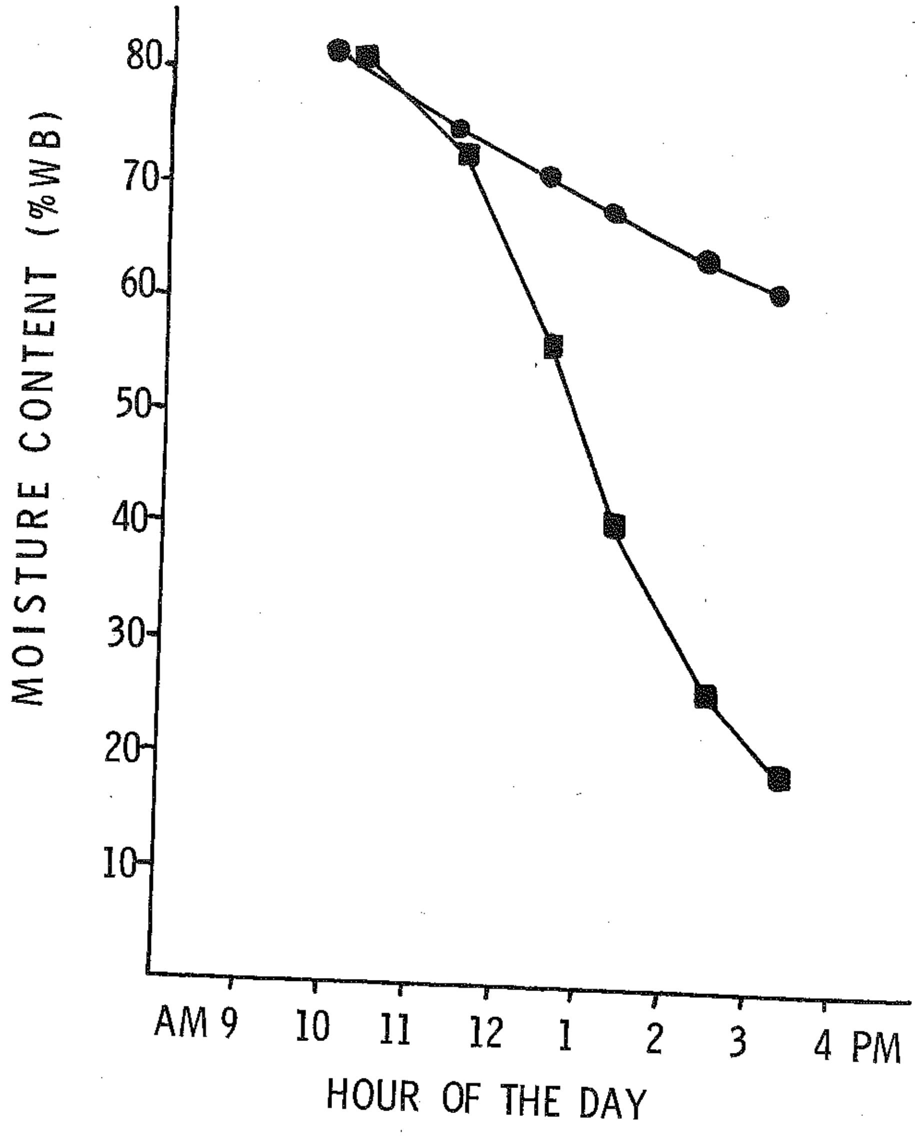

Figure 2. Moisture content of untreated (●) and macerated (■) alfalfa during drying. (From Krutz et al., 1978.)

Enhanced Drying - Field Applications. Hay conditioning, which is an attempt to break the plant enough to speed drying, has been successful and is widely practiced. However, the drying rates of conditioned hay are still far below those that could potentially be achieved if plant resistance to evaporation was eliminated.

Several field trails have been conducted in which potassium carbonate has been used to enhance drying. Potassium carbonate apparently disrupts the cuticle and thus speeds water loss from plants. The most promising field results have been reported by Tullberg and Minson (1978) in Australia. Results of one of their studies are shown in Figure 3. Carbonate treated hay dried to less than 25% moisture by midday on the day after cutting. Application rates of approximately 85 gallons/acre of 2% potassium carbonate solution effectively enhanced drying. Similar results have been reported in laboratory studies in the U.S. (Wieghart et al., 1980). Potassium carbonate treatment should have no detrimental effect on forage quality.

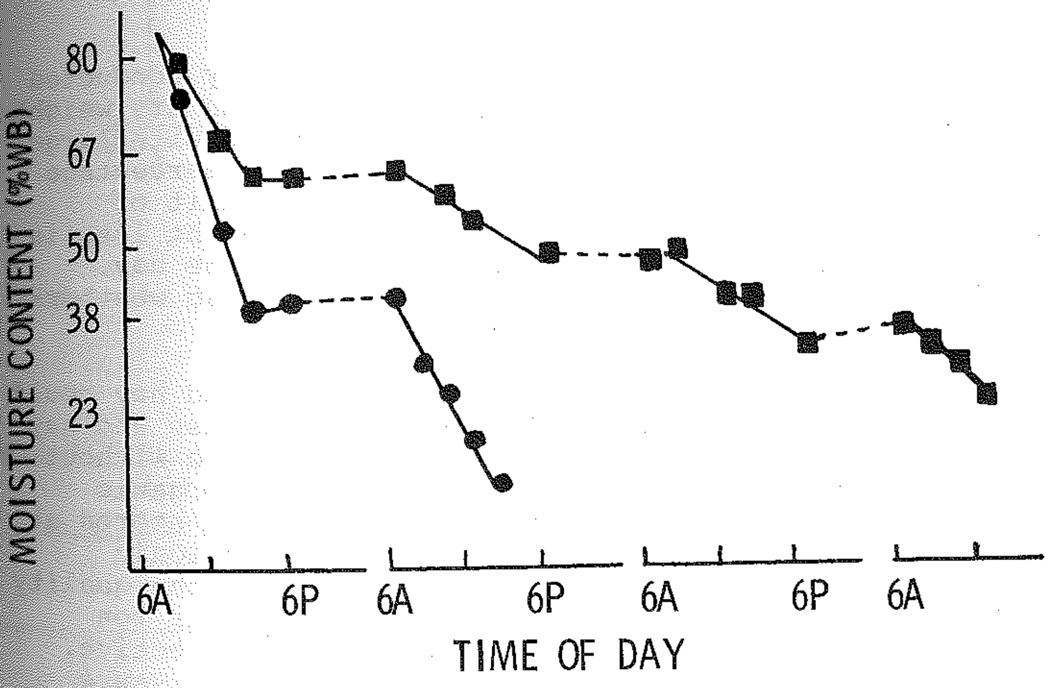

Figure 3. Moisture content of potassium carbonate (●) and untreated (■) alfalfa during field drying. (From Tullberg and Minson, 1978.)

Other researchers (Wieghart et al., 1980; Seif, 1981; Harris and May-Brown, 1976; and Harris, 1978) have used various chemicals to speed hay drying. Long chain fatty acids (Wieghart et al., 1980) and organic phosphates (Harris, 1978; and Sief, 1981) appear to be effective drying aids. However, these materials have only been used experimentally and additional research is needed before their effectiveness under field conditions can be determined. Also, their effect on forage quality is unknown.

HIGH MOISTURE STORAGE

Hay stored above 20% moisture approaches 90 to 100% relative humidity (Greenhill et al., 1961) and favors the development of mold organisms (Gregory et al., 1963). The heat generated by the metabolic activity of these organisms causes the temperature of the hay to increase. Heat resistant fungi remain active when the temperature of the hay is 115 to 150^{o}F. If the hay temperature rises above 150^{o}F, chemical reactions occur which can lead to spontaneous combustion. These reactions are most likely to occur if hay is stored at 30 to 40% moisture. Some microbial growth occurs in hay even when it is stored at less than 20% moisture. As a result, dry matter loss occurs during storage. Hodgenson et al. (1946) reported that hay stored below 20% moisture lost from 4 to 10% of its dry weight during storage. The amount of dry weight lost depends upon the moisture content of the hay.

Figure 4 shows the results of a study we recently conducted at Purdue University in which the relationship between dry weight loss and moisture percentage at baling was determined with large round bales. These results indicate that almost one percentage unit of dry weight was lost during storage for each unit of moisture above approximately 10% at baling. This weight loss is presumed to reflect primarily metabolic lossed from the hay. These weight losses do not include weight losses due to weathering since the bales were stored inside.

Acid Preservatives. If microbial growth in stored hay could be prevented, dry weight losses in storage would be less and hay could presumably be stored at more than 20-25% moisture without spoilage. Sheaffer and Clark (1975) have shown that organic acids and related compounds inhibit mold growth in hay stored at high moisture. Knapp et al. (1976) reported that propionic acid reduced heating and storage losses and preserved the quality of high moisture alfalfa hay when applied at 20 lbs. per ton of hay (Table 1). Lower application rates were not effective. While organic acids are effective in preserving high moisture hay, they are quite corrosive to equipment and reasonably expensive when applied at effective rates.

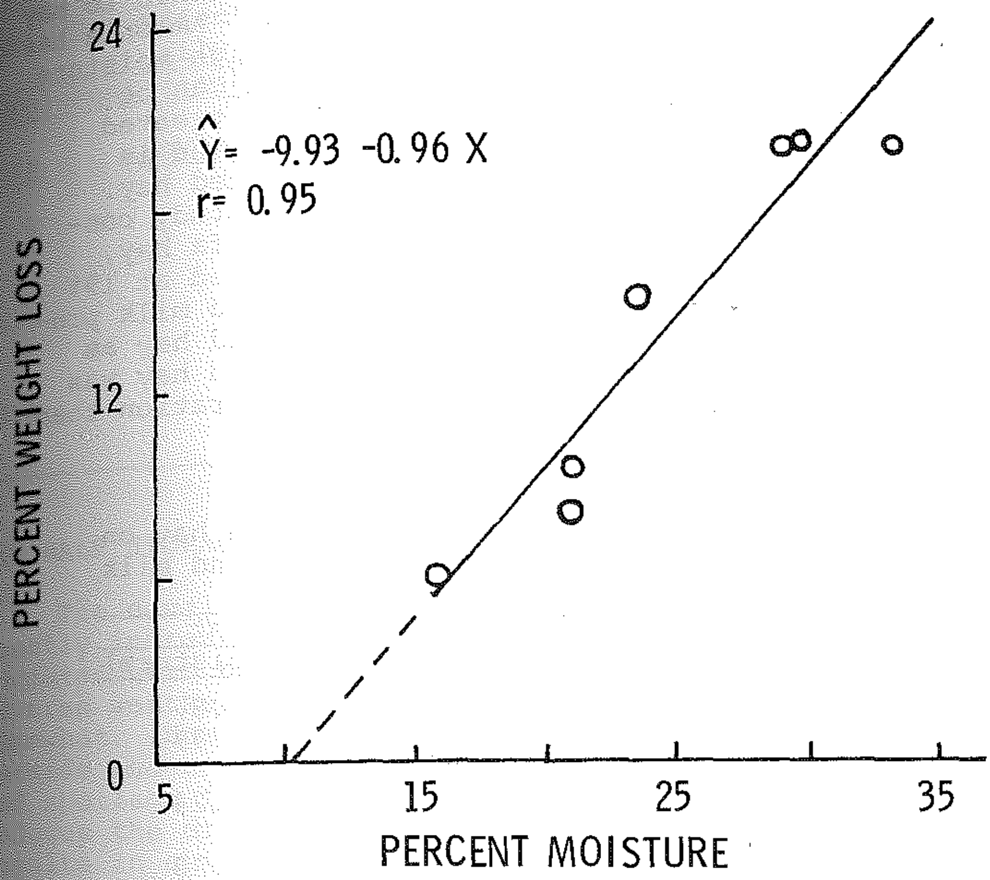

Figure 4. Relationship between moisture percentage at baling and dry weight loss during storage of large grass hay bales.

Table 1. Storage losses and composition of alfalfa hay baled at 32% moisture and treated with different rates of propionic acid at baling (from Knapp et al., 1976).

	Max. Storage Temp.	Dry Weight Loss	IVDMD	Crude Protein	In Vitro Fiber Digest.
	F	%	%	%	%
Control	124	15.1	60.5	16.2	47.0
Propionic acid					
.02%	127	16.7	61.8	16.9	48.2
.2%	115	13.2	62.2	16.9	49.6
.5%	104	11.7	61.0	16.9	49.9
1.0%	86	7.6	65.0[1]	16.9	50.8[1]

[1]Hay at harvest was 70.5% IVDMD (*in vitro* dry matter disappearance) and had a fiber digestibility of 51.1%.

Anhydrous Ammonia. The addition of anhydrous ammonia to hay has the potential to provide two important benefits. Ammonia has fungicidal properties and can be used to sterilize high moisture hay. Hay effectively treated with anhydrous ammonia can be baled at 30% moisture without spoilage. Alfalfa hay treated and baled in this manner is excellent livestock feed and is higher in total nitrogen (crude protein) than untreated hay. Table 2 shows data obtained from a recent lactation study conducted at Purdue University in which ammoniated alfalfa hay, baled at 32% moisture, and similar untreated hay, baled at 19% moisture, were fed to dairy cows. Hay consumption and milk production were as good with the high moisture ammoniated hay as with untreated hay baled at 19% moisture. The treated hay was five percentage units higher in crude protein concentration than untreated hay.

Table 2. Effect of ammoniating high moisture alfalfa hay on crude protein percentage, hay consumption and milk production.

	Baling Treatment	
	Ammoniated (32% Moisture)	Untreated (19% Moisture)
Crude Protein (%)	23.8	18.8
Hay Consumed (% of body wt.)	2.02	1.99
Total Ration Consumed (% of body wt.) 1/	3.32	3.24
Fat Corrected Milk (lb/day)	47.1	47.7
Milk Fat (%)	3.83	3.70
Milk Protein (%)	3.13	3.14

1/Rations approximately 60% hay and 40% concentrate. Total rations equal in protein percentage.

Ammonia treatment also has potential as a means of increasing the protein percentage and digestibility of low quality hay stored dry. When added to mature grass hay, baled dry, crude protein percentage has been doubled. Fiber digestibility has also been increased greatly and hay consumption by animals has been increased 22%. As a result of these changes in the hay, ammoniation has increased animal gains on hay rations. Table 3 shows the results of a study in which ammoniated and control hays were fed with and without grain and soybean meal supplementation. Ammoniation of the hay increased animal gain in each case. Protein supplementation of ammoniated hay did not increase gain, indicating that the crude protein added by ammoniation was effective in meeting the animal's needs.

Table 3. Effect of ammonia treatment and supplementation on daily gain and hay consumption by steers.

Supplement (lb/hd/day) Corn	Soybean meal	Hay	Daily Gain (lb/hd)	Hay consumed (dry matter) (lb/hd/day)
0	0	Untreated	0.35	8.70
		Ammoniated	0.81	10.47
4.0	0	Untreated	1.00	8.02
		Ammoniated	1.56	9.47
3.0	1.0	Untreated	1.17	7.95
		Ammoniated	1.53	9.80

BIG BALE STORAGE

The development and use of large package hay machinery has greatly increased the mechanization and reduced the labor associated with haymaking operations. As a result, the risk of adverse weather affecting the field operations has been reduced somewhat. However, large hay packages are generally stored outside and are, therefore, subjected to weather deterioration and spoilage from harvest until feeding. Weathering not only reduces the dry weight of outside stored hay bales, but also results in changes in the composition of the weathered hay. These compositional changes may drastically reduce the nutritive value of the weathered fraction. Part of these losses result from deterioration around the top and sides of bales. Additional deterioration occurs where the bale contacts moist ground.

In studies that we have conducted in southern Indiana, the *in vitro* dry matter disappearance (IVDMD) of the weathered fraction of grass hay bales averaged 16.3 percentage units lower than the unweathered fraction. Mixed grass-alfalfa hay decreased 22.4 percentage units due to weathering, while the IVDMD of the unweathered fraction had decreased only 2 percentage units during storage. Total nitrogen (crude protein) was greater in the weathered fraction than in the unweathered fraction (Lechtenberg, 1978).

The combination of weathering and dry weight loss represents the total loss associated with storing hay outside. The best estimate of these total losses is the proportion of the original package weight remaining unweathered after storage. This proportion, expressed as a percentage of the dry weight, has been calculated for hay bales stored outside on the ground and on crushed rock during two years in southern Indiana (Table 4). Crushed rock storage was used in an attempt to reduce the amount of deterioration at the soil surface.

An average of 76.8% of the original hay dry weight remained unweathered at the end of storage when the hay was stored on the ground. Storing the large bales on crushed rock increased the percentage to 85.5%. Ninety-two percent of the hay stored inside during the second year remained at the end of storage. Since there was no weathering of the inside stored hay, this loss represents dry weight loss during storage.

The proportion of the final package dry weight in the unweathered fraction is also shown in Table 4. These values are considerably higher than the above values because they represent only the visibly deteriorated hay and do not include the dry weight lost during storage.

The difference between the proportion of the hay remaining unweathered when stored outside and when stored inside represents the loss due to outside storage, 15.2% in this study. Crushed rock storage reduced the loss due to outside storage to 6.5%. This suggests that more than half (57%) of the storage loss associated with outside storage of large hay bales occurs where the bale contacts the ground.

Even though weathering losses with big hay bales stored outside are rather large, it is difficult to economically justify building conventional type structures for hay storage, considering present interest rates. We have experimented with a pipe-frame, plastic-covered greenhouse as a bale storage structure. A 30 x 32 ft. structure can hold 54 bales and can be built at a cost of about $1.50/square foot. Out present structure has lasted two seasons without replacing the plastic cover. We anticipate that it will need to be replaced before a third season. The cost of replacing the cover will be approximately $70 (7¢/square foot). The structure is still being used experimentally, but we feel that a low cost structure of this nature may have considerable potential for large hay bale storage. We have also used the greenhouse to ammoniate large hay bales.

Table 4. Proportion of the original and final bale dry weight unweathered with large round bales stored on the ground, on crushed rock, and inside.

	Year	Ground	Crushed Rock	Inside
Unweathered Fraction	1	72.2	82.8	--
(% of Original Bale Wt)	2	81.3	88.2	92.0
	Mean	76.8	85.5	92.0
Unweathered Fraction	1	82.5	94.1	--
(% of Final Bale Wt)	2	93.0	94.6	--
	Mean	87.8	94.4	

References

Gregory, P.H., M.E. Lacey, G.N. Festenstein, and F.A. Skinner. 1963. Microbial and biochemical changes during the moulding of hay. J. Gen. Microbiol. 33:147-174.

Greenhill, W.L., J.F. Couchman, and J. De Freitas. 1961. Storage of hay. III. Effect of temperature and moisture on loss of dry matter and changes in composition. J. Sci. Fd. Agric. 12:293-297.

Harris, C.E. 1978. The effect of organic phosphates on the drying rate of grass leaves, and dry matter losses during drying. J. of Agric. Sci. 91:185-189.

Harris, C.E. and R. May-Brown. 1976. Effect of tri-n-butyl phosphate on the drying rate and respiration rate of grass leaves measured in the laboratory. J. of Agric. Sci., Cambridge 86:531-535.

Hodgeson, R.E., J.B. Shepard, L.G. Schoenleber, H.M. Tysdal, and W.H. Harterman. 1946. Progress report on comparing the efficiency of three methods of harvesting and preserving forage crops. Agric. Engr. 77:219-222.

Knapp, W.R., D.A. Holt, and V.L. Lechtenberg. 1976. Propionic acid as a hay preservative. Agron. J. 68:120-122.

Krutz, D.W., D.A. Holt, and D. Miller. 1978. New process for fast field drying of alfalfa. Proceed. of the Second Intl. Green Crop Drying Congress 186:192.

Lechtenberg, V.L. 1978. Preserving and increasing quality in harvested forages. Proceed. American Forage and Grassland Council. p. 85-91.

Leshem, Y., R. Thaine, C.E. Harris, and R. J. Canaway. 1972. Water loss from cut grass with special reference to haymaking. Annuals of Applied Biology 72:89-104.

Shaeffer, C.C. and N.A. Clark. 1975. Effects of organic preservatives on the quality of aerobically stored high moisture baled hay. Agronomy J. 67:660-662.

Seif, Seif A. 1981. The effect of chemical, physical, physiological, and environmental factors on drying and respiration rates in alfalfa (Medicago sativa L.). Ph.D. thesis Purdue University. 132 pages.

Tullberg, J.N. and D. J. Minson. 1978. The effect of potassium carbonate solution on the drying of lucerne. J. of Agric. Sci., Cambridge 91:557-561.

Wieghart, M., J.W. Thomas, and M.B. Tesar. 1980. Hastening drying rate of cut alfalfa with chemical treatment. J. Anim. Sci. 51:1-9.