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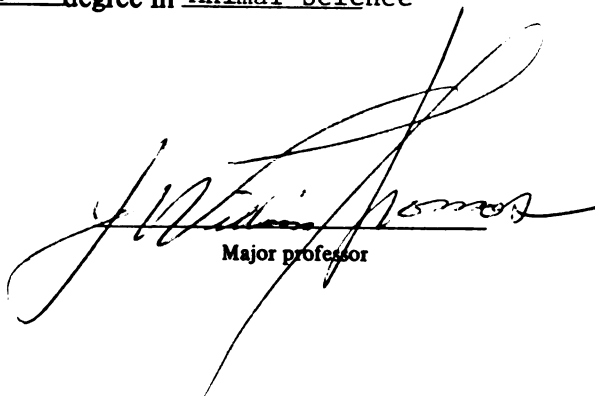
Hastening Drying Rate of Cut Forage
by Chemical Treatment

presented by

Timothy R. Johnson

has been accepted towards fulfillment
of the requirements for

M.S. degree in Animal Science



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ABSTRACT

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By

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Timothy R. Johnson

A THESIS

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Both K_2CO_3 and Submitted to (MS) of long chain fatty acids in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Animal Science

1982

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I would like to express my appreciation to Dr. J. W. Thomas, my major Professor, for his help and guidance both in my studies and in my research program.

Solutions containing emulsified lipid mixtures and/or alkali salts were sprayed on cut forage in laboratory and field trials to increase rate of drying, thus reducing length of time cut forage would be at risk to adverse weather.

Alkali metal carbonates increased mean DM content and drying rate of cut alfalfa (Alf) $Li < Na < Rb < K < Cs$. Magnitude of increase in mean DM after treatment with solutions containing K salts was greatest for solutions of Ph 13.

Both K_2CO_3 and methyl esters (ME) of long chain fatty acids hastened drying of Alf. Combinations of these two components increased drying rates above use of either component alone. The minimum effective application of ME in K_2CO_3 solutions was 0.5 gr ME/kg fresh forage weight. The most effective application was 2 to 3 grams ME/kg. Effectiveness of applied ME, K_2CO_3 mixtures increased with increases in liquid application rates. Methyl ester, K_2CO_3 solutions hastened drying of red clover and birdsfoot trefoil but not of brome or orchard grass. Spray treatment reduced respiration loss during field drying and interval from cutting to baling Alf at a DM "safe" for storage. Analytical values of sprayed and unsprayed forage at baling and during storage were similar.

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Effect of Swath Micro Climate on Forage Drying	15
Methods of Increasing the Drying Rate and Reducing Field Exposure Time of Conserved Forage	18
Mechanical Treatments for Shortening Drying Time	19
Reducing Tissue Resistance	19
Treatments to Decrease Moist Resistance to Drying	22
Chemical and Thermal Treatments to Increase Forage Drying Rates	25
Inhibition of Stomach Passage	26
Destruction of Barriers to Water Uptake	27
Increasing Permeability of Cuticular Barrier	31

	Page
OBJECTIVES	37
MATERIALS AND METHOD	39
Laboratory Procedures	39
Field Procedures	Page
ACKNOWLEDGEMENTS	ii
LIST OF TABLES	vi
LIST OF FIGURES	viii
INTRODUCTION	1
LITERATURE REVIEW	3
Factors Affecting Water Loss from Cut Forage	3
Plant Mechanisms for Maintaining Moisture Equi- librium	3
Physiological Restraints to Water Loss in Cut Forage	10
Environmental Constraints to Forage Drying . . .	14
Effect of Swath Micro Climate on Forage Drying .	15
Methods of Increasing the Drying Rate and Reducing Field Exposure Time of Conserved Forage	18
Mechanical Treatments for Decreasing Drying Time	19
Reducing Tissue Resistance	19
Treatments to Decrease Swath Resistance to Drying	22
RESULTS AND DISCUSSION	33
Chemical and Thermal Treatments to Increase For- age Drying Rates	25
Inhibition of Stomatal Closure	26
Destruction of Cuticular and Cellular Bar- riers to Water Loss	27
Increasing Transpiration by Reversible Al- teration of Cuticle Surface Waxes	31

	Page
OBJECTIVES	37
MATERIALS AND METHODS	39
Laboratory Procedures	39
Field Procedures	41
Application of Chemicals to Increase Drying of Cut Forage Under Laboratory and Field Conditions	45
Hastening Forage Drying with Carbonates and Other Salts of the Alkali Metal Group	45
Influence of Methyl Ester Source and Composition	46
Emulsifiers and Surfactants Importance in Solution Formulation and Forage Drying	47
Combined Effects of Potassium Carbonate and Methyl Esters	47
Optimum Amounts of Methyl Ester Addition	47
Influence of Changing Liquid Application Rate and Spray Pump Pressure on Forage Drying	48
SUMMARY	
Chemical Treatment of Different Forage Species and Plants in Different Physiological States	48
Influence of Chemical Treatment on Length of Field Drying and Losses of Dry Matter and Nutrients During Harvest and Storage	49
Laboratory Analysis	52
Experimental Design and Statistical Analysis	52
RESULTS AND DISCUSSION	53
Drying of Alfalfa Treated with Carbonates and Other Salts of the Alkali Metal Group	53
Influence of Methyl Ester Source and Composition	66
The Effectiveness of Various Emulsifiers and Surfactants in Maintaining Lipid Water Emulsions and Speeding Drying	70

	Page
Additive Effects of Methyl Esters and Potassium Carbonate	73
Optimum Amounts of Methyl Ester Addition	87
Maximizing Coverage by Changes in Liquid Application Rate and Spray Pump Pressure	93
Chemical Treatment of Different Forage Species and Methods of Expressing and Evaluating Treatment Effects	100
Drying of Alfalfa in Swaths or Windrows Under Variable Field Weather Conditions	119
Apparent Respiration Losses During Field Drying	123
Dry Matter Losses from Mowing and Raking as a Function of Chemical Treatment and Method of Estimation	128
Changes in Amount of Dry Matter, Bale Temperatures, and Analytical Values of Baled Hay During Storage as a Function of Dry Matter Content and Chemical Treatment	130
SUMMARY	142
BIBLIOGRAPHY	147
Emulsifiers and Surfactants Effectiveness in Hastening Drying of Alfalfa Treated with Potassium Carbonate and Methyl Ester Emulsions	71
Measures of Drying When Alfalfa Was Treated With Methyl Esters or Potassium Carbonate Used Alone or in Combination	74
Drying Rates for the First and Second Days Following Treatment with Potassium Carbonate or a Combination of Methyl Esters and Potassium Carbonate	83
Mean Drying Rates and Dry Matter Content During First and Second Days After Treatment of Alfalfa With Potassium Carbonate or a Combination of Methyl Esters and Potassium Carbonate	86

TABLE

PAGE

12	Measurements of Drying After Treatment of Alfalfa With Increasing Amounts of Methyl Esters in Potassium Carbonate Solutions	88
LIST OF TABLES		
13	Drying of Alfalfa as Influenced by Changes in Amounts of Applied Liquid or Spray Pump Pressure	97
TABLE		PAGE
1	Methods of Expressing Ratios of Moisture to Dry Matter During Drying of a Forage	12
2	Laboratory Experiments Testing Drying Parameters of Alfalfa Treated With Carbonates and Other Salts of the Alkali Metals	55
3	Field Trials Testing Drying Parameters of Alfalfa Treated With Carbonates and Other Salts of the Alkali Metals	59
4	Drying Rates During Given Periods Post-Cutting for Three Laboratory Trials	62
5	Ionic Radii and First Ionization Energies of the Alkali Metals	63
6	Composition of Methyl Esters, Other Lipids and Emulsifiers Used in Spray Solutions	67
7	Description of Drying Parameters for Laboratory Trials Testing Different Methyl Esters and Lipid Emulsions	68
8	Emulsifiers and Surfactants Effectiveness in Hastening Drying of Alfalfa Treated with Potassium Carbonate and Methyl Ester Emulsions	71
9	Measures of Drying When Alfalfa Was Treated With Methyl Esters or Potassium Carbonate Used Alone or in Combination	74
10	Drying Rates for the First and Second Days Following Treatment with Potassium Carbonate or a Combination of Methyl Esters and Potassium Carbonate	83
11	Mean Drying Rates and Dry Matter Content During First and Second Days After Treatment of Alfalfa With Potassium Carbonate, or a Combination of Methyl Esters and Potassium Carbonate	86

TABLE	LIST OF FIGURES	PAGE
12	Measurements of Drying After Treatment of Alfalfa With Increasing Amounts of Methyl Esters in Potassium Carbonate Solutions	88
13	Drying of Alfalfa as Influenced by Changes in Amounts of Applied Liquid or Spray Pump Pressure	97
14	Description of Drying Parameters for Control and Chemically Treated Red Clover (RC), Alfalfa (Alf) and Birdsfoot Trefoil (Bft)	101
15	Measurements of Drying Responses of Bromegrass (BG), Orchard Grass (OG) and Alfalfa (Alf) at Different Maturities or Grown Under Different Conditions to Chemical Treatment	113
16	Drying Rates of Brome Grass, Orchard Grass and Alfalfa at Given Water Contents Between 5.0 to 0.5	116
17	Characteristics of Alfalfa Grown Under Green House and Field Conditions	118
18	Measures of Drying for Chemically Sprayed and Unsprayed Alfalfa that Was Left in a Swath or Windrow After Mowing	120
19	Drying Rates of Alfalfa Before and After Dew and Rain in Two Field Trials	122
20	Apparent Respiration Losses During Drying in Eight Field Trials	124
21	Dry Matter Losses from Mowing and Raking as Estimated by Two Methods	129
22	Interval from Cutting to Baling, Dry Matter Content at Baling, Bale Temperatures and Dry Matter Losses During Storage for Five Field Trials	131
23	Analytical Values for Control and Sprayed Alfalfa at Baling and After Storage	134
24	Analytical Values for Unsprayed and Sprayed Alfalfa as Baled at 77 to 82% Dry Matter and After Storage	137

LIST OF FIGURES

FIGURE		PAGE
1	Generalized plant cuticle structure	6
2	Drying rates of alfalfa treated with potassium carbonate, emulsified methyl esters or a combination of these compounds over 47 hours of drying (Trial L14).	78
3	Drying rates between water contents of 6.0 and 0.5 for alfalfa treated with potassium carbonate, emulsified methyl esters or a combination of these compounds (Trial L14).	80
4	Dry matter content of three legume species during 23 hours of drying with or without chemical treatment at cutting (Trial L17).	103
5	Drying rates between water contents 3.5 and 0.5 for three legume species with or without chemical treatment (Trial L17).	106
6	Percentage of initial water remaining in three legume species with or without chemical treatment over 23 hours of drying (Trial L17).	110

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Proper conservation of forages as dry hay or silage at the optimum stage of maturity can maintain ration quality and animal performance throughout the year.

A considerable amount of research effort has been directed towards improving cultural practices and breeding forages with high yield potential. Attempts to increase utilization of crop residue and low quality forages through mechanical and chemical treatments have also received much attention. On

INTRODUCTION

Forages are important in the United States livestock industry, supplying more than half the feed units consumed by farm animals. Increases in world population and demand for cereal grains as human food sources and to produce alcohol fuels may increase the importance of both yield and quality of forages as they are substituted for feed grains in livestock rations.

Several factors limiting the utilization of roughage based rations have been identified. Intake can be limited by gut fill when forages of low quality are fed, while fermentation by-products have been shown to limit consumption of some hay crop silages. Digestability of forages is generally lower than for cereal grains due to a greater cell wall fraction, and to lignin and silica complexes with this fraction.

Proper conservation of forages as dry hay or silage at the optimum stage of maturity can maintain ration quality and animal performance throughout the year.

A considerable amount of research effort has been directed towards improving cultural practices and breeding forages with high yield potential. Attempts to increase utilization of crop residue and low quality forages through mechanical and chemical treatments have also received much attention. On

the other hand, comparatively little emphasis has been directed toward the problem of large dry matter and nutrient losses during harvest and storage of high quality forage crops.

Length of time the crop is exposed in the field is related to reductions in digestibility and intake potential. We therefore undertook the present investigations examining the feasibility of applying chemicals at cutting to alfalfa and other forages to speed drying and decrease length of field exposure.

For producing conserved forages of high intake potential and nutritive value, proper consideration should be given to speed of moisture removal and losses of dry matter and nutrients in the field and in storage.

Factors that control water loss and homeostasis in the growing plant may be related to speed of water loss after cutting. Physiological limits to water removal are set by genetically controlled factors and by the environment. This potential for water loss is further modified by environmental conditions during field drying and by the harvesting methods employed.

Plant Mechanisms for Maintaining Moisture Equilibrium

In the intact plant, moisture equilibrium must be maintained under wide variations of temperature, humidity, air movement and water availability. Several mechanisms which govern gain or loss of water by the aerial portion of plants in extreme conditions have been identified and will be briefly discussed.

The primary pathway of water and gaseous transpiration in the intact plant is through the stomata. About 80 to 90% of water lost in a plant has been estimated to follow this route (Sullivan, 1974).

LITERATURE REVIEW

Factors Affecting Water Loss From Cut Forage
led by the guard cells on each side

Production of high quality wilted silages and hays requires that a considerable amount of water originally present in the fresh forage be removed. To evaluate management programs for producing conserved forages of high intake potential and nutritive value, proper consideration should be given to speed of moisture removal and losses of dry matter and nutrients in the field and in storage.

Factors that control water loss and homeostasis in the growing plant may be related to speed of water loss after cutting. Physiological limits to water removal are set by genetically controlled factors and by the environment. This potential for water loss is further modified by environmental conditions during field drying and by the harvesting methods employed.

Stomatal frequencies in alfalfa leaves and stems of
Plant Mechanisms for Maintaining Moisture Equilibrium observed

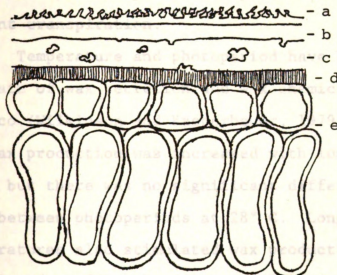
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The primary pathway of water and gaseous transpiration in the intact plant is through the stomata. About 80 to 90% of water lost in growing plants has been estimated to follow this route (Sullivan, 1973). Stomatal aperture is controlled by the turgor of the two guard cells located on each side of the stomatal cavity. The active transport of Potassium (K^+) ions into the guard cells causes an increase in turgor and an opening of the stomata (Fisher, 1968). Potassium deficiency in tea (*Camellia Sinensis*) has been shown to increase stomatal resistance to water loss by limiting K^+ available for transport into the guard cells. Sodium ions (Na^+) can partially substitute for K^+ but Na^+ additions cannot completely overcome the effects of potassium deficiency (Nagarajh, 1979). Stomatal opening and closure follow a diurnal rhythm in alfalfa primarily affected by light intensity and concentration of intercellular CO_2 . Stomata began to open at dawn and a maximum percentage of open stomata is reached at mid-day (Jones and Palmer, 1932). Stomatal frequencies in alfalfa leaves and stems of 292-700/sq mm and 300/sq mm respectively, have been observed (Hayward, 1938). These are randomly spaced with about equal numbers on both the abaxial and adaxial leaf surfaces. Grass leaf blades on the other hand, have only 71-121 stomata/sq mm. These are primarily located on the adaxial surface in single or double rows. The stomata lie between bands of motor or bulliform cells which are not cutinized and thus

rapidly lose water in moisture stress conditions. The decrease in turgor of these cells causes leaf rolling (Hayward, 1938). A subsequent decrease in transpiration has been shown in water stressed rice (O'Toole and Cruz, 1979). Stomata quickly close during conditions of moisture stress. In both clover and tall fescue closure is complete when 30% of the water normally contained in the plants has been lost (Johns, 1972).

Once the stomata are closed the primary route for water loss in either grasses or legumes is through the plant cuticle. The cuticle covers most of the exposed surface of plants, excluding the guard and bulliform cells. The cuticle protects the epidermal cells from water loss, abrasion, and from entrance of pathogens or water in wet conditions. The cuticle is composed of four layers (Figure 1): 1) An epicuticular wax layer made up of wax platelets or rods; 2) Cutin; 3) A cutinized layer embedded with wax; and 4) A pectin layer (Eglinton and Hamilton, 1967). Epicuticular waxes are only secreted in actively growing leaves (Hall and Jones, 1961). If this wax is removed by weathering or artificially by brushing or wiping leaves (Hall and Jones, 1961; Schieferstein and Loomis, 1956) or apples (Hall, 1966) transpiration is increased. When leaves are still actively growing any wax removed stimulates additional wax secretion. While this regeneration of surface waxes will not occur in mature leaves, waxes may still be produced and deposited as wax inclusions as the

cuticle thickens (Sitts and Rannier, 1963). Halloway (1969) has stated that this wax imbedded in the cuticle is primarily responsible for cuticular resistance to water loss, while surface waxes primarily act to repel surface water allowing efficient



the rate of transpiration. It has been shown to affect the rate of transpiration in tobacco. The chemical composition in tobacco cuticle varies with long photoperiods at 18° C but there are no significant differences in wax production between long photoperiods and cold temperatures. Wax production in clover which may be related to frost hardness (Smith and Jones, 1961). Periods of water stress, long photoperiods and low relative humidity caused increases in wax production in populus clones (Ballard and Kozlowski, 1980). These authors also noted that ledges of wax form and cause occlusion of the stomata in young water stressed leaves, suggesting that cuticular waxes can affect stomatal transpiration. Variations in wax structure between "greenhouse" and field grown velvet mesquite (*Prosopis Velutina*) (1980). Cuticular thickness was 10 times greater for field grown plants. The size of the crystallized wax platelets and rods were also much greater in field samples.

^a Epicuticular wax layer.

^b Cutin.

^c Cutinized tissue with wax inclusions.

^d Pectin

^e Subcuticular cellular layers.

Figure 1. Generalized Plant Cuticle Structure.

Cuticular wax characteristics have been studied by many workers interested in improving herbicide action and penetration.

cuticle thickens (Sitte and Rennier, 1963). Halloway (1969) has stated that this wax imbedded in the cuticle is primarily responsible for cuticular resistance to water loss, while surface waxes primarily act to repel surface water allowing efficient transpiration.

Temperature and photoperiod have been shown to effect the rate of wax secretion and wax chemical composition in tobacco (Wilkinson and Kasperbauer, 1979). Total epicuticular wax production was increased with long photoperiods at 18° C but there was no significant differences in wax production between photoperiods at 28° C. Long photoperiods and cold temperatures also stimulated wax production in clover which may be related to frost hardiness (Hall and Jones, 1961). Periods of water stress, long photoperiods and low relative humidity caused increases in wax production in populus clones (Pallard and Kozlowski, 1980). These authors also noted that ledges of wax form and cause occlusion of the stomata in young water stressed leaves, suggesting that cuticular waxes can affect stomatal transpiration. Variations in wax structure between "greenhouse" and field grown velvet mesquite (*Prosopis Velutina* woot) have been noted (Bleckmann et al., 1980). Cuticular thickness was 10 times greater for field grown plants. The size of the crystallized wax platelets and rods were also much greater in field samples.

Cuticular wax characteristics have been studied by many workers interested in improving herbicide wetting and penetration.

Holloway (1969) states that wax texture and the exposed chemical groups of the waxes govern wetting of leaves. Epicuticular wax dissolved in various organic solvents and then recrystallized regains the original ultrastructure (Jeffree et al., 1975). This shows that chemical composition can determine surface wax structure.

Cuticular waxes are primarily composed of mixtures of aliphatic even carbon alkanes, secondary alcohols, odd numbered carbon chain esters, and primary alcohols (Holloway, 1969). These chains are oriented so the terminal methyl groups are exposed on the surface. The more closely these methyl groups are packed the less wettable the wax is. Pure alkanes pack the closest because they lack side groups. The presence of esters, ketones and primary alcohols in the wax mixture increase wetting substantially (Holloway, 1969).

Composition of surface waxes can change during the growth process. Increased photoperiod has been shown to increase the relative amounts of even carbon chain fatty acids and alcohols in tobacco (Wilkinson and Kasperbauer, 1980). Low temperatures along with long photoperiods increased the relative amounts of alkanes and fatty alcohols present in epicuticular waxes, while little change in composition due to leaf maturity was reported (Wilkinson and Kasperbauer, 1980). On the other hand, an increase in neutral lipids and a decrease in polar lipids has been reported in maturing grape berries (Gallander and Peng, 1980).

Aldehydes, hydrocarbons and alcohols isolated from grape berry cuticles have been shown to be the components most important in reducing transpiration. Fatty acids, C_{24-28} , are intermediate in effectiveness while oleanolic acid, the principal component of the hard wax fraction, does not significantly reduce water transpiration (Grncarevic and Radler, 1971).

The principal constituents of alfalfa cuticular waxes are the long chain primary alcohols n-triacontanol, n-octaconsanol and esters of these two alcohols. Hydrocarbons of C_{29} to C_{31} are also present (Blair et al., 1953). Rye-grass cuticular waxes contain esters of long chain C_{27} to C_{33} hydrocarbons and B-diketones (Eglington et al., 1962).

Research directly comparing drying rates of cut forages grown under different environmental conditions has not been reported in the literature. Low humidity, water stress, long photoperiods and cold temperatures cause thickening of plant surface waxes (Hall and Jones, 1961; Pallard and Kozlowski, 1980; Bleckmann et al., 1980). These environmental conditions would be expected to decrease subsequent rates of water removal after cutting. On the other hand, the weathering of forages as maturity increases removes surface waxes and would be expected to increase the rate of drying. Slow drying of cut forages in early spring and late fall may be related to a thickened wax layer developed during the growing period.

The cutin matrix, made up of cutin, cutinized tissues imbedded with wax and pectin (Figure 1) may also limit diffusion of water to the plant surface. Changes in the permeability of isolated cuticles treated with a solvent to remove surface waxes is dependent on pH and presence or absence of monovalent cations in the media (Schonherr, 1976). Permeability increases five fold as pH is increased from 3 to 11 in the presence of monovalent cations. The effectiveness of various cations in decreasing order is: $Rb^{+} > K^{+} > Na^{+} > Li^{+}$. The author suggests that permeability is increased to a greater extent by the largest cations due to a lower charge density and preferential association of these ions with non-esterified carboxyl groups in the cutin matrix. Between pH 3 and 9 two different carboxyl groups dissociate at the base of pores within the cuticle. The second group dissociating only in the presence of alkali metal ions. Above pH 9 phenolic hydroxyl groups begin to dissociate causing a further opening of these pores, allowing even greater amounts of water to pass through the cuticle matrix (Schonherr, 1976).

Physiological Restraints to Water Loss in Cut Forage

Evaporation of water from wet blotting paper is more than 40 times as fast as from freshly cut ryegrass when they are both subjected to 7% relative humidity (RH) and a wind speed of 80 cm/sec (Lessem et al., 1972). Internal resistance

to evaporation increases progressively as the water content (WC) of cut forage declines during drying (Klinner and Shepperson, 1975). The considerable tissue resistance and nonlinear decrease in rate of water removal has led to a search for proper mathematical expressions for moisture content and for rate of water removal in cut forage. The most commonly used expressions for moisture content are % dry matter (DM)¹ and its reciprocal % moisture,² water content³ and % of initial water remaining.⁴ The latter two have denominators which are theoretically constant during the whole drying process. This allows these two expressions to be used in equations which determine rates of water removal over time. WC and % of initial water remaining also place emphasis on the large amounts of water which must be removed before forages can be safely stored. An example of the expression of moisture content by each method over a typical range of moisture contents for alfalfa cut for hay is presented in Table 1.

$$^1 \text{DM\%} = \frac{\text{units DM}}{\text{units total sample wt}} \times 100.$$

$$^2 \text{Moisture \%} = \frac{\text{units water}}{\text{units total sample wt}} \times 100.$$

$$^3 \text{WC} = \frac{\text{units water}}{\text{units dry matter}}.$$

$$^4 \frac{\text{units water at time t}}{\text{units water initially present}} \times 100.$$

Table 1. Methods Expressing Ratios of Moisture to Dry Matter During Drying of a Forage.

Hours	Dry Matter %	Moisture %	Water Content	% of Initial Water Remaining
0	20	80	4.0	100.0
4	30	70	2.3	57.5
10	50	50	1.0	25.0
26	70	30	0.4	10.7
30	75	25	0.3	8.3
38	80	20	0.25	6.3

Increases in tissue resistance and the subsequent decrease in rate of water loss during drying is due to a combination of factors and is best understood by following the physiological changes in the plant after cutting and during drying. Immediately after cutting there is a temporary increase in respiration due to opening of the stomata (Sullivan, 1973). The duration of this stomatal phase has been estimated to last from 30 minutes (Clark and McDonald, 1977) to 2 hours (Jones and Palmer, 1932). Shepard (1964) demonstrated that the leaf stomata from white clover close before those on the petiole. This suggests that there may be a critical moisture content at which stomata close, leaf stomata closing before those on the stem because leaves dry faster. Hall and Jones (1961) on the other hand noted a dramatic decrease in the rate of water loss, from white clover at 2 to 3 hours after cutting with no second deflection of the curve of DM

vs time after cutting. They attribute this to complete stomatal closure by that time. Green (1975) reported that, during the first 2 to 3 hours of drying, tissue resistance increases from 2 to 5 sec/cm in the standing crop to 20-100 sec/cm as the stomata close.

The two major routes for water loss after the stomata close are diffusion through the cuticle and direct evaporation from surfaces exposed during cutting and conditioning. Water movement in cut herbage is both radial and longitudinal. Bagnell et al. (1970) found a 30% decrease in water loss from two inch sections of alfalfa stems when radial movement of water was limited by putting the stems in tight fitting glass tubes. In whole stems of alfalfa crimping has been shown to increase longitudinal movement of water (Pendersen and Buchele, 1960). These data suggest that there is strong resistance to radial diffusion and that water will move along the path of least resistance. Transfer of stem water to the petioles and leaves where resistance to diffusion is lower has been demonstrated in both grasses (Jones, 1973), and legumes (Byers and Routely, 1965; Shepard, 1964). Harris and Tullberg (1980) have extensively reviewed this subject and estimate that up to 35% of the water contained in the stems at cutting exits the plant by this route which remains active until the stems reach 40% DM. As plants mature the stem:leaf ratio and tissue resistance to drying both increase (Green and Jagger, 1977). This finding is probably related

to the larger surface to mass ratio of leaves, but may also reflect a very active stem to leaf transfer in leafy crops.

The importance of the plant cuticle in limiting diffusion of water vapor in the cut plant has been demonstrated by Bagnell et al. (1970). Scraping alfalfa stems to remove the cuticle and epidermal cell layer greatly increased drying rates while further scraping down to the vascular layer gave little further response. Removal of the epicuticular waxes by brushing leaves (Hall and Jones, 1961) or dipping leaves in petroleum ether (Harris et al., 1979) has also been shown to greatly increase drying rates. These data support the idea that these waxes contribute significantly to cuticular resistance to drying.

at noon on a favorable summer drying day. This is maintained
Environmental Constraints to Forage Drying

For drying of forage to proceed a positive gradient of vapor pressure between the plant and atmosphere must exist. There must also be sufficient energy to evaporate this diffused moisture from the plant surface. Forage water content and temperature control the vapor pressure within the plant. As the plant dries internal vapor pressure decreases, thus increasing the importance of external vapor pressure in limiting further drying. Drying ceases when equilibrium humidity, defined as the relative humidity at which vapor pressure within the plant is equal to vapor pressure in the surrounding air, is reached. Equilibrium humidity values decrease in a curvilinear fashion, decreasing slowly to a WC of 0.5 and then

falling sharply below this point (Green and Jagger, 1977). Because drying can only proceed if relative humidity is less than equilibrium humidity a low relative humidity becomes an increasingly important factor as the plant dries.

Leshem et al. (1972) studying single grass stem and leaf sections found a direct relationship between the speed of moisture loss and vapor pressure deficit (VPD), where VPD is defined by the equation:

$$\text{VPD} = [1 - (\text{RH}/100)] \times (\text{saturation vapor pressure})$$

This offers the possibility of predicting drying from routine weather data by calculating a value that reflects drying potential. In the field VPD generally follows a diurnal pattern being low in the early morning and increasing to a peak at noon on a favorable summer drying day. This is maintained for several hours and then declines steeply in the late afternoon as solar radiation decreases (Clark and McDonald, 1977).

Effects of Swath Micro Climate on Forage Drying

For the first 6 to 10 hours after cutting the top layer of the swath dries at a rate 5 to 10 times faster than the lower layers. External and internal swath environmental parameters were compared during this period by Green et al. (1976). With an ambient relative humidity of 50%, air speed of 2 to 3 meters/sec and direct solar radiation at the surface of the swath, they found that RH increased to 80% and wind speed decreased to .1 to .2 m/sec at 2 cm depth in the swath.

Solar radiation was calculated to be 50% of what struck the surface at 2 cm and only 10% at a depth of 10 cm. The authors concluded that poor ventilation led to high humidity within the swath and a lack of sufficient energy to evaporate water from the surface of the forage added to the unfavorable conditions for drying.

Water loss from wet blotting paper is increased with high wind speeds but no significant increase in evaporation from single cocksfoot leaves was noted (Leshem et al., 1972). On the other hand, Shepard (1965) found a 49% increase, for the first 3 hours, in the drying of single clover stems with an air speed of .4 m/sec compared to still air. He found that the importance of wind speed decreases during the drying period until at a WC of 1.0 (50% DM) wind speed had no significant effect. In the field optimum wind speeds for bulked material over the total drying period have been estimated to be 2.2 m/sec (Klinner and Shepperson, 1975).

Soil moisture is frequently high especially during June or after irrigation in Michigan. Laboratory studies have compared the drying of crimped alfalfa on air dry soil, soil of 15% moisture and a soil of 15% moisture covered by a plastic vapor barrier. Alfalfa dry matter contents after 22 hours of drying were 84.3%, 59.7%, and 85.9% respectively (Penderson and Buchele, 1960). Increasing stubble length from 50 mm to 130 mm has also been shown to increase drying rates (Klinner 1976), possibly by keeping the swath from contracting the soil

and allowing more air movement around and under the swath.

In the final stages of the forage drying process there is a sharp increase in tissue resistance which may often exceed the importance of environmental constraints to forage drying. Increases in solute concentration and in the length of travel for vapor to reach an evaporative surface have been proposed as possible causes for the large increases in tissue resistance when herbage is between 60 and 80% DM. Green and Jagger (1977) demonstrated that increasing the rate of evaporation can increase tissue resistance. Shrinking of the plant tissue during dehydration and the development of a moisture gradient between stem surface tissues and internal tissue may be responsible for this finding. Equilibrium humidity is a function of surface moisture content and could limit water loss if a moisture gradient occurs between internal and external tissues.

This relationship has been altered by scraping, treatment with petroleum ether, or potassium carbonate (Harris, 1979). These treatments, all thought to work by removing surface waxes or changing wax ultrastructure, increased drying rates even in the final stages of drying from 65 to 80% DM. These data generated in the laboratory warrant further investigation and should stimulate interest in development of practical systems to speed hay drying in the field by the use of some effectiveness and mechanical treatments to reduce tissue resistance. The practicality of these treatments should be discussed.

Methods of Increasing the Drying Rate and
Reducing Field Exposure Time of Conserved Forages

Losses of dry matter and nutrients have been related directly to field exposure time (Shepard et al., 1954). Losses of dry matter under rainy unfavorable weather may approach 30 to 40% (Klinner, 1975; Shepard et al., 1954). These high losses are primarily due to leaching, continued respiration, microbial fermentation and leaf shatter during subsequent harvesting. Hoglund (1964) reported that field DM loss is roughly proportional to DM content at harvest. Conservation methods which allow removal of the forage from the field at lower DM contents such as wilted silages or high moisture hay, to be artificially dried, reduce field losses. Storage losses which are inversely related to DM at harvest are generally larger when forage is harvested at a relatively high moisture content.

Field cured hay, barn finished hay and wilted silage had comparable total DM losses at first harvest of 17.3%, 15.1% and 18.1% respectively, when drying conditions were favorable, while total DM loss for hay that experienced 1.68 cm rain was elevated to 33.8% (Shepard et al., 1954).

Because of these large potential losses several investigators have attempted to increase the drying rate of hay. Mechanical, thermal and chemical treatments have all shown some effectiveness and certain aspects of their action will be discussed. The practicality of any system which increases

drying rates will depend on the cost of materials, labor, and energy balanced against the potential saving of available nutrients.

Mechanical Treatments for Decreasing Drying Time

Mechanical treatments that increase the drying rate of forages can be divided into two groups: 1) treatments primarily acting to reduce tissue resistance by crushing or splitting the stems and abrading the cuticle; and 2) treatments providing a more favorable microclimate for forage drying within the swath; the latter usually by disturbing the swath structure during the drying period.

Reducing Tissue Resistance

Mechanical conditioning can reduce cuticular resistance by: 1) removing some of the cuticular waxes and 2) by splitting open plant tissues thus bypassing the cuticular barrier.

Increases in drying due to traditional crushing treatments are generally less in grasses than in legumes (Boyd, 1959). Complete crushing of the pseudo stem with high roller tension is needed to increase drying rates of annual sorghum-sudan grass crosses (Barrington and Bruhn, 1970). Alfalfa on the other hand, will respond adequately to milder crimping or crushing which primarily acts to equalize the drying rates of the stem and leaves.

The magnitude of increases in legume drying rates is directly related to the severity of treatment, with flail chopping being more effective than crushing which is more effective than crimping (Boyd, 1959; Bruhn, 1959; Klinner, 1975). Increasing increments of laceration by flail chopping alfalfa has shown that there is an optimum severity of damage to the plant beyond which drying is decreased (Hall, 1964). The author attributes this to matting of the more finely chopped material in the swath.

No advantage in drying was observed for delaying crushing while a second conditioning 0.5 hour after the initial cutting and crushing did significantly increase drying rates (Barrington and Bruhn, 1970).

Increasing the severity of mechanical treatments is also associated with increased field DM losses. Total losses were 15 to 30% with flail conditioned hay compared to 9 to 11% for crimped hay under good drying conditions (Boyd, 1959; Barrington and Bruhn, 1970). Losses of DM and cell solubles after flail mowing can be particularly high if rain occurs (Klinner, 1975).

In a review of early literature Shepherd et al. (1954) stated leaching losses from rain could range from 5 to 14% of the original DM. Respiration losses after extended periods of rain were higher for conditioned than non-conditioned forage as measured by CO_2 evolution (Honing, 1980). The

author suggests that large losses of DM after rain, usually attributed to leaching may primarily be due to microbial action, reducing soluble carbohydrates by as much as 50%.

Respiration losses in the absence of rain have been reported to range from 4 to 18% of the initial DM present in legumes (Shepherd et al., 1954, and Dale, 1980) and from 3 to 7% for grasses (Schukking and Overvest, 1980, and Honing, 1980). The magnitude of this loss is related to temperature and the time required to reach 60 to 65% DM (Dale, 1980), but is unrelated to severity of usual mechanical conditioning (Honing, 1980).

Total mechanical losses from mowing, conditioning, raking and packaging vary greatly with weather conditions and drying time (Shepherd et al., 1954), the number and severity of machine operations (Barrington and Bruhn, 1970, and Coitti and Cavallero, 1980), and the DM content of the herbage at the time the operations are performed (Honing, 1980).

Conditioning treatments primarily increase drying rates during the early stages of drying from 20 to 40% DM (Klinner, 1976). Drying rates during the final critical stages of field drying from 65 to 80% DM have been increased by "Maceration" of alfalfa. This process involves passing forage through differential speed, serrated rollers (Krutz and Holt, 1979). Increase in drying rate may in part be due to the increase in absorption of solar radiation in "macerated" alfalfa shown by Ajibola et al. (1980).

Research in the United States has tended to involve severe mechanical treatments in an attempt to dry forage sufficiently for baling the same day that it was cut. European investigators on the other hand have been primarily concerned with developing methods which provide even cuticle abrasion without reducing stem strength. Scraping away epicuticular waxes was more effective than splitting alfalfa stems longitudinally (Bagnell et al., 1970). This idea led to the development of several experimental and commercial mowers which combined either a reciprocating cutter bar or drum mower, with a rotary beater that hurled the forage against a shield, stem end first (Klinner, 1975). In addition to cuticle abrasion these machines also produced a high loose windrow structure. Increased drying rate from use of these machines was comparable to standard crimping procedures but was smaller than from flail mowing. Field losses were also similar to those for crimping. No data were presented on losses after rain damage but the author suggested that losses would be smaller compared to treatments that tended to rupture plant cells.

Treatments to Decrease Swath Resistance to Drying

Environmental conditions, as previously indicated, are often the most limiting factors to forage water loss during early drying while tissue resistance is minimal. Drying slows as the lower layers of the swath develop a high relative humidity within the bulked forage. Drying rates of uncrimped and crimped alfalfa mowed and left in a swath as wide as the

machine cut dried at a faster rate than forage cut, crimped and windrowed in one pass (Fairbanks and Thierstein, 1966; Barrington and Bruhn, 1970). This indicates that the decreased surface area for interception of solar radiation and increased swath density associated with windrowing at cutting are more limiting than cuticular resistance during early stages of drying. Jones and Palmer (1932) found that raking immediately after cutting decreased drying rates. They attributed this to premature stomatal closure in the dark interior of the windrow.

Tedding of forage involves scattering the cut swath by use of a machine with rotary tines during the drying period. Tedding twice or more during drying is a routine practice in many parts of Europe but is not generally practiced in the United States. Tedding disturbs the microclimate within the swath and brings wetter material from the inner layers to the surface where conditions for drying are more optimum. Tedding immediately after mowing has increased drying rates, possibly due to increased cuticle abrasion, but tedding was most effective between a WC of 2.0 and 0.5 (33 to 67% DM) in grass swaths (Jones and Pickett, 1977).

In Europe much of the teded hay is grass. Dry matter losses due to leaf shatter would be expected to be much smaller for grass than legume hays at the low WC of 0.5. The type and adjustment of the tedding machine would be critical in

minimizing dry matter losses during this operation. Barrington and Bruhn (1970) utilized a rotary tedder as a conditioning treatment for alfalfa soon after mowing. Increases in drying rates were smaller than for crushing while DM losses were larger, 10% for tedding and 7% for crushing.

Swathed forages are generally bulked into a windrow for the final stages of drying with a side delivery, rotary or finger type raking device. Raking treatments expose damp pockets of forage at the base of the swath to conditions more favorable for drying and create a structure which allows more passage of air through the herbage. Raking at a DM of 40 to 50% produced the fastest drying to a DM suitable for storage as hay (Jones and Palmer, 1932). Raking into a windrow at the end of the first day, if possible, was emphasized because during the night swaths picked up more moisture from dew than did hay in a windrow. Windrowed hay responded more slowly to weather changes than did hay in the swath (Fairbanks and Thierstein, 1966). Thus windrowed hay would be less effected than swathed hay during short periods of unfavorable weather but after extended periods of rain or high humidity windrowed material would redry more slowly.

Delaying raking until the forage averages above 50 to 60% DM is usually associated with excessive leaf loss. The susceptibility of alfalfa to leaf loss during mechanical treatments is greater when stem-leaf moisture differences are high (Raghavan and Bilanski, 1974). This would indicate that

treatments such as crushing or crimping at cutting which increase the drying rate of stems more than leaves have the potential to decrease leaf loss during raking. A high degree of management ability must be practiced to effectively maximize drying potential by the use of mechanical conditioning, tedding, and raking operations while keeping dry matter losses at an acceptable level.

Chemical and Thermal Treatments to Increase Forage Drying Rates

Interest in chemical and thermal treatment of forage to hasten drying has been generated due to the large field losses and lack of sufficiently satisfactory improvements in forage drying and quality following mechanical conditioning. Results from trials using a combination of mechanical and chemical conditioning have also generally shown larger responses than for either treatment alone. This suggests that modes of action may be different, and provides the challenge of finding a combination of chemical and mechanical treatments which maximize drying potential while minimizing nutrient losses and added costs.

Chemical and thermal treatments of forage have followed two major approaches: 1) desiccation of the standing forage by treatment 24 to 48 hours before cutting and 2) applying treatment at, or soon after cutting. The first alternative

by preventing water influx from the roots. This treatment

has several disadvantages. An extra field operation is required, standing forage is trampled, and results may be variable if weather conditions are not favorable during desiccation. This also brings up the question of whether precutting treatments would have any advantage over a control cut at the same time that the treatment is applied. Most researchers in this area have recognized these limitations and investigations are now generally directed toward developing treatments that are effective when applied at cutting. Work in both of these areas will be briefly discussed, emphasizing modes of action and practical field applications.

Inhibition of Stomatal Closure

Fusicoccin, a wilt toxin produced by the fungus fusicoccum amygdali Del., sprayed 3 hours precutting as a $10^{-5}M$ solution in 0.001% ethyl alcohol decreased time for hay to reach 80% DM by one-half and reduced soluble carbohydrate losses due to respiration (Turner, 1970). In the field this same treatment applied by a field sprayer 3 hours before cutting decreased the time to reach 78% DM from 54 to 46 hours. Fusicoccin is thought to act by inhibiting stomatal closure, thus prolonging the initial drying period of minimal tissue resistance. Fusicoccin initially increased stomatal resistance to water loss but at 3 hours resistance declined to only 27.5% of control (Turner and Antonio, 1969).

Sodium azide has been shown to inhibit stomatal closure by preventing water efflux from the guard cells. This treatment

is most effective when the stomata are fully open (Stalfet, 1957). In laboratory studies dipping alfalfa in solutions of 5×10^{-3} M sodium azide in a sodium tartrate buffer at pH 4.5 caused an initial increase in drying rate (Tullberg and Angus, 1972). This increase was primarily due to an increase in leaf drying and resulted in a slower drying of the stems in the later stages of drying. Only a small reduction in time to reach a DM sufficient for storage was reported (Tullberg and Angus, 1972).

Destruction of Cuticular and Cellular Barriers to Water Loss

Heat or various herbicides known to change cuticle structure or alter cell wall integrity have been used to increase the drying rate of forages. These treatments are generally more effective when applied 24 to 48 hr before cutting to allow for wilting of standing forage. This may be due to a more complete disruption of cellular membranes in the turgid actively growing plant.

Steam treatment of cut perennial ryegrass at 100° C for 60 seconds decreased the time to reach 46% DM by half under laboratory conditions. When samples were exposed to the vapor from a 10% petroleum ether, water mixture a further decrease to one-fourth the time required for controls to reach 46% DM was obtained (Harris et al., 1974). Examination of steamed alfalfa stems with the scanning electron microscope has shown splitting of the epidermis and a disappearance of

the wax platelet structure with little change in internal cell structure (Byers and Routely, 1965). These authors compared mechanical crushing, steam treatment and a combination of these treatments in the laboratory and reported that while crushing was more effective in speeding drying than steaming, the combination of the two treatments was better than either treatment alone. They concluded that a combination of treatments which would both increase exposure of internal tissues and reduce cuticular resistance would optimize drying. A machine for field application of steam to standing hay crops has been built (Philipsen, 1969). Application of steam to a standing crop of alfalfa 24 hours before cutting using this machine was compared to a control cut at the same time the steam was applied. After tedding the hay twice daily, time to reach a DM suitable for storage as hay was the same for the two treatments (Wilkins and Tetlow, 1972).

The field effectiveness of rapid treatment of alfalfa with a butane flame has been tested both 24 hours before cutting and immediately after cutting (Person and Sorensen, 1970). Flaming 24 hours before cutting caused a 17% drop in the water content of the standing crop. This treatment was compared to mechanical conditioning, flaming plus mechanical conditioning and an untreated control. Hours to reach 80% DM were 100 for flame; 95 for conditioning; 78 for flame plus conditioning; and 100 for control. Flaming alone had an initial advantage over conditioning until 50% DM was attained; it then dried

more slowly than conditioned or control material. The combination of flaming and conditioning forage continued to have a significantly higher dry matter content.

Herbicides have been used as an effective aid in the preharvest desiccation of alfalfa and clover for seed production. Several attempts have been made to increase forage drying rate by applying contact herbicides at or before cutting for hay. Endothal, dinitro-ortho-secondary butylphenol (DNOSBP) and tributyl phosphate were applied at a rate of 1.1 lb/acre (1.5 kg/ha) in 46 to 130 liters water/ha at 0, 24 and 48 hours before cutting (Kennedy et al., 1954). No significant effect for any of the treatments when applied at cutting was reported. The extent of precutting desiccation was directly related to the interval between treatment and cutting. The initial advantage for precutting treatments over control was primarily due to drying of the leaves. At 48 hours the DM % was 78 for both endothal and control treatments.

Sheperd (1959) also reported that the effect of the herbicide ethylene dipyridilium was much greater on the leaves than on the stems of alfalfa.

The mode of action of DNOSBP and ethylene dipyridilium is to penetrate cell membranes and destroy their selectivity to ion permeability. Disruption of the cell walls also allows free movement of water to the surface (Audus, 1964). The application of .25% tributyl phosphate doubled the drying rate and decreased soluble carbohydrate losses in cut ryegrass

(Harris, 1975). Tributyl phosphate sprayed on alfalfa before cutting in the field also increased drying rates but caused yellowing and excessive leaf losses during harvest (Kennedy, 1954).

The use of contact herbicides for increasing drying rates of hay has two major limitations: 1) herbicides have only been shown to be consistently effective in precutting treatments and 2) chemical residue problems may preclude their use as desiccants on animal feed crops.

In a laboratory trial formic acid sprayed at 1, 3 or 5% of fresh plant weight produced a four-fold increase in drying rate (Thaine and Harris, 1973). Increasing application rate above 1% produced no greater response. Formic, propionic and acetic acids sprayed on standing field forage increased DM content 8 to 10%, 8 hours after application (Zimmer, 1973).

These organic acids change the surface tension of water on the cuticle. This led to the idea that they may act by changing either the structure or hydrophobic nature of the epicuticular waxes. Because formic acid is highly ionic and a strong reducing agent, treatment with this acid might also be expected to disrupt cell membranes (Thaine and Harris, 1973). Formic acid sprayed at .85% of the fresh forage weight was applied in 680 liters of spray/ha to standing alfalfa and allowed to wilt the crop for 24 hours before cutting. A control was cut at the same time the standing alfalfa was sprayed.

Both treatments were tedded twice daily. The formic acid treatment required a longer time interval to reach a DM safe for storage as hay (Wilkins and Tetlow, 1972). The authors attributed this to a failure of the spray to reach the lower portions of the standing alfalfa. Faster drying of the leaves than the stems may also have limited water removal from the stem by the stem to leaf transfer mechanism (Wilkins and Tetlow, 1972). They concluded that formic acid could be useful as a preharvest desiccant for direct-cut hay crop silage but had little merit as a desiccant in hay production.

Increasing Transpiration by Reversible Alteration of Cuticle Surface Waxes

Emulsions of olive oil and wood ashes, containing primarily potassium carbonate (K_2CO_3), have been used since ca. 60 AD in Greece and Crete to speed the drying of grapes to raisins. Two modifications of this process are still widely used in parts of Australia. One, a cold dip uses 1 to 2% grape dipping oil, a mixture of long-chain fatty acids, primarily C_{16-18} , and esters and sulfated esters of these fatty acids. These methyl esters are completely emulsified with 4.5% K_2CO_3 and .5% $NaCO_3$ in water. A five minute dipping time is required. The second method is carried out at 37.7° C. Olive oil or grape dipping oil is floated on top of a 3% sodium bicarbonate (Na_2CO_3), 0.1% sodium hydroxide (NaOH) solution. Dipping time is only momentary (Winkler et al., 1974). The

cold dipping method is preferred because it results in a golden colored raisin with uncracked skin (Grncarevic, 1963). At the present time some grapes are being sprayed before or after picking in certain areas of California. The solution is made of methyl esters of lard or tallow (methyl lardate, or tallowate), oleic acid and K_2CO_3 and/or Na_2CO_3 (Petrucci et al., 1974).

Treatment of forages cut for conservation with methyl esters (ME) and/or K_2CO_3 to increase drying rates is of recent origin (Tullberg and Angus, 1972; Wieghart et al., 1980). Research on the mechanism of action as understood in grape berries will be briefly reviewed in light of the lack of research in this area for forage crops.

Electron micrographs of undipped grape berries show an even distribution of wax platelets oriented perpendicular to the cuticle. Examination of dipped grapes shows a marked flattening of the wax platelets to the surface of the grape berry (Chambers and Possingham, 1963). These authors theorized that methyl esters, responsible for this change, may allow the formation of a continuous aqueous phase between water inside the grape and the outside atmosphere which bypasses the less efficient diffusion through a vapor phase in the undipped grape cuticle. Potassium carbonate may act by saponifying cuticular fatty acids, exposing carboxyl groups and changing the hydrophobic properties of surface waxes (Chambers and Possingham, 1963). In addition K_2CO_3 may increase cuticular permeability through a pH effect (Schonherr, 1976).

Very little wax is actually removed during dipping. Changes in wax platelet structure and increases in drying rate are reversible if the grape berry is washed within the first 12 hours after dipping (Grncarevic, 1963). The gradual decrease in the effectiveness of the dipping treatment in the later stages of drying may be due to a volatilization of the methyl and ethyl esters (Stafford et al., 1980). Losses of 72 and 74% of the applied methyl and ethyl esters during drying at 20° C over an 18-day period have been reported. At higher temperatures loss of methyl esters may be much more rapid. Redipping grapes dried in a forced air drier at 43° C at 12 and 24 hours significantly increased drying rate over grapes dipped only once. These authors concluded that the concentration of ME on the grape surface is an important factor in maintaining elevated drying rates. The possibility that methyl esters increase drying by a covolatilization process is an area which merits further research.

Dipping alfalfa in solutions of 0.045 to .72 M K_2CO_3 has been shown to increase drying rates of both stems and leaves under controlled laboratory conditions (Tullberg and Angus, 1972). Drying was maximized at a concentration of .18 M K_2CO_3 . The effect of the dipping treatment was shown to be independent of the length of emersion. No methyl esters were used in these trials because the authors believed that K_2CO_3 was the active ingredient in grape dip emulsions used to increase the drying rate of alfalfa.

Spraying solutions of .2, .4 and .6 M K_2CO_3 at 9.5% of fresh weight all significantly increased mean DM content of alfalfa above untreated control and alfalfa sprayed with distilled water in the laboratory. There were no significant differences between levels of carbonate with .2 M K_2CO_3 being as satisfactory as .4 or .6 M K_2CO_3 solutions (Wieghart et al., 1980).

Methyl esters of C_{12-18} applied along with a surfactant X-77 at 3.8 grams ME per kg fresh forage have been shown to increase mean DM over time in five laboratory trials (Wieghart et al., 1980). Methyl ester mixtures containing large proportions of C_{16-18} fatty acids were more effective in speeding drying than mixtures containing primarily C_{12} fatty acids. This difference was especially noticeable in the latter stages of drying perhaps because the shorter chain acids may have been more volatile.

The addition of .2 M K_2CO_3 to emulsions of 2% ME in two trials produced a significant increase in drying over the ME - X-77 emulsion alone. At higher concentrations of 3.7% ME the effect of adding K_2CO_3 was nonsignificant. The addition of methyl esters and X-77 consistently increased drying rate over K_2CO_3 alone or untreated controls in these laboratory trials. Increasing application rate (AR) five-fold by dipping plants in the three component emulsion of ME, X-77, and K_2CO_3 produced no advantage over spraying these same emulsions at a 10% AR.

Increasing the concentration of ME in the three component spray from 5% to 10% and 15% increased mean DM 2 to 3% for each addition of 5% ME in a linear manner. This suggests that although increasing the grams of ME applied per kg forage increases drying rates in the range studied, that the optimal AR of ME will be determined by both economic and biological constraints.

Field spraying a .2 M K_2CO_3 solution on freshly mown alfalfa at an application rate of 3000 l/ha has been shown to significantly increase drying rate over conventional mowing and mower conditioner treatments (Tullberg and Minson, 1978). Further trials comparing application rates of 875 l/ha, 500 l/ha and 200 l/ha to an untreated control showed significant differences between treated and control swaths only at 29 and 32 hours after cutting. Drying rate increased as AR was increased but differences were small and nonsignificant (Tullberg and Minson, 1978).

Wieghart et al. (in press) found only nonsignificant increases in mean DM after spraying alfalfa as cut in the field with .4 M K_2CO_3 at a 15% AR. Addition of 0.3% X-77 and 2 to 3% ME, supplying 1.7 grams ME per kg forage, produced a significant increase in mean DM. Increasing grams ME per kg forage from 1.8 to 2.9 or from 2.7 to 3.7 and 7.2 gave a linear but nonsignificant increase in mean DM over the lowest concentration of ME.

The effect of a three-component spray on seed stage and 1/10th bloom alfalfa showed that treatment reduced time to reach 75% DM by 7 hours for both maturities.

Severity of crimping and the presence or absence of the three-component spray both had a significant effect on mean DM while the interaction of these two factors was nonsignificant. These data suggest that spraying and crimping are not fully additive. Spraying and a light crimping could replace heavy crimping or crushing treatments and subsequently reduce field losses.

In vitro dry matter disappearance of treated and control forage after drying have been similar in laboratory or field trials (Wieghart et al., 1980).

OBJECTIVES

The overall objective of these studies was to hasten drying of cut forage thereby reducing exposure to adverse environmental conditions that decrease quality. The present research is based on previous investigations by Tullberg and Angus (1972) and (1978), Tullberg and Minson (1978), and Wieghart et al. (1980), showing that drying of cut alfalfa can be hastened by spray treatments containing potassium carbonate (K_2CO_3) or methyl esters (ME) and K_2CO_3 . General objectives and areas of study are listed below.

1. To study the magnitude and consistency of increases in drying rates produced by spraying alfalfa with solutions containing sodium or potassium carbonate or other carbonates and salts of the alkali metals.
2. To clarify the role of ME in hastening drying, and the relationship between K_2CO_3 and different levels of ME in increasing rates of water loss.
3. To determine efficacy of chemical treatment in increasing drying of several other legume and grass forage species of economic importance.
4. To demonstrate the field effectiveness of chemical treatment in reducing the interval from cutting to harvest.

5. And to determine losses of DM and changes in nutritive value of alfalfa from cutting through storage of baled hay as a function of chemical treatment.

MATERIALS AND METHODS

Laboratory trials utilized greenhouse grown alfalfa to obtain information on the drying of alfalfa when treated with methyl esters (ME) of long chain fatty acids from several sources in combination with potassium carbonate (K_2CO_3) or other alkaline salts. The influence of rate of ME and solution application and effect of several emulsifiers (EM) were also studied in preparation for tests in the field.

Field trials were conducted under typical hay making conditions as part of a three or four cut management system. These trials utilized conventional field machinery to apply the spray solutions at cutting. Tests were performed under widely varied weather conditions and several environmental variables were monitored during the trial. In addition to measuring changes in DM and water content (WC) over time, as in laboratory trials, apparent respiration losses, harvesting losses and changes in dry matter and forage quality during storage of baled hay were studied.

Laboratory and field trial procedures were different in several regards and will be described separately.

Laboratory Procedures

Alfalfa was grown in a greenhouse at approximately 20° C with a constant 16 hour photo period. The alfalfa was

innoculated at seeding with rizobia spp. and was fertilized with the equivalent of 50 lbs P_2O_5 and 100 lbs K_2O /acre after each cutting. Sufficient water was supplied by overhead automatic waterers twice daily.

Spray solution components were mixed on a volume basis for laboratory trials with the exception of K_2CO_3 and the other alkali metal salts which were added by weight to obtain the desired concentration in the final solution. The salt was first dissolved in 50 to 200 mls of distilled water, and then ME and an EM were pipetted into the solution and this mixture was brought to a final volume of 100 to 400 mls with distilled water. Solutions were usually used within one day of preparation.

Alfalfa was harvested at 10-50% bloom and within 15 minutes placed in 100 gram portions on screens for treatment and subsequent drying. The screens were constructed with a frame of Number 9 gauge wire covered with plastic window screening. The screens were numbered and weighed prior to the trial and then the screen plus alfalfa was weighed and either treated or left as a control. Treated material was then reweighed to determine solution application rate.

Treatments were applied by spraying solutions over the plants on the screens from a house plant "Mister" at application rates of 1 to 4% of the fresh plant weight. The entire screen with alfalfa was then weighed at 2 or 3 hour intervals for the first 12 hours and then weighed at 6 to 8

hour intervals until treated hay approached or reached 75 to 80% DM. During the drying process the screens were placed on plastic cafeteria trays to allow a 3 cm space for air movement under the screen. Temperature and relative humidity were recorded each time the screens were weighed using a stationary hygrometer.^a

At the termination of the trial the plant material on each screen was placed in a separate paper bag and dried at 100° C for 48 hours to determine the final amount of dry matter on each screen. The amount of dry matter on each screen was assumed to be constant from the initial to final weighings. The final weight of DM on each screen was used to calculate the DM% and WC of the alfalfa at each weighing time during drying. Drying rates were calculated for the intervals between each weighing as the change in WC divided by the change in time, and given the units, change in grams water per hour per gram DM. Calculations were made using a high-speed computer and an iterative fortran program.

Field Procedures

All solution components for field trials were added on a weight basis with the exception of EM which were added by volume. Solutions were mixed in plastic 5 gallon (18.9 liter) containers which had been previously weighed. Potassium

^a70.552 Mason's Form Hydrometer, Taylor Instruments, Arden, N. C.

carbonate or another alkali salt was weighed and dissolved in approximately 7.6 liters of tap water. The desired weight of ME and volume of EM was then added. The container and solution was then weighed and brought up to a weight of 19.5 kg, excluding the weight of the container, with tap water.

Alfalfa of the Iroquis or Spreader II variety was mowed with a Sperry New Holland haybine;^b usually between 9:00 a.m. and noon. Width of cut was 2.9 meters and the baffles were set to form either a 1-meter wide windrow or a 2.0 to 2.3-meter wide swath. Solutions were sprayed on the forage from two spray booms one mounted 30 cm in front and 35 cm above the crimping rollers and the other mounted 30 cm behind and 35 cm below the rollers. Six low pressure nozzles^c were set 30 cm apart on each spray boom. A six roller pump driven by a hydraulic motor was mounted on the side of the mower and used to pump solutions to the spray booms at 20 to 60 P.S.I. The hay received the spray treatment from the top bar when it was in a thin layer just before being crimped, and just after conditioning, from the bottom spray boom. Application rates were varied by changes in tractor ground speed or nozzle tip size while engine and PTO speed stayed constant at 1900 RPM. Application rates were measured

^bSperry-New Holland Model No. 488, New Holland, Pennsylvania.

^cSpraying Systems Equipment, Nozzles No. 80010L20 or 80015L20.

by the change in weight of the solution container after spraying a 30.5 meter length of swath and are expressed as a percent of fresh forage weight and as grams of ME applied per Kg fresh forage.

As each treatment was cut and sprayed 3 to 5 kg of forage was placed on 1.5 by 0.8 meter window screens or 2.75 by 0.92 meter hardware cloth covered screens with a 0.6 cm mesh, in a density that approximated the swath or windrows original density. Screens were fitted with a twine or wire harness attached to each corner of the screen and to a central ring to allow repeated weighings with a 20 pound capacity hanging balance.^d The balance was calibrated with 2 and 5 pound weights and screens were weighed before the trial and immediately after placing the forage on the screens. A yield estimate was then made by averaging the weight of 3 randomly selected 3.0 by 2.75 meter section of the swath.

The screens were then weighed at two-hour intervals during the first day until 8:00 p.m. and at three-hour intervals the second and third days between the hours of 8:00 a.m. and 8:00 p.m. Wet and dry bulb temperatures were recorded for each weighing as described in laboratory procedures and precipitation was also measured at each weighing with a rain gauge^e mounted on a 0.5 meter stake in the field. Average

^dHanson Hanging Balance Scale Model 842, Nasco Ft. Atkinson, WI.

^eTrue-Chek Rain Gauge, Tru-Zol Edwards Mfg. Co., Albert Lea, Minn.

wind speed and minutes of sun each day were obtained from Capital City Airport 12 km to the northwest of the field site. Field trials were terminated when sprayed material reached 75-80% DM. All the material from each screen was placed in an individual paper bag and dried at 85-95° C for 48 hours to determine the final weight of DM on each screen. Percent DM, WC and drying rates were calculated as described for laboratory trials.

Application of Chemicals to Increase Drying
of Cut Forage Under Laboratory and Field Conditions

Thirty laboratory and 35 field trials exploring the use of chemical treatments to hasten drying of forages were conducted. Many of the areas of interest presented earlier in the objectives sections were explored under both laboratory and field conditions, and several replications usually were performed. Specific laboratory or field methods differing from the general procedures outlined above will be presented together under the subject area heading. Laboratory and field trials are distinguished by the prefix (L) for laboratory and (F) for field, followed by a chronological trial number. Trial and table numbers for each area of study will be specified.

Hastening Forage Drying with Carbonates and Other Salts of
the Alkali Metal Group

Alkali metal carbonates solutions alone and in combination with methyl esters (ME) and an emulsifier (EM) were tested for effectiveness for increasing mean DM and drying rates (DRt) of alfalfa in trials L2, L15, L21, L22, L23, L27, F8, F12, F23 and F25. Influence of solution pH and anion type on speed of water removal were studied by utilizing .4 normal solutions of the chloride, carbonate and hydroxide salts of

sodium and potassium^f in trials L15, L19, L20, L27, F23 and F25. The pH of K_2CO_3 and KOH solutions were adjusted to pH 9 to 11 by the addition of ammonium carbonate in L19 and L20 or Hydrochloric Acid (HCl) in trial L27. Solution pH was measured by the use of a glass electrode attached to a Orion Research pH meter that had been standardized with pH 7 and pH 10 buffers. Data from these trials are presented in Tables 2 and 3.

Influence of Methyl Ester Source and Composition

Methyl esters and other lipids (Table 6) combined with alkali salts were compared in Trials L1, L18 and L28. In trial L18, a concentrated solution of potassium hydroxide (KOH) was prepared by mixing 11.2 grams KOH with 60 mls of distilled water, 20 mls olive oil, and 20 mls of ethanol. The mixture was stirred, covered, and allowed to stand for 10 hours. Four hundred mls of distilled water, 1.0 ml X-77 and 0.8 ml oleic acid were added to obtain an emulsion of 4% lipid, .4M KOH, .25% X-77, and .2% oleic acid (treatment number 5, Table 7). Another solution containing olive oil was prepared 2 hours before the trial by dissolving 5.53 grams K_2CO_3 in 191 mls distilled water and adding 8 mls of olive oil and .5 mls X-77 and .4 mls oleic acid (treatment 4, L18, Table 7).

^fAnalytical reagents Mallinckrodt, Inc., Paris, Ky 40361, used in laboratory trials. Industrial grade Na_2CO_3 and K_2CO_3 , Allied Chemical Co, Morristown, N.J., used in field trials.

Emulsifiers and Surfactants Importance in Solution Formulation and Forage Drying

The effect of various emulsifiers (Table 6) on stability of lipid water emulsions, and drying of forage sprayed with these solutions were examined in trials L6, L8, L10, L12, F17, F26 and F27, Table 8.

Combined Effects of Potassium Carbonate and Methyl Esters

Trials L13, L14, F11, F20, F21, F22, F24, F29, F32, F33 and F34 examined the effectiveness of K_2CO_3 , emulsified ME or a combination of these components for hastening drying of cut alfalfa. A 2x2 factorial design and orthogonal contrasts were used in trials L14 and F34 to determine main effects of both K_2CO_3 and ME and to check for interaction between the effect of these two components on plant drying. Results, details of solution application, and conditions during drying are presented in Tables 8, 9, 10, and 11.

Optimum Amounts of Methyl Ester Addition

Rate of ME application was increased by elevating the concentration of emulsified ME in a .2M K_2CO_3 solution, while total volume of liquid applied remained constant in trials L4, L9, F7, F21, F22, F29 and F32. Description of solution concentrations, application rates and measure of subsequent drying are presented in Table 12.

Influence of Changing Liquid Application Rate and Spray Pump Pressure on Forage Drying

Liquid application rates were increased while amount of ME K_2CO_3 and EM were usually maintained constant by decreasing their concentration in the spray solution. Increases in liquid application rates were obtained by changing tractor ground speed (F15 and F18), changing nozzle tip size (F26 and F27) or by changing flow rate to the spray booms (F35).

In two trials (F16 and F18) spray pump pressure was elevated by limiting return of solution through the agitation hose. Application rates were held approximately constant by changes in tractor ground speed. Description of solutions, application rates and pump pressures are presented in Table 13.

Chemical Treatment of Different Forage Species and Plants in Different Physiological States

Drying of Red Clover (RC), Alfalfa (Alf), and Birdsfoot Trefoil (Bft), sprayed with the three component solution or left as control were compared using several methods of expressing results in trial L17 (Table 14).

Drying rates and Mean DM content of brome and orchard grass at vegetative and seed stages of maturity were compared to alfalfa in trials L32 and L34 (Tables 15 and 16). Influence of the addition of crop oil concentrate to the three component

solution sprayed on mixtures of brome and orchard grass was investigated in trials L12 and L26 (Table 15).

Rates of moisture loss and responses to treatment were determined for alfalfa grown under field and green house environments in late fall and early spring (trials L11 and L16, Tables 15 and 16). Physical characteristics, period of growth, and initial DM content for these alfalfas are presented in Table 17.

Influence of Chemical Treatment on Length of Field Drying,
and Losses of Dry Matter and Nutrients During Harvest and
Storage

Changes in DM content and drying rates over time for alfalfa placed in 1.0 meter wide windrows or 2.3 meter wide swaths were studied in trials F3 and F9, results are presented in Tables 18 and 19.

Apparent respiration losses for sprayed and control forages were measured in 8 field trials during the summers of 1980 and 1981. The initial amount of dry matter on each screen was determined by taking a composite of three initial DM grab samples from each swath or windrow immediately after mowing. These samples were then frozen on dry ice in 1980 or heated in a microwave oven for 1.5 minutes in 1981, to deactivate respiratory enzymes, and then dried for 24 hours at 100° C to determine initial DM%. The initial weight of DM on each screen was then calculated

as the initial DM% X initial forage weight. The final amount of dry matter on each screen was determined as described previously. The change in amount of dry matter during drying was termed apparent respiration loss. This was then expressed as a percentage change from the initial weight of DM. Apparent respiration loss, mean DM content and hours to reach 75% DM are presented for trials F7, F9, F10, F13, F26, F27, F34, and F35 in Table 20.

DM loss after mowing and raking was compared for sprayed and control hay raked at 60 to 65% DM in trial F35. Losses were estimated by two methods. The first method involved picking up leaf and stem parts from 3 randomly assigned square meter areas after raking with a roller bar^g side delivery rake at 3.5 m.p.h. The second method utilized a shop vacuum cleaner^h which was used to collect residual material from 3 randomly chosen meter square areas. Because the vacuum picked up trash from previous cuttings as well as newly shattered material, a measure of the original residue was made by removing hay soon after it was cut, from three one meter square areas by hand and the original residues and forage dislodged during mowing vacuumed up. Raking loss was then determined by difference. Samples were dried at 100° C for 48 hours and weighed to determine loss per square meter. Total DM loss from mowing and/or

^gInternational Harvester Model No. 35.

^hSears Home-Shop Vac. Model No. 758.17885.

raking was then calculated in kg per Ha and as a % of total DM yield at cutting, results are presented in Table 21.

A series of trials were conducted to determine losses of DM and changes in analytical values during storage of control and sprayed baled alfalfa. In the first set of tests all swaths were raked when treated material reached 60 to 65% DM and were baled when treated hay reached 75 to 80% DM. The second set of trials were designed to compare interval to baling, analytical values of sprayed and unsprayed hay as baled, and changes in visual and analytical quality measurements for treated and control hay baled at the same DM content.

Ten to 12 bales per treatment were core sampled, weighed usually fitted with thermocouples and stacked under cover. Temperatures were monitored 2 or 3 times weekly for 3 to 4 weeks. When bale temperatures stabilized near ambient temperature the bales were reweighed core sampled and visually examined for mold growth and color changes. Core samples were frozen immediately and stored at -5°C until analyzed for DM, ash, water soluble carbohydrate, In vitro DM disappearance (IvDMD), and fiber and nitrogen fractions using standard laboratory procedures.

Losses of dry matter were calculated by multiplying the total bale weights for each treatment by their respective DM%, the final weight of DM was then subtracted from the initial weight of DM for each set of bales, and this change expressed

as a percent of the initial weight of DM that entered into storage. Results are presented in Tables 22, 23 and 24.

Laboratory Analysis

Dry matter percent of initial-cut forage samples and bale samples were determined by oven drying at 100° C for 24 hours. Neutral and acid detergent fiber analysis by the methods of Goering and Van Soest (1970) and Kjeldahl nitrogen and ash by the AOAC methods (1970). In vitro dry matter disappearance (IVDMD) was by a modified terry-tilly pepsin digestion (Tinnmet and Thomas, 1974) and water soluble carbohydrates by a modified method of Doboys et al. (1951).

Experimental Design and Statistical Analysis

A split plot repeat measurement design was employed for the drying trials. Data were analyzed by analysis of variance, and Bonferroni-t or designed orthogonal contrasts were used to evaluate differences between treatment DM or drying rate means for all replicates and all weighings.

Linear and quadratic functions were tested for fit in trials L9, F7, F29 and F32 where application rates of ME were increased to test for a dose response.

The students-t test was used in bale storage trials to evaluate differences in mean or maximum bale temperatures for the means of all replicates for each treatment over the storage period.

RESULTS AND DISCUSSION

Drying of Alfalfa Treated with Carbonates and Other Salts of the Alkali Metal Group

Solutions of sodium or potassium carbonate sprayed on alfalfa usually increased mean DM content above control ($p < .05$) in L15, Table 2, and F12, Table 3, and at $P < .01$ in trial L21, Table 2. In trial L22, Table 2, sodium carbonate (Na_2CO_3) did not hasten drying while potassium carbonate (K_2CO_3) increased ($P < .01$) mean DM. Where forage was approximately 60% grass in trial F23, Table 2, neither Na_2CO_3 or K_2CO_3 increased mean DM above untreated control ($p > .20$).

Forage treated with K_2CO_3 had a greater mean DM than did Na_2CO_3 treated material in two trials ($P < .05$) L22, Table 2, and F12, Table 3.

The trend for faster drying of forage sprayed with K_2CO_3 than that sprayed with Na_2CO_3 was also apparent when these salts were combined with low levels of methyl esters (ME) and an emulsifier (EM) ($55.8 > 51.8\%$ Mean DM at $P > .20$ in trial L2, Table 2) and was significant ($P < .05$) in L23, Table 1, and F8, Table 2.

In 4 out of 5 laboratory, and 2 out of 4 field trials mean DM of K_2CO_3 sprayed forage exceeded that for Na_2CO_3 sprayed material. In 2 laboratory and 2 field trials differences exceeded $P < .05$. Sodium carbonate treatments had mean DM contents similar or slightly greater ($P > .20$) than K_2CO_3

treated material in 3 trials F25, Table 3, and L15 and L21, Table 2.

Hours required for both control and sprayed alfalfa to attain 75% DM were usually greater in field trials than laboratory trials, often not reaching 75% DM in 40 to 50 hours. This difference is primarily due to cessation of drying during night periods in field trials while forage continued to lose water over night under laboratory conditions.

Although Na_2CO_3 and K_2CO_3 are the least expensive and most available carbonates of the alkali metal group, carbonates of other alkali metals were also tested. In two out of three trials (L22 and L23, Table 2) the ranking of these elements from least to most effective was $\text{Li} < \text{Na} < \text{Rb} < \text{K} < \text{Cs}$, while in trial L21, Table 2, the ranking was $\text{K} < \text{Na} < \text{Rb} < \text{Cs}$.

In general alkali metals with larger ionic radii increased drying more than did those with smaller radii. Rubidium is a possible exception, producing a smaller increase in drying than potassium in two out of three trials. A bimodal split in the effectiveness of these compounds was noted in all three trials, lithium and sodium carbonate treatments produced only small increases in drying while rubidium, potassium and cesium carbonates were usually much more effective in hastening drying.

The lack of a distinct separation between the effectiveness of K_2CO_3 and Rb_2CO_3 solutions in these trials could be

Table 2. Laboratory Experiments Testing Drying Parameters of Alfalfa Treated With Carbonates and Other Salts of the Alkali Metals

Trial	ID	Treatment Description	Solution Ph	Application Rate %a grME/kgb	Hours to Reach 40% DMC	75% DM	Meand DMC	Bonferroni t Contrasts	
								Interaction	Mean DM
L15	1	None	-	0	28.5	>50	36.1	2,5 vs 3,4	P<.05
	2	.2m Na2CO3	11.4	2	23	>50	38.7	1 vs 2,4	P<.05
	3	.4m NaOH	13.2	2	28.5	>50	35.6	2 vs 3	P<.10
	4	.2m K2C03	11.3	2	23	50	39.5	4 vs 5	NS ^e
	5	.4m KOH	13.4	2	21	46.5	41.5	2 vs 4	NS
								3 vs 5	P<.01
L21	1	None	-	0	12.0	28.5	40.7	1 vs 2,3,4,5	P<.01
	2	.2m Na2CO3	-	2	10.5	26.0	43.4	2 vs 3	NS ^e
	3	.2m K2CO3	-	2	11.0	26.5	42.6	3 vs 4	P<.10
	4	.2m Rb2C03	-	2	8.5	22.0	47.3	3 vs 5	P<.05
	5	.2m Cs2CO3	-	2	8.0	22.0	48.5		
L22	1	None	-	0	11.5	>42.0	48.1	1 vs 2,3,4,5,6	P<.01
	2	.2m Li2CO3	-	2	13.0	>42.0	46.1	3 vs 4	P<.05
	3	.2m Na2CO3	11.7	2	11.7	42.0	48.4	2,3 vs 4	P<.01
	4	.2m K2CO3	11.5	2	7.0	25.5	59.9	4 vs 5,6	NS
	5	.2m Rb2CO3	11.8	2	8.0	26.5	58.0		
	6	.2m Cs2CO3	11.6	2	6.0	24.0	60.9		

Table 2. Continued.

Trial	ID	Treatment Description	Sol. Ph	Application Rate %a grME/kgb	Cationic Radius	Hours to Reach		Means ^d DMC	Bonferroni t Contrasts	
						40%DMc	75%DMC		Mean DM	DRT ⁱ
L2	1	None	-	0	-	11	32	46.7	1 vs 3,4	P<.01
	2	.2m Li ₂ CO ₃ + 7%ME+.5%x-77	11.2	3.5	.60	7	20	53.5	1 vs 2	P<.01
	3	.2m Na ₂ CO ₃ + 7%ME+.5%x-77	11.0	3.5	.95	7	23	51.8	3 vs 4	NS ^e
	4	.2m K ₂ CO ₃ + 7%ME+.5%x-77	11.2	3.5	1.33	5	18	55.8	2 vs 3,4	NS
56										
L23	1	None	-	0		6.5	>30	47.2	1 vs 2,3,4,5,6	P<.01
	2	.2m Li ₂ CO ₃ + 2%ME+.25%x-77	11.3	2	.4	5/8	>30	49.1	3 vs 4	P<.01
	3	.2m Na ₂ CO ₃ + 2%ME+.25%x-77	11.5	2	.4	5.0	>30	51.7	2, 3 vs 4	P<.01
	4	.2m K ₂ CO ₃ + 2%ME+.25%x-77	11.4	2	.4	3.2	17.5	59.8	4 vs 5,6	NS ^e
	5	.2m Rb ₂ CO ₃ + 2%ME+.25%x-77	11.6	2	.4	3.3	20.5	58.0		
	6	.2m Cs ₂ CO ₃ + 2%ME+.25%x-77	11.3	2	.4	2.5	17.0	61.8		

Table 2. Continued.

Trial	ID	Treatment Description	Solution Ph	Application Rate % grME/kg ^b	Hours to Reach 40% DMC	75% DM	Meand DMC	Bonferroni t Contrasts	
								Interaction	Mean DM
L27	1	None	-	0	20.7	>45	37.7	2,5 vs 3,4	P<.01
	2	.4m NaCl	7.2	2	17.7	>45	40.2		
	3	.4m NaOH	13.3	2	18.6	>45	39.9	1 vs 2,3	NS ^e
	4	.4m KCl	7.2	2	22.8	>45	36.3	1 vs 4	NS
	5	.4m KOH + HCl	11.0	2	19.9	>45	38.5	1 vs 6	P<.01
	6	.4m KOH	13.3	2	15.5	>45	43.4	2 vs 3	NS
								4 vs 5	NS
								5 vs 6	P<.05
								2 vs 5	P<.05
								3 vs 6	P<.10
L19	1	None	-	0	6.0	>29.5	50.5	1 vs 2,3,4,5	P<.01
	2	.4m(NH ₄) ₂ CO ₃	8.3	2	5.0	>29.5	53.1	4 vs 3,5	P<.05
	3	.2m K ₂ CO ₃ + .1m NaOH ³	13.0	2	5.0	24.0	56.1	3 vs 4	P = .2
	4	.2m K ₂ CO ₃ + .2m(NH ₃) ₂ CO ₃	9.6	2	5.0	25.5	55.6	3 vs 5	NS
	5	.4m KOH	13.5	2	6.0	25.0	56.4		

Table 2. Continued.

Trial ID	Treatment Description	Solution Ph	Application Rate $\frac{\%a}{grME/kgb}$	Hours to Reach $\frac{40\% DMC}{75\% DM}$	Mean ^d $\frac{DMC}{DM}$	Bonferroni t Contrasts Mean DM
L20	1 None	-	0	16.0	42.5	1 vs 2,3,4,5 P<.01
	2 2% ME + .25% x-77	4.3	.4	15.0	43.4	2 vs 3,4,5 P<.01
	3 .2m KCO ₃ 2% ME + .25% x-77	11.4	.4	11.0	47.5	3 vs 4 NS ^e
	4 .4m KOH + 2% ME +.25% x-77	13.6	.4	10.5	49.2	4 vs 5 NS
	5 .4m KOH .2m(NH ₄) ₂ CO ₃ 2% ME + .25% x-77	10.7	.4	11.0	47.2	

^aVolume of spray applied as a percentage of fresh forage weight.^bGrams of methyl esters applied per kg fresh forage weight.^cDM = Dry matter content as a percentage of total sample weight.^dMean of 4 replicates.^eP>.20.

Table 3. Field Trials Testing Drying Parameters of Alfalfa Treated With Carbonates and Other Salts of the Alkali Metals

Trial ID	Treatment Description	Application Rate %a grME/kgb	Weatherf & Starting Dateg	Hours to Reachh 40% DMC	75% DMC	Bonferroni t Contrasts	
						Mean	DM
F12	1 None	0	29° C	4.5	10	42.1	1 vs 2,3 P<.05
			0 cm				
	2 .4m Na ₂ CO ₃	2.1	74%	4	10	45.4	2 vs 3 P<.05
			15 kph				
	3 .4m K ₂ CO ₃	2.7	8/25/80	3	10	50.2	
F23	1 None	0	25° C	5.5	41.5	47.4	1 vs 2,3,4 NS ^e
Grass 60%							
	2 .2m Na ₂ CO ₃	1.5	.05 cm	5.5	42.5	47.1	3 vs 4 NS
			67%				
	3 .2m K ₂ CO ₃	1.5	19.8 kph	5.5	45.0	44.8	2 vs 3 NS
	4 .4m KOH	1.5	6/15/81	5.5	43.0	46.0	
F8	1 None	0	25° C	2.5	>50	35.4	1 vs 3 P<.05
	2 .4m Na ₂ CO ₃ + 5% ME + .25% x-77	1.5	.7 cm	2.5	>50	35.7	1 vs 2 NSe
			87%				2 vs 3 P<.05
	3 .4m K ₂ CO ₃ + 5% ME + .25% x-77	2.0	7/29/80	2.0	>50	38.8	

Table 3. Continued.

Trial ID	Treatment Description	Application Rate % ^a grME/kgb	Weather ^f & Starting Dateg	Hours to Reach ^h		Mean ^d DMc	Bonferroni t Contrasts	
				40% DMc	75% DM		Mean DM	
F25	1 None	0	0	26° C	4.0	26.5	49.4	1 vs 2, 3, 4
	2 .2m Na ₂ CO ₃ + 2% ME + .25% x-77	1.4	.28	0.0 cm 53% 14.7 kph	3.0	25.5	53.3	2 vs 3
	3 .2m K ₂ CO ₃ + 2% ME + .25% x-77	1.4	.28		3.5	25.0	52.7	2, 3 vs 4
	4 .4m KOH 2% ME + .25% x-77	1.6	.32		3.0	23.5	56.3	

a,b,c,e See Table 1 for explanation.

d Mean of 5 replicates.

f Mean temperature and relative humidities between 8:00 a.m. and 8:00 p.m., total centimeters of rain during the trial, average wind speed during the entire trial in kilometers per hour.

g Starting date of field trial.

h Hours required to reach the specified DM content, including night periods.

due to an added effect of the potassium ion on the plant stomata. The concentration of intracellular potassium ions in the guard cells regulate stomatal appature and thus transpiration rates in the growing plant (Fisher, 1968). Potassium ions in the spray solution could have been preferentially absorbed into the unprotected guard cells, causing opening of the stomata. If this were the primary mode of action for K_2CO_3 or the other carbonates of the alkali metals, greatly increased Drt during the first few hours after treatment followed by an abrupt decrease in water loss rates similar to those reported for alfalfa treated with fusicoccin (Stalfet, 1957) and sodium azide (Tullberg and Angus, 1972) would be expected.

Drying rates for alfalfa treated with any of the alkali metal carbonates excluding lithium were greater than for untreated control during the first six hours of drying in trials L21, L22, and L23, Table 4. During the first two hours after treatment Cs_2CO_3 or Rb_2CO_3 treated alfalfa had the highest drying rate with the other carbonates ranking in an order similar to how they had been ranked for effectiveness in increasing mean DM. Because Cs_2CO_3 was generally more effective than K_2CO_3 during the initial 2 hours of drying, little evidence exists for a preferential effect of potassium ions on guard cell mediated stomatal opening. The maintenance of drying rates greater than untreated controls during the first 6 hours after treatment with alkali metal carbonates suggest that the

Table 4. Drying Rates During Given Periods Post-Cutting for Three Laboratory Trials.

Trial	Treatment	Drying Rate ^a		
		0 to 2 hr	2 to 4 hr ^b	4 to 6 hr
L21	None	.523	.308	.205
	.2m Na ₂ CO ₃	.550	.361	.222
	.2m K ₂ CO ₃	.543	.308	.227
	.2m Rb ₂ CO ₃	.653	.413	.253
	.2m Cs ₂ CO ₃	.540	.383	.242
L22	None	.170	.132	.092
	.2m Li ₂ CO ₃	.143	.122	.090
	.2m Na ₂ CO ₃	.197	.152	.097
	.2m K ₂ CO ₃	.213	.180	.134
	.2m Rb ₂ CO ₃	.203	.203	.140
	.2m Cs ₂ CO ₃	.235	.270	.142
L23	None	.163	.120	.115
	.2m Li ₂ CO ₃ 2% ME + EM	.193	.133	.132
	.2m Na ₂ CO ₃ 2% ME + EM	.171	.138	.135
	.2m K ₂ CO ₃ 2% ME + EM	.329	.220	.178
	.2m Rb ₂ CO ₃ 2% ME + EM	.271	.209	.162
	.2m Cs ₂ CO ₃ 2% ME + EM	.341	.260	.148

^aDrying rate, loss in grams water per hour per gram DM.^bHr. = hour post-cutting.

principal action of these compounds is on the plant cuticle rather than on stomatal appature alone.

These data tend to support the work of Schroher (1976) where he ranked the alkali metal ions ability to increase permeability of isolated citrus cuticles in the order of increasing ionic radius ($\text{Li} < \text{Na} < \text{K} < \text{Rb}$). The author suggested that increases in water permeability were a result of enlargement of polar pores in the cutin matrix due to preferential association of the largest alkali metal cations, having the lowest charge density, with non-esterified carboxyl groups. The alkali metals have larger ionic radii and lower first ionization energies than any other group of elements. Within the alkali metal group ionic radius increases and first ionization energy decreases from lithium to cesium (Table 5).

Table 5. Ionic Radii and First Ionization Energies of the Alkali Metals

Alkali Metal Ion	<u>Ionic Radius</u> Å ^a	<u>First Ionization Energy</u> Kcals/mole ^b
Li	.60	126
Na	.95	120
K	1.33	102
Rb	1.48	98
Cs	1.69	90

^aAngstrom.

^bKilo calories per mole.

Whether increases in drying of intact alfalfa plants sprayed with solutions containing alkali metal ions are due to similar changes in cutin matrix pore size, or to changes in epicuticular or imbedded waxes is not clear. Perhaps removal of surface waxes with petroleum ether and subsequent treatment with carbonate solutions could provide an answer.

The work of Schroner (1976), implicating increases in Ph as an important factor in alkali metal mediated changes in cuticular permeability led to examination of the influence of solution Ph and anions on drying of alfalfa. Interactions between the effects of cation (K^+ or Na^+) and solution Ph (11 or 13) were detected in both L15, ($P < .05$) and in L27, ($P < .01$), Table 2. Mean DM of Na_2CO_3 treated alfalfa was greater than that of NaOH treated alfalfa ($38.7 > 35.6$ at $P < .10$, L15, Table 2). Yet mean DM of K_2CO_3 treated alfalfa was less than that of KOH treated material ($52.7 < 56.3$ at $P < .10$ in F25, Table 3, and $39.5 < 41.5$ in L15, Table 2, and $44.8 < 46.0$ in F23, Table 3, at $P > .20$). Mean DM of KOH treated alfalfa was greater than that of NaOH treated alfalfa in two trials ($41.5 > 35.6$ at $P < .01$ in L15 and $43.47 > 39.9$ at $P < .10$ in L27, Table 2).

In L27 solutions of sodium or potassium chloride (NaCl) or (KCl), Ph 7, KOH titrated to Ph 11 with hydrochloric acid (HCl) and NaOH, at Ph 13, failed to increase ($P > .20$) mean DM above untreated control. Sodium chloride treatment had greater mean DM than did KCl ($P < .05$) which is not consistent with results comparing sodium and potassium salts at Ph 11 and 13.

A solution of ammonium carbonate, Ph 8 was less effective in increasing mean DM than a K_2CO_3 , NaOH solution at Ph 13, or a KOH solution at Ph 13.5 ($53.1 < 56.1$ and 56.4 at $P < .05$ in trial L19, Table 2). The addition of ammonium carbonate to a K_2CO_3 solution or to an emulsified ME, KOH mixture decreased Ph from 11.3 to 9.5 and from 13.5 to 10.5 respectively in trials L19 and L20, Table 2. These reductions in Ph, due to release of ammonia gas and hydrogen ions, also tended to diminish the magnitude of increases in mean DM from treatment of alfalfa with K_2CO_3 or KOH solutions ($55.6 < 56.1$ at $P = .20$ in L19 and $47.2 < 49.2$ at $P > .20$ in L20).

Although there was considerable variability between the results of trials L15 and L27, several major trends are apparent that may help to explain the detected interactions. Solutions containing sodium salts were similar in effectiveness between Ph 7 and 13, while mean DM of alfalfa treated with solutions containing potassium salts increased as the Ph of the solution increased within this same range.

Potassium hydroxide was the most effective alkali metal salt in 5 out of the 6 trials where it was tested. The effectiveness of KOH solutions was diminished when Ph was decreased by addition of HCl or ammonium carbonate suggesting that high solution Ph may 1) facilitate movement of the potassium ion into the cuticle by disruption of surface waxes or 2) may directly cause extensive hydrolyzation of ester linkages within the cutin matrix.

Influence of Methyl Ester Source and Composition

Different methyl esters (ME) with similar fatty acid distributions were screened for effectiveness in hastening the drying of alfalfa (Table 6). Methyl tallowate, methyl lardate, and methyl oleate in combination with K_2CO_3 and an emulsifier (EM) all increased mean DM over untreated control alfalfa ($P < .01$), but were not different from each other ($P > .20$; L1, Table 7). Food grade methyl tallowate, or lardate, industrial grade soap stock of unknown composition, and olive oil emulsions, all in combination with K_2CO_3 , increased mean DM content of alfalfa above untreated control ($P < .05$; L18, L28, and L34, Table 7). Methyl esters of lard and tallow were more effective than soap stock ($P < .20$; L28) but were not different from two olive oil preparations ($P > .20$; L18, Table 7).

These trials indicate that lipids of both plant and animal origin containing primarily C16 and C18 fatty acids are of similar effectiveness in increasing drying, while the soap stock tested appears to have less pronounced effects on plant drying. Further research appears warranted on identification of other effective low cost lipid preparations that will increase plant drying rates.

Table 6. Composition of Methyl Ester, other Lipids and Emulsifiers Used in Spray Solutions.

	Max. Acid Value	Saponification Value	Iodine Value	Melting Point	Fatty Acid Chain Length						
					C6-10	Cl4	Cl6	Cl8	Cl8.1	Cl8.2	
				- ° C -	----- % of total -----						
Methyl ⁱ Tallowate E-2203	1	190-200	47-53	-	0	3	28	24	42	3	
Methyl ⁱ D-2202 Lardate	1	188-196	60-70	9	0	2	28	11	50	9	
Methyl Oleate ⁱ E-2301	1.7	-	82-88	23	0	0	0	0	100	0	
Oleic Acid ⁱ	198.6	-	89.9	7	0	0	0	0	82	12	67
TE 1618 ^j	-	-	-	-	0	3	32	22	40	3	
Olive Oil ^m	.2-2.8	187-196	79-90	5	0	0	9	2	84	4	
Soap Stock ⁱ											

Principal Functioning Agents

X - 77^k Alkylar polyoxethylene, glycols, free fatty acids, and isopropanol.
Herbimax^l (crop oil concentrate) Petrol Hydrocarbons, 80% w/w; surfactants, 16% w/w; formulation aids, 4% w/w.

ⁱ Obtained from Emery Industries, Inc., 4900 Este Ave., Cincinnati, Ohio 45232.

^j Obtained from Procter and Gamble Distributing Co., Oakbrook, Ill.

^k Chevron Chemical Co., Ortho Division, San Francisco, CA 94119.

^l Loveland Industries, Inc., Loveland, Colorado 80537.

^m Values obtained from Merk Index, 1968, 8th Ed., Merk and Co., Inc., Rahway, N.J., p. 764.

Table 7. Description of Drying Parameters for Laboratory Trials Testing Different Methyl Esters and Lipid Emulsions.

Trial ID	Treatment Description	Application Rate %a grME/kgb	Hours to Reach 40% DMc	75% DM	Mean DM	Bonferroni t Contrasts on Mean DM
L1	1 None	0	0	15.0	38.7	1 vs 2,3,4,5 P<.01
2	7% TEL1618 + .2M K ₂ CO ₃ + 5% X-77	3.5	2.5	10.2	47.1	2 vs 3 Nse
3	7% Methyl oleate + .2M K ₂ CO ₃ + .5% X-77	3.5	2.5	10.5	46.1	2 vs 4,5 NS
4	7% Methyl Tallowate + .2M K ₂ CO ₃ + .5% X-77	3.5	2.5	11.0	44.6	
5	7% Methyl Lardate + .2M K ₂ CO ₃ + .5% X-77	3.5	2.5	10.2	46.3	
L18	1 None	0	0	16	39.9	1 vs 2,3,4,5 P<.01
2	4% Methyl Tallowate + .2M K ₂ CO ₃ + .25% x-77 + .25% Oleic Acid	2	.8	5.5	56.9	2 vs 3 NS
3	4% Methyl Lardate + .2M K ₂ CO ₃ + .25% x-77 + .25% Oleic Acid	2	.8	6.0	54.8	4 vs 5 NS
4	4% Olive Oil + .2M K ₂ CO ₃ + .25% X-77 + .25% Oleic Acid	2	.8	7.5	53.2	2,3 vs 4,5 NS
5	4% Olive Oil + 4% ETOH9 + .4M KOH + .25% X-77 + .25% Oleic Acid	2	.8	6.2	55.2	

Table 7. Continued.

Trial ID	Treatment Description	Application Rate %a grME/kgb	Hours to Reach 40% DMC 75% DM	Mean d DM	Bonferroni t contrasts on Mean DM
L35					
1	None	0	18	35.4	1 vs 2 N.S.
2	.2M K ₂ CO ₃	2	16	36.6	1 vs 3,4,5 P<.01
3	4% Methyl tallowate .2M K ₂ CO ₃ + .25% X-77 + .25% OA	2	8	48.5	3 vs 4 P<.05 4 vs 5 N.S.
4	4% Olive Oil + .2M K ₂ CO ₃ + .25% X-77 + .25% OA	2	13	41.1	
5	4% Olive Oil + 4% ETOH ^g + .4M KOH + .25% X-77 + .25% Oleic acid	2	12	42.0	
L28					
1	None		29.2	32.5	1 vs 2,3,4,5 P<.05
2	2% Methyl Tallowate + .2M K ₂ CO ₃ + .25% X-77	2	21.4	37.5	5 vs 2,3,4 P<.20
3	2% Methyl Lardate + .2M K ₂ CO ₃ + .25% X-77	2	17.7	40.5	2,3 vs 4 P<.20
4	2% Soap Stock + .2M K ₂ CO ₃ + .25% X-77	2	24.8	35.0	
5	.2M K ₂ CO ₃	2	27.2	33.9	

a,b,c,d,e See Table 1 for explanations.

f_{ME} = Methyl Ester or other lipid.g_{ETOH} = Ethanol.

The Effectiveness of Various Emulsifiers and Surfactants In
Maintaining Lipid Water Emulsions and Speeding Drying

The addition of 0.05 to 0.8% X-77, oleic acid (OA) or crop oil concentrate (COC) to solutions containing up to 20% ME produced a white colored, visually complete, emulsion of lipid and water that was stable for up to 7 minutes without agitation.

In two trials the addition of 0.4% OA (L6) or 0.8% OA or X-77 (L8) to a 20% ME, water mixture tended to increase mean DM of sprayed alfalfa above treatment with ME or ME plus K_2CO_3 alone ($P < .20$; Table 8). There was a trend for OA to be more effective than X-77 in increasing drying in trial L6 ($P < .10$) while in trial L8 0.8% X-77 appeared to be more effective than 0.8% OA, although these differences lacked statistical significance ($P > .20$).

Crop oil concentrate substituted for X-77 in a 10% ME .2 M K_2CO_3 , .25% X-77 solution increased mean DM of sprayed alfalfa above the solution containing X-77 ($P < .05$; trial L10, Table 8). This trend was also apparent in F17 ($P > .20$) though differences in application rate and several light rains during the trial confound these results.

In two field trials the addition of a mixture of X-77 and OA to K_2CO_3 solutions did not hasten drying (treatments 2 vs 4 in trials F26 and F27, Table 8).

Both observational and drying trials indicate that the addition of a surface active agent to solutions containing ME

Table 8. Emulsifiers and Surfactant Effectiveness in Hastening Drying of Alfalfa Treated with Potassium Carbonate and Methyl Ester Emulsions.

Trial ID	Treatment Description	Application Rate %a grME/kgb	Hours to Reach 40% DMC 75% DM	Meand DM	Bonferroni t Contrasts on Mean DM
L6	1 20% ME .2M K ₂ CO ₃	1.6	4.5	17.0	48.8 1 vs 2,3,4 NSE
	2 20% ME .2M K ₂ CO ₃ + .4% X-77	2.4	4.5	17.5	48.4 2 vs 3 P<.10
	3 20% ME .2M K ₂ CO ₃ + .4% Oleic Acid	1.8	4.5	13.0	52.4 1 vs 2,3 P<.20
	4 20% ME .2M K ₂ CO ₃ + .2% X-77 + .2% OA	1.9	4.0	13.5	51.7
L8	1 None	0	18.0	>37.0	36.2 1 vs 2,3,4,5 P<.20
	2 20% ME	1	17.0	>37.0	38.1 2 vs 3,4,5 P<.20
	3 20% ME + .8% X-77	1	12.5	31.0	46.5 3 vs 4 NS
	4 20% ME + .8M K ₂ CO ₃ + .8% X-77	1	12.5	29.0	46.5 4 vs 5 NS
	5 20% ME + .8M K ₂ CO ₃ + .8% Oleic Acid	1	14.0	35.0	42.9
L10	1 None	0	23	>31	30.1 1 vs 2,3,4 P<.05
	2 10% ME .2M K ₂ CO ₃ + .25% X-77	1	21	>31	31.5 2 vs 3,4 P<.05
	3 10% ME .2M K ₂ CO ₃ + .25% Crop Oil Concentrate	1	17	>31	35.4
	4 10% ME .2M K ₂ CO ₃ + .5% Crop Oil Concentrate	1	20	>31	32.0

Table 8. Continued.

Trial ID	Treatment Description	Application Rate %a grME/kgb	Weatherg Starting Dateh	Hours to Reach 40% DMC 75% DM	Meand DM	Bonferroni t Contrasts on Mean DM
F17	1 None	0	19° C	>56	25/6	1 vs 2,3 P<.01
	2 5% ME .2M K ₂ CO ₃ + .25% X-77	2.1	1.1 cm 85%	>56	26.7	2 vs 3 Nse
	3 5% ME .2M K ₂ CO ₃ + .25% Crop Oil Concentrate	.48 2.5	10.4 kph 9/8/81	>56	28.3	
F26	1 None	0	24° C	8.0	32.0	1 vs 2,3,4,5 P<.01
	2 .2M K ₂ CO ₃	2.3	0.0 cm	4.5	28.0	2 vs 4 NS
	3 .2M K ₂ CO ₃	3.3	59%	5.0	29.0	2 vs 5 NS
	4 .2M K ₂ CO ₃ + .1% Oleic Acid + .1% X-77	4.1	11.7 kph 6/22/81	4.5	28.5	3 vs 4 NS
	5 2% ME 2M K ₂ CO ₃ + .25% X-77	2.0	.46	5.0	28.0	
F27	1 None	0	22° C	7.5	27.0	1 vs 2,3,4,5 P<.01
	2 .2M K ₂ CO ₃	2.0 ^g	0.0 cm	4.5	24.0	2 vs 3 P<.01
	3 .2M K ₂ CO ₃ + .1M NaOH	2.25	47%	6.5	25.0	2 vs 4 P<.01
	4 .2M K ₂ CO ₃ + .1% X-77 + .1% Oleic Acid	2.0	16.3 kph 6/24/81	6.5	26.5	2 vs 5 P<.01
	5 2% ME + .2M K ₂ CO ₃ + .25% X-77	1.9		6.0	25.0	4 vs 5 P<.01

a,b,c,d,e See Table 1 for explanation.

f,g,h See Table 2 for explanation.

i Estimate of application rate.

provided a more uniform emulsion which tended to be more effective than ME or ME plus K_2CO_3 solutions alone for increasing drying. On the other hand the effectiveness of K_2CO_3 solutions was not enhanced by the addition of surface active agents. Therefore, in subsequent trials an emulsifier was added to all solutions containing ME, but were not included in solutions containing only K_2CO_3 or other salts.

Additive Effects of Methyl Esters and Potassium Carbonate

Combining emulsified methyl esters (ME) with potassium carbonate (K_2CO_3) was more effective in hastening drying of sprayed alfalfa than the use of either compound alone ($P < .01$, L14 and $P > .20$; trials L13 and F34, Table 9). Mean DM for ME treated alfalfa exceeded that for K_2CO_3 treatments in each of 3 trials ($P > .20$, L13, L14 and F34). The average values were 46.6 for ME and 44.5% for K_2CO_3 while the combined treatment averaged 49.0. Main effects of K_2CO_3 or ME and their interaction were tested in only 2 trials (L14 and F34) that could be analyzed as factorials. The main effects of K_2CO_3 were $P < .10$ and $P > .20$ while those for ME were somewhat more significant $P < .01$ and $P < .20$, respectively. Tests for an interaction between ME and K_2CO_3 as components in the spray solution were not significant for both trials ($P > .20$) indicating that the effects of ME and K_2CO_3 are additive rather than synergistic.

Table 9. Measures of Drying When Alfalfa Was Treated With Methyl Esters or Potassium Carbonate Used Alone or in Combination.

Trial	ID	Treatment Description	Application Rate		Hours to Reach		Means ^d		Contrasts	
			% a	grME/kgb	40% DM ^c	75% DM	DM	Drt ⁱ	Mean	DM
L14	1	None	0	0	29.0	>48	31.7	.130	2,3 vs 4	P<.01
	2	.2M K ₂ CO ₃	2	0	27.0	>48	33.6	.135	2 vs 3	NS
	3	5% ME + .25% X-77	2	1	20.0	45	37.0	.134	1 vs 2,3,4	P<.05
	4	5% ME .2M K ₂ CO ₃ + .25% X-77	2	1	18.0	33	40.2	.140	Main effect K ₂ CO ₃ 1,3 vs 2,4	P<.10
Main effect ME										
Interaction										
1,2 vs 3,4 P<.01										
1,4 vs 2,3 NS ^e										
L13	1	.2M K ₂ CO ₃	2	0	11.5	28	43.2		1,2 vs 3	NS
	2	5% ME + .25% X-77	2	1	10.5	26	45.2		1 vs 2	NS
	3	5% ME .2M K ₂ CO ₃ + .25% X-77	2	1	9.0	28	47.9			

Table 9. Continued.

Trial ID	Treatment Description	Application Rate %a grME/kgb	Weatherf Starting Dateg	Hours to Reach 40% DMc 75% DM	Meand DM	Contrasts	
						Mean	DM
F11	1 None	0	21° C	20	48.7	1 vs 2,3,4	NSe
	2 .4M K ₂ CO ₃	2.3	0.0 cm	20	49.3	2 vs 3	P<.10
	3 5% ME +.25% X-77	2.3	70%	20	45.7	2.4 vs 3	NS
	4 5% ME .2M K ₂ CO ₃ + .25% X-77	2.3	15.0 kph 8/22/80	20	48.1		
F20	1 None	0	14° C	22	39.1	1 vs 2,3	NS
	2 .2M K ₂ CO ₃ + .25% X-77	4g	0.0 cm 71%	20	40.1	2 vs 3	NS
	3 5% ME .2M K ₂ CO ₃ + .25% X-77	4g	16.9 kph 10/7/80	20	38.9		
F33	1 None	0	28° C	2.2	56.6	1 vs 2,3	NS
	2 .2M K ₂ CO ₃	3.4g	0.0 cm	3.5	53.8	1 vs 4,5	NS
	3 .2M K ₂ CO ₃	4.5g	85%	2.0	57.2	3 vs 5	NS
	4 5% ME .25% X-77 + .25% Oleic Acid	3.4g	12.5 kph 8/12/81	3.0	53.6	2 vs 3	NS
	5 5% ME .2M K ₂ CO ₃ + .25% X-77 + .25% Oleic Acid	3.4g		2.2	60.3		

Table 9. Continued.

Trial ID	Treatment Description	Application Rate %a grME/kgb	Weather ^f Starting Date ^g	Hours to Reach 40% DMC 75% DM		Mean ^d DMC DRT ⁱ		Contrasts Mean DM	
F34	1 None	0	0	21° C	3.0	29	51.4	.169	1 vs 2,3 P<.20
	2 .2M K ₂ CO ₃	2.8	0	0.0 cm	2.5	27.5	56.3	.182	2 vs 3 NSE
	3 .2M K ₂ CO ₃	4.4	0	52%	2.7	27.5	56.9	.173	1 vs 4,5 P<.05
	4 5% ME + .25% X-77 + .25% Oleic Acid	2.8	1.4	8.4 kph 8/17/81	2.5	27.5	57.5	.166	2,3 vs 4,5 NS
	5 5% ME .2M K ₂ CO ₃ + .25% X-77 2.8 + .25% Oleic Acid	1.4			2.0	27.5	58.8	.164	2.3.4 vs 5 NS Main effect K ₂ CO ₃ 1,4 vs 2,5 NS Main effect ME 1,2 vs 4,5 P .20 Interaction 1,5 vs 2,4 NS

a,b,c,d,e See Table 1 for explanation.

f,g,h See Table 2 for explanation.

ⁱDrying rate, grams water lost per hour per gram DM.^gEstimate of application rate.

Less clear results with no significant increases in mean DM content due to any treatment resulted from field trials F11, F20 and F33. Several reasons are offered for this lack of treatment effect. Forage for F11 was cut at 4:30 p.m. and a very heavy dew occurred that night. Application rates presented for trials F20 and F33 are only an estimate due to improper regulation of pump pressure. Other evidence indicates that treatment number 3 in F20 was effective. The resulting hay from one half acre of sprayed and control hay was baled 3 days after cutting and core samples from these bales were 68% DM for control and 76% DM for treated hay.

In an attempt to more fully explore treatment effects drying rates (DRt) for all treatments in trial L14 were compared over time (Figure 2) and at different WC as moisture was removed (Figure 3).

Potassium carbonate increased DRt more than did ME during the first 2 hours of drying. This advantage diminished rapidly and by 8 to 12 hours postcutting DRt for K_2CO_3 treated alfalfa was similar to control (Figure 2). Methyl ester and ME plus K_2CO_3 treatments elevated DRt above control until 21 and 23 hours respectively, and then decreased below control until trial termination at 43 hours.

When drying rates for the various treatments were compared at the same WC the rate for alfalfa treated with K_2CO_3 was higher than that for ME or ME plus K_2CO_3 treatment at a WC

Figure 2. Drying rates of alfalfa treated with potassium carbonate, emulsified methyl esters or a combination of these compounds over 47 hours of drying (trial L14). UC = untreated control; K_2CO_3 = potassium carbonate; ME = methyl esters; EM = emulsifier.

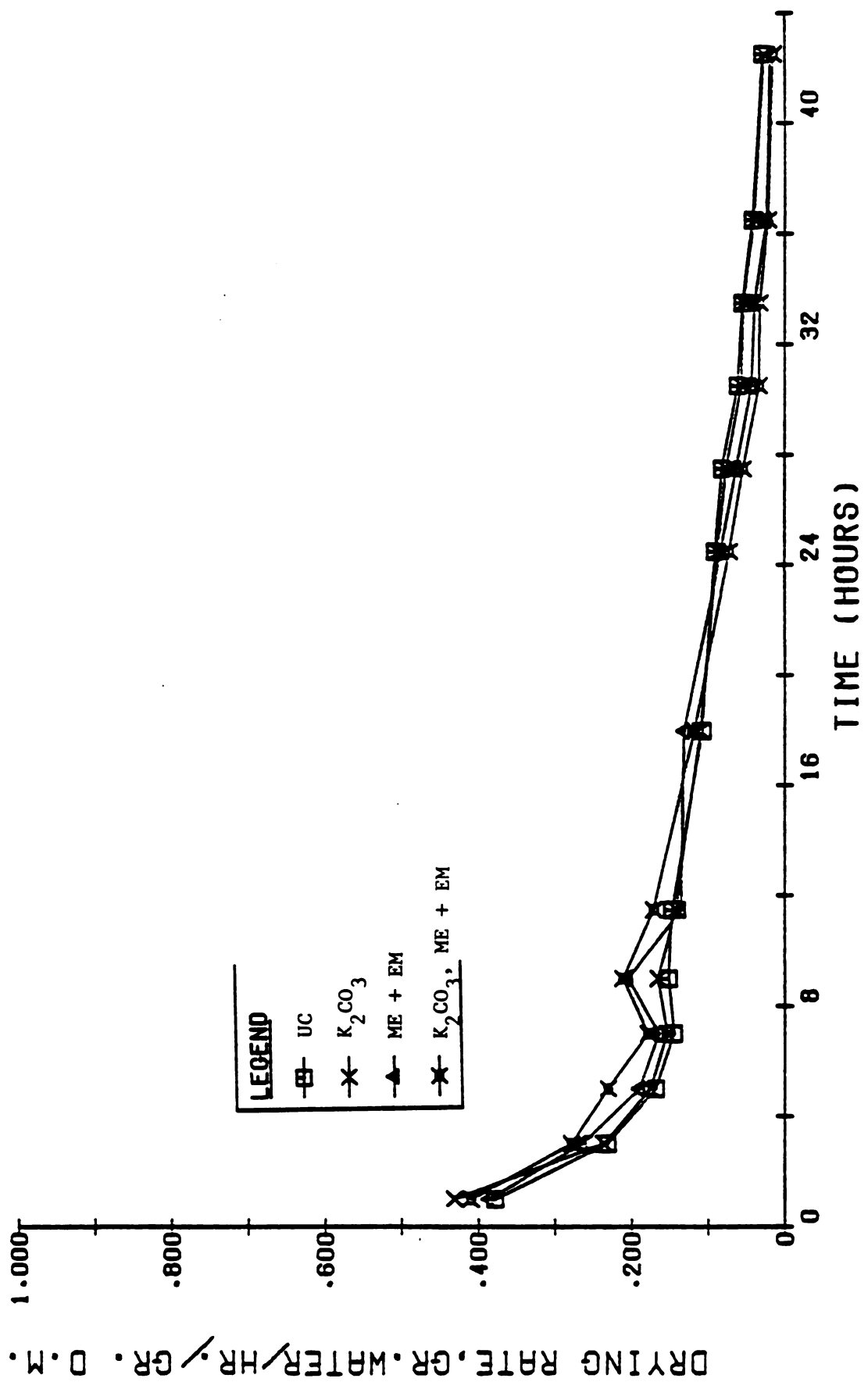


Figure 2.

Figure 3. Drying rates between water contents of 6.0 and 0.5 for alfalfa treated with potassium carbonate, emulsified methyl esters or a combination of these compounds (trial L14). UC = untreated control; K_2CO_3 = potassium carbonate; ME = methyl esters; EM = emulsifier.

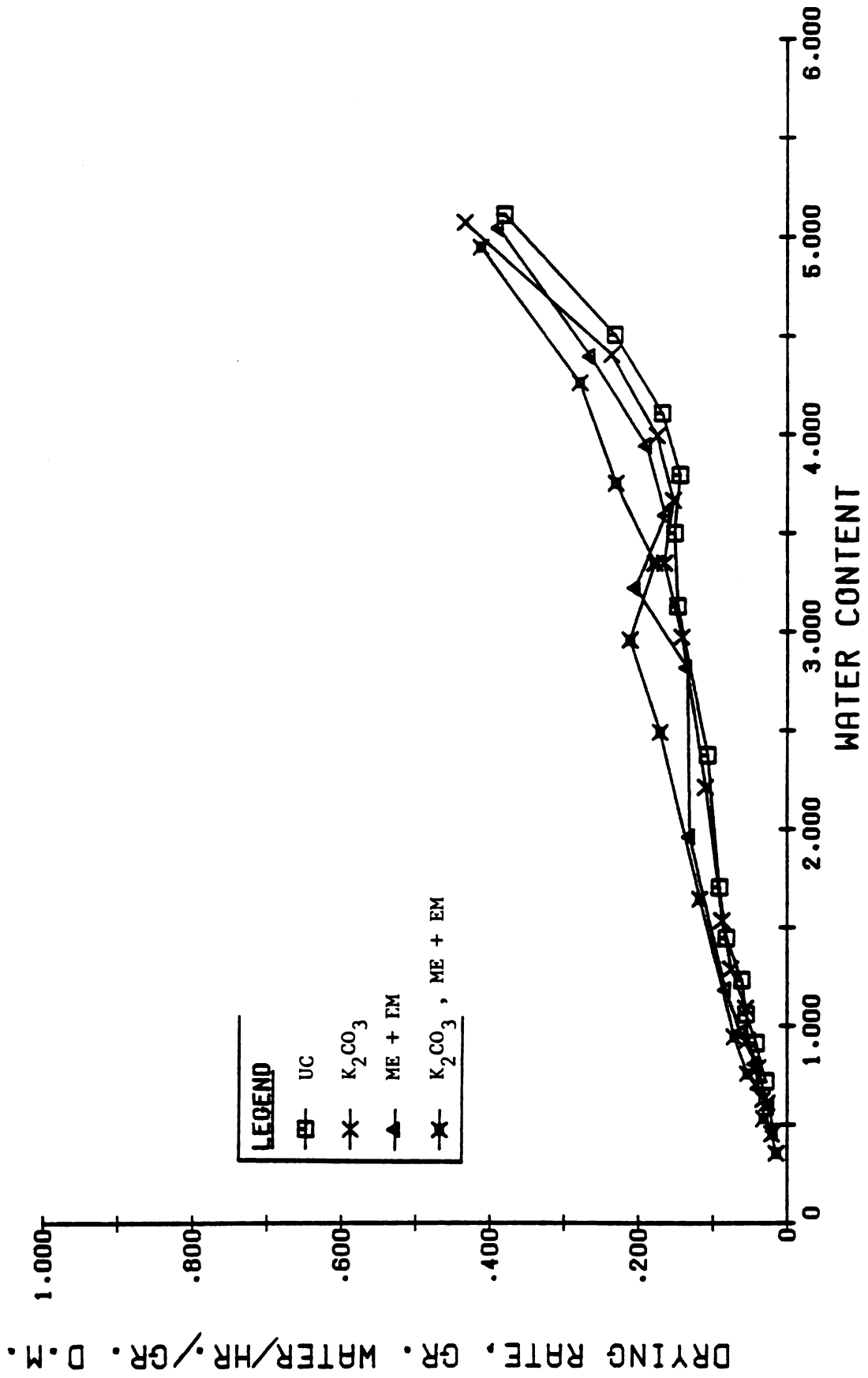


Figure 3.

of 5.0 (17% DM) (Figure 3). Rate of water loss for the K_2CO_3 treatment then declined rapidly and became similar to control at a WC of 3.0 (25% DM). Treatments containing ME maintained drying rates greater than control from WC 5.0 to 0.5 or 0.6 (63 or 67% DM).

These data indicate that ME increased Drt over a longer interval and broader range of WC than did K_2CO_3 . Green and Jagger (1977) found that tissue resistance to water loss increased as forage WC decreased. The data from both treated and control alfalfa presented in Figure 3 are consistent with that finding.

Five trials, discussed in a following section, which examined the effect of increasing amounts of ME applied to alfalfa under field conditions contain information pertinent to the present discussion. Data from these trials and trial F34 were used to compare the effectiveness of K_2CO_3 solutions and K_2CO_3 , ME emulsions supplying approximately 1 grME/kg forage in hastening drying. For each trial mean drying rates during days 1 and 2, DM content at the last weighing each day, and hours required to reach 75% DM are presented for untreated control, K_2CO_3 and K_2CO_3 , ME treatments in Table 10.

First day drying rates were greater than control in 4 out of 6 trials for K_2CO_3 treatment and in 5 out of 6 trials for ME plus K_2CO_3 treatment. Dry matter content at the last weighing for both days 1 and 2 was also greater than control for K_2CO_3 and ME plus K_2CO_3 treatments in 5 out of 6

Table 10. Drying Rates for the First and Second Days Following Treatment with Potassium Carbonate, Methyl Esters or a Combination of These Compounds.

Cutting and Trial		Treatment Description			Mean ^a DRT ⁱ		DM ^e at last weighing		Hours to 75% DM
		ME ^a gr/kg	K ₂ CO ₃ ^b M	EMC ^c %	Day 1	Day 2	Day 1	Day 2	
First Cutting									
F 21	1	0	0	0	.577	.067	36.5	59.5	>33
Init. DM ^f =	2	0	.2	0	.617	.070	38.0	61.0	>33
19.0%	4	.9	.2	.25	.603	.148	46.0	71.0	>33
F22									
Init. DM =	1	0	0	0	.276	.055	45.5	82.5	35.0
21%	2	0	.2	0	.311	.057	44.0	81.0	36.5
	4	.52	.2	.25	.301	.073	41.0	76.0	37.0
F 24									
Init. DM =	1	0	0	0	.269	.055	51.0	76.5	32.0
20%	2	0	.2	0	.264	.059	55.0	82.5	28.0
	4	.8	.2	.25	.287	.059	53.0	81.0	29.5
Second Cutting									
F29	1	0	0	0	.343	.121	36.1	69.0	>34
Init DM =	2	0	.2	0	.277	.120	37.9	69.0	>34
21%	4	.8	.2	.25	.313	.124	41.0	76.0	33.5

Table 10. Continued.

Cutting and Trial	ID	Treatment Description			Mean ^a DRT ⁱ		DM ^e at last weighing		Hours to 75% DM
		ME ^a gr/kg	K ₂ CO ₃ ^b M	EMC %	Day 1	Day 2	Day 1	Day 2	
Second Cutting									
F32	1	0	0	0	.139	.092	52.3	74.7	27.0
Init DM =	2	0	.2	0	.187	.078	63.4	88.9	26.0
28%	4	1.0	.2	.25	.193	.073	65.1	91.9	25.0
F34	1	0	0	0	.241	.072	57.4	75.0	29.0
Init DM =	2	0	.2	0	.292	.063	64.0	83.8	27.5
27%	5	1.4	.2	.25	.276	.052	68.5	81.0	27.5

^aME, gr/kg = methyl esters applied expressed as grams ME per kg fresh forage weight.

^bK₂CO₃, M = potassium carbonate molarity.

^cEM, % = emulsifier, % of spray solution by volume.

^dMean of 5 (F21, F22, F24) or 4 (F29, F32, F34) replicates.

^eDM = dry matter percent.

^fInit DM = Initial dry matter present at cutting.

ⁱDRT = Drying rate, loss of grams water per hour per gram DM.

(Table 10). Second day drying rates are related to first day drying and dew pickup over night. Both spray treatments increased second day drying rates in first cutting trials (F21, F22 and F24) while rates of water loss were lower or similar to control during the second day in trials performed during the second cutting (F29, F32 and F34). This may have been due to the generally higher DM content of second cutting forage at mowing and at the end of day 1.

Overall mean drying rates for each treatment over all six trials were greater for K_2CO_3 and ME plus K_2CO_3 treatments than for control during day 1 while during day 2 only the ME plus K_2CO_3 treatment had greater drying rates than control ($P < .01$), Table 11.

These data support the results of L14 (Figure 2) which indicate that the presence of ME increased DRT for a longer period of time than did K_2CO_3 alone. Additional investigations will be necessary to determine cost effectiveness of using these chemicals in commercial farming operations.

Table 11. Mean Drying Rate and Dry Matter Content During First and Second Days After Treatment of Alfalfa with Potassium Carbonate, or a Combination of Methyl Esters and Potassium Carbonate.

Treatment	Mean DRT ^d		DM ^d Content at Last Weighing	
	Day 1	Day 2	Day 1	Day 2
1. None	.308	.077 ^b	46.5	72.9
2. .2M K ₂ CO ₃	.325	.075 ^b	50.4	77.7
3. ME ^c + .2M K ₂ CO ₃	.329	.089 ^a	52.4	79.5

^{a,b}Subscripts differing (P<.01).

^c≈1 g ME/kg forage.

^dValue is mean of six trials.

Optimum Amounts of Methyl Ester Addition

In two laboratory trials ME and an emulsifier added to K_2CO_3 solutions and sprayed on alfalfa to supply from 1 to 4 grams ME/kg forage increased mean DM over untreated control ($P < .10$; L4 and $P < .01$ in trial L9; Table 12). Increasing amount of ME applied from 1 to 4 grams per kg produced a trend for a linear increase ($P < .09$) in mean DM as ME application was increased in L9 while nonsignificant increases in mean DM resulted, due to a high experimental error term, in trial L4 ($P > .20$). Response to increased amounts of ME appeared to maximize between 2 and 4 grams ME/kg although a test for curvilinearity of response was not significant ($P > .20$).

Field trial F7, also tested the effectiveness of 1 to 4 grams ME/kg added to a K_2CO_3 solution. The results were similar to L4 and L9 with 2.2 gr ME/kg being more effective than 1.2 gr ME/kg in increasing ($P < .05$) mean DM, while 3.4 gr ME/kg produced no further increase in mean DM ($P > .20$; Table 12). Mean DM content increased in a linear trend ($P < .01$) as ME application rate increased and no curvilinear response was detected ($P > .20$).

Results from laboratory trials performed during the winter of 1981 testing the efficacy of K_2CO_3 and ME alone and in combination, discussed in the previous section, prompted us to include a treatment containing only K_2CO_3 in all subsequent trials examining optimum levels of ME application.

Table 12. Measurements of Drying After Treatment of Alfalfa with Increasing Amounts of Methyl Esters in Potassium Carbonate Solutions.

Trial	ID	Treatment Description	Application Rate		Hours to Reach		Mean DM	Contrasts--Mean DM	
			%a	grME/kgb	40% DM	75% DM			
L4	1	None	0	0	17.8	>30	32.4	1 vs 2,3,4,5	P<.10
	2	2.9% ME .2M K ₂ CO ₃ + .25% X-77	3.4	1.0	11.8	27.6	39.1	2 vs 3	Nse
	3	5.7% ME .2M K ₂ CO ₃ + .25% X-77	3.0	1.7	11.8	28.0	39.5	3 vs 4	NS
	4	8.6% ME .2M K ₂ CO ₃ + .25% X-77	3.4	2.9	9.6	23.8	43.3	4 vs 5	NS
	5	11.4% ME .2M K ₂ CO ₃ + .25% X-77	3.6	4.1	10.0	25.6	42.2		
									88
L9	1	None	0	0	8.7	>21	45.1	1 vs 2,3,4,5	P<.01
	2	11.8% ME .2M K ₂ CO ₃ + .25% X-77 + .25% OA	1.0	1.0	4.9	17.6	54.1	2 vs 3	NS
	3	17.6% ME .2M K ₂ CO ₃ + .25% X-77 + .25% OA	1.0	1.5	4.5	14.0	57.5	3 vs 4	NS
	4	23.5% ME .2M K ₂ CO ₃ + .25% X-77 + .25% OA	1.0	2.0	5.2	15.4	55.7	4 vs 5	NS
	5	47% ME .2M K ₂ CO ₃	1.0	4.0	4.1	13.0	58.7	Linear Quadratic	P<.09 NS

Table 12. Continued

Trial	ID	Treatment Description	Application Rate %a	Rate grME/kgb	Weatherf Starting Dateg	Hours to Reachh			Contrasts--Mean DM		
						40% DM	75% DM	DM	1 vs 2,3,4	2 vs 3	3 vs 4
F7	1	None	0	0	25° C	3.3	>24	48.0	1 vs 2,3,4		P<.01
	2	5% ME .2M K ₂ CO ₃ + .25% X-77 + .25% OA	2	1.2	0 cm 69%	2.5	23.5	54.8	2 vs 3		P<.05
	3	10% ME .2M K ₂ CO ₃ + .25% X-77 + .25% OA	2	2.2	9.2 kph 7/23/80	1.5	22.5	59.9	3 vs 4		NS
	4	15% ME .2M K ₂ CO ₃ + .25% X-77 + .25% OA	2	3.4		2	23.3	58.1	Linear Quadratic		P<.01 NS
F24	1	None	0	0	25° C	6.0	32.0	48.6	1 vs 2,3,4,5		P<.208
	2	.2M K ₂ CO ₃	1.2	0	0.0 cm	5.0	28.0	51.5	2 vs 3,4,5		NS
	3	1% ME .2M K ₂ CO ₃ + .25% X-77	1.6	.16	49% 14.0 kph	5.0	29.0	51.5	3 vs 4		NS
	4	2% ME .2M K ₂ CO ₃ + .25% X-77	1.6	.32	6/17/81	6.0	29.5	50.6	4 vs 5		NS
	5	4% ME .2M K ₂ CO ₃ + .25% X-77	1.6	.64		5.0	28.5	52.1			
F22	1	None	0	0	22° C	6.0	35.0	47.1	1 vs 2,3,4		NS
	2	.2M K ₂ CO ₃	1.5	0	0.0 cm	7.0	36.5	45.1	2 vs 3,4		NS
	3	2% ME .2M K ₂ CO ₃ + .25% X-77	1.5	.29	53% 15.3 kph	6.0	34.0	47.0	3 vs 4		NS
	4	4% ME .2M K ₂ CO ₃ + .25% X-77	1.3	.52	6/5/81	9.0	37.0	42.3			

Table 12. Continued.

Trial	ID	Treatment Description	Application Rate %a	Weatherf Starting Date	and Hours to Reach 40% DM	h 75% DM	Mean DM	Contrasts--Mean DM	
F21	1	None	0	23° C	18.0	32.0	39.4	1 vs 2,3,4	P<.01
	2	.2M K ₂ CO ₃	1.7	0.0 cm	18.0	33.0	39.9	2 vs 3	P<.01
	3	2% ME .2M K ₂ CO ₃ + .25% X-77	1.1	60%	7.5	27.0	45.4	2 vs 4	P<.01
	4	4% ME .2M K ₂ CO ₃ + .25% X-77	2.2	16.8 kph 6/1/81	6.0	25.0	47.8	3 vs 4	P<.20
F29	1	None	0	24° C	25.0	>34	43.0	1 vs 2	NS
	2	.2M K ₂ CO ₃	3	0.0 cm	25.5	>34	43.3	2 vs 3,4,5	P<.10
	3	1% ME .2M K ₂ CO ₃ + .25% X-77	4	68%	6.0	>34	45.7	3 vs 4	NS
	4	2% ME .2M K ₂ CO ₃ + .25% X-77	4	14.6 kph 7/1/81	5.5	33.5	48.0	4 vs 5	NS
	5	6% ME .2M K ₂ CO ₃ + .25% X-77	6		5.5	34.0	47.9	Linear Quadratic	P=.111 NS

Table 12. Continued.

Trial	ID	Treatment Description	Application Rate % ^a	grME/kg ^b	Weatherf Starting Date ^g	and 40% DM	Hours to Reach ^h 75% DM	Mean DM	Contrasts--Mean DM
F32	1	Control	0	0	27° C	4.0	>27	49.3	1 vs 2, 3, 4, 5 P<.01
2nd cut	2	.2M K ₂ CO ₃	2.2	0	0.0 cm	3.5	27	57.1	2 vs 3, 4, 5 NS
	3	2% ME .2M K ₂ CO ₃ + .25% X-77 + .2% OA	2.2	.5	78% 9.7 kph 8/5/81	3.5	25	57.5	1 vs 2 P<.01 3 vs 4 NS 4 vs 5 P<.10
	4	4% ME .2M K ₂ CO ₃ + .25% X-77 + .25% OA	2.2	1.0		3.0	25	59.7	Linear NS Quadratic NS
	5	8% ME .2M K ₂ CO ₃ + .25% X-77 + .25% OA	2.2	2.0		3.5	27	55.9	

a,b,c,e See Table 1 for explanations.

d Mean of 5 replicates, F21 and F22, and of 4 replicates L4, L9, F24, F29 and F32.

f,g,h See Table 2 for explanations.

The addition of small amounts of emulsified ME to K_2CO_3 solutions supplying 0.16 to 0.64 gr ME/kg did not increase mean DM above treatment with K_2CO_3 alone in trial F24 or above control in F22 ($P>.20$, Table 12). On the other hand in trial F21 where K_2CO_3 alone did not increase ($P>.20$) drying, addition of 0.2 or 0.9 gr ME/kg further increased ($P<.01$) mean DM (Table 12).

Since ME K_2CO_3 emulsions supplying less than 0.5 gr ME/kg forage appeared to have more limited effectiveness above the use of a K_2CO_3 solution, trials F29 and F32 were designed to test ME applications of 0.5 to 3.0 gr ME/kg. Potassium carbonate alone increased ($P<.01$) mean DM in F32 but was not effective in F29 ($P>.20$, Table 12). Addition of ME hastened drying more effectively than did K_2CO_3 alone (43.3<45.7, 48.0, and 47.9 in F29 at $P<.01$), while only a non-significant increase was noted in F32 (57.1<57.5, and 59.7 at $P>.20$).

Application of 0.4 (F29) or 0.5 (F32) gr ME/kg produced a small increase in mean DM above K_2CO_3 treatment in F29 but had no effect in F32. Increasing application to 0.8 (F29) or 1.0 (F32) gr ME/kg increased mean DM (48.0>45.7 and 59.7>57.5 at $P>.20$ in trials F29 and F32 respectively) and decreased hours to 75% DM, but further increases to 2.0 (F32) or 3.6 (F29) gr ME/kg slightly depressed mean DM and increased hours to 75% DM. Increasing application of ME tended to increase mean DM in a linear trend ($P= .11$) in F29 but not in F32 ($P>.20$).

Curvilinear responses ($P > .20$) were not significant in either trial.

The minimum effective dose of ME when combined with K_2CO_3 and an EM, at solution application rates of 1 to 4% appears to be approximately 0.5 gr ME/kg, while the most effective rate is between 1 and 3 grams ME/kg. A trend towards a linear response to increased ME application was detected in 3 trials while a curvilinear response was not significant. This finding may be due to having only one treatment in each trial supplying more than 2 or 3 gr ME/kg.

Maximizing Coverage by Changes in Liquid Application Rate and Spray Pump Pressure

In two trials application rates of .2M K_2CO_3 solutions were increased from 2.3 to 3.3% (F26) or from 2.8 to 4.4% (F34), with no attempt being made to keep the weight of K_2CO_3 applied per kg forage constant. In both trials K_2CO_3 at either rate increased mean DM ($P < .01$ in F26, Table 8, and $P < .20$ in trial F34, Table 9) while no differences ($P > .20$) in mean DM content were detected between the low and high application rates.

These results are consistent with the work of Tullberg and Minson (1978) who also found no significant difference in drying of alfalfa due to increasing the application rate of .2M K_2CO_3 from 200 to 875 liter per hectare (approximately 0.8 to 3.7% of wet forage weight).

When ME plus an EM was added to a K_2CO_3 solution to supply approximately 1 gram (L3) or 2 grams (L5) ME/kg forage in spray volumes ranging from 1 up to 4% all treatments increased mean DM above that of untreated control ($P < .01$; Table 13). Increasing solution application rates from 0.87 to 1.3% (L3) or from 1.2 to 1.8% (L5) while maintaining a nearly constant application of active ingredients by changing concentrations, produced no increase in drying (treatments 3 vs 4 in trials L3 and L5; Table 13). Further increases in the volume of liquid applied from 1.3 to 3.0% or from 1.8 to 3.9% did produce a large but non-significant increase ($P > .20$) in mean DM (47.5 > 43.8 in L3 and 51.6 > 45.9 in trial L5; Table 13).

In three field trials where 1.2 grams (F35) or 2 grams (F15 and F18) ME per kg forage were applied at liquid application rates of 1 to 4%, all treatments increased mean DM over untreated control ($P < .01$; Table 13). Increasing liquid application rate from 1 to 2% produced a small non-significant increase in mean DM while increasing solution application rate from 1.5 to 3.0% (F35) or from 2 to 4% (L15 and L18) increased mean DM ($P < .05$).

The application of 9.4% distilled water did not hasten drying (Weighart et al., 1980), thus increased mean DM from a larger volume of liquid is most likely due to a more complete or more even coverage of the sprayed chemicals on the forage.

For practical field use low spray volumes of 15 to 20 gallons per acre would be desirable for ease of operations and

minimization of labor costs. A typical yield of 1.5 tons DM per acre during second cutting would require 18 gallons solution per acre to attain a 1% application rate of liquid to fresh forage. Data from F18 and F15 (Table 13) indicate that an application rate of 2% (36 gallons/acre) supplying 2 gr ME/kg decreased time to 40% DM from 36 to 4 hours (F18) and from 24 to 4 hours in F15, while increasing liquid application further to 72 gallons per acre (GPA) (4%) reduced interval to 40% DM by another 1 to 2 hours in both trials. In trial F35 hours to 75% DM were 26 for control and 7 for alfalfa treated with a solution supplying 1.2 gr ME/kg at a 15 GPA (1.5%) liquid application rate. Doubling application rate to 30 GPA (3%) decreased interval to 75% DM to 6 hours.

In three field trials spray treatments of 15 or 36 gallons of liquid per acre increased mean DM content and decreased interval to 40 or 75% DM by an average of 24 hours compared to untreated control, while further reductions of 1 to 2 hours were obtained by increasing rate of liquid application to 30 or 70 GPA.

These data indicate that while satisfactory increases in drying of cut alfalfa can be obtained with liquid application rates of 1 to 2%, larger volumes of water can be used to obtain a greater effect from the same amount of applied chemicals. Experiments designed to explore other possible methods of liquid application which could maximize coverage with smaller volumes of water appeared warranted.

Increasing spray pump pressure decreases mean droplet size (Spray System Co., 1977) this could increase distribution of the spray material but could also increase loss of spray due to drift.

In two trials increasing spray pump pressures from 30 to 50 Psi (F16) or to 60 Psi (F18) at liquid application rates of 2 or 3% produced no increase in mean DM ($P > .20$; Table 13). Visual examination of spray patterns using solution containing floricine dye showed similar extent of coverage for both pressures with a finer droplet size resulting from the higher pressure in F16 while coverage of leaves and stems was superior for the lower pressure in L18.

These trials indicate that spray pressures of 30 Psi are sufficient when flat fan Tee jet nozzle tips are used. Further research on type and location of nozzles and spray bars is desirable.

Table 13. Drying of Alfalfa as Influenced by Changes in Amounts of Applied Liquid or Spray Pump Pressure.

Trial ID	Treatment Description	Application Rate %a	Weatherf Starting Date	Hours to Reach ^b		Mean ^d	Bonferroni t	
				40% DM	75% DM		Contrasts	Mean DM
L3								
1	None	0	0	12.0	30.0	37.0	1 vs 2,3,4	P .01
2	3% ME .2M K ₂ CO ₃ + .2% X-77	3.0	.9	5.6	21.4	47.5	2 vs 3	NS ^e
3	6% ME .4M K ₂ CO ₃ + .4% X-77	1.3	.8	7.2	23.0	43.8	3 vs 4	NS
4	12% ME .8M K ₂ CO ₃ + .8% X-77	.87	1.0	7.6	25.0	43.7	2 vs 4	NS
							2 vs 3,4	NS
L5								
1	Control	0	0	10.6	24	35.7	1 vs 2,3,4	P .01
2	5% ME .2M K ₂ CO ₃ + .2% X-77	3.9	1.95	4.4	13.6	51.6	2 vs 3	NS
3	10% ME .4M K ₂ CO ₃ + .4% X-77	1.8	1.8	5.9	18.8	45.9	3 vs 4	NS
4	20% ME .8M K ₂ CO ₃ + .8% X-77	1.2	2.4	6.0	17.6	47.6	2 vs 3,4	NS

Table 13. Continued.

Trial	ID	Treatment Description	Application Rate %a	Weather ^f Starting Dateg	Hours to Reach ^h 40% DMC 75% DM	Means ^d		Bonferroni t Contrasts--Mean DM
						DM	DRt	
F35	1	None	0	27° C	1.0	26.0	59.1	1 vs 2,4 P<.01
	2	4% ME .2M K ₂ CO ₃ + .25% X-77		0.0 cm				1 vs 3 NS
		+ .25% OA	3.0	55%	0.5	6.0	67.8	2 vs 4 P<.05
	3	4% ME .2M K ₂ CO ₃ + .25% X-77		8.8 kph	1.0	25.0	61.8	2 vs 3 P<.01
		+ .25% OA	1.5	8/20/81				
	4	8% ME .2M K ₂ CO ₃ + .25% X-77			1.0	7.0	64.1	
		+ .25% OA	1.5					
F15	1	None	0	18° C	24	>33	36.6	1 vs 2,3,4 P<.01
	2	5% ME .2M K ₂ CO ₃ + .25% X-77	4	0 cm	3	>33	49.4	2 vs 3 P<.05
				77%				3 vs 4 NS
	3	10% ME .4M K ₂ CO ₃ + .4% X-77	2	13.2 kph	4	>33	44.6	2 vs 4 P<.01
				9/7/80				
	4	20% ME .8M K ₂ CO ₃ + .8% X-77	1		5	>33	41.3	
F18	1	None	0	20° C	26.5	>41.0	31.0	1 vs 2,3,4 P<.01
	2	5% ME .2M K ₂ CO ₃ + .25% X-77	4 ⁱ	0.0 cm	4.0	>41.0	44.0	2 vs 3,4 P<.05
				79%			.304	3 vs 4 NS
	3	10% ME .4M K ₂ CO ₃ + .5% X-77	2 ^j	19.7 kph	6.0	>41.0	39.8	.267
				9/18/80				
	4	10% ME .4M K ₂ CO ₃ + .5% X-77	2 ⁱ		6.0	>41.0	39.9	.257

Table 13. Continued.

Trial ID	Description	Application Rate % ^a grME/kg ^b	Weather ^f Starting Date ^g	Hours to Reach ^h		Means ^d DM	DRT	Bonferroni t Contrasts--Mean DM	
				40% DM ^c	75% DM			1 vs 2,3,4	2 vs 3,4
F18	1	-	24° C	-	>75	44.9	.164	1 vs 2,3,4	P<.01
Redry- ing af- ter rain	2	-	.25 cm	-	73.0	63.0	.171	2 vs 3,4	P<.2
	3	-	80%	-	>75	55.3	.176	3 vs 4	NS
	4	-	15.0 kph	-	>75	57.5	.171		
			9/20/80						
F16	1	None	21° C	25	>30	33.6		1 vs 2,3	P<.01
2	5% ME .2M K ₂ CO ₃ + .25% X-77 ²	0	0.0 cm						
	2.6 ⁱ	1.3	80%	6.5	>30	39.1		2 vs 3	NS
3	5% ME .2M K ₂ CO ₃ + .25% X-77 ²	2.4 ^k	11.5 kph	5.0	>30	40.3			
			9/5/80						

a,b,c,e See Table 1 for explanations.

d,f,g See Table 2 for explanations.

ⁱ Spray pump pressure 30 psi.

^j Spray pump pressure 60 psi.

^k Spray pump pressure 50 psi.

Chemical Treatment of Different Forage Species
and Methods of Expressing and Evaluating Treatment Effects

Interpretation of results from drying trials with different forage species may be complicated by differences in initial moisture content or differential responses to chemical treatment. Several methods were used to express differences in drying, due to chemical treatment, within and between three legume species in trial L17. Discussion of the data and validity of the methods of expression follow.

One way analysis of variance for the repeat measure split plot showed that spray solutions of ME, K_2CO_3 and an emulsifier (EM) increased mean DM of red clover (RC) ($P < .05$), alfalfa (Alf), and birdsfoot trefoil (Bft) ($P < .01$), above respective controls for each species, L17, Table 14.

Initial DM contents of the three legumes were 29, 28, and 20% for RC, Alf and Bft, respectively (Table 14). Time required for sprayed forage to attain 40% DM was reduced by 2.5, 4.0 and 7.0 hours for RC, Alf and Bft compared to respective controls. Although these values can give a good indication of differences in relative drying rates between treated and untreated forage within species, they have limited meaning for comparisons between species which have different initial DM content. In this case Bft initially contained much more water per gram DM than did RC or Alf and thus would be expected to require a longer interval to reach a specified DM%.

Table 14. Description of Drying Parameters for Control and Chemically Treated Red Clover (RC), Alfalfa (Alf) and Birdsfoot Trefoil (Bft).

Trial ID	Treatment Description & Species	Application Rate		Initial		Hours to Reach		Interval Between 30 & 60% DM	Mean ^d DM	Mean Drt ^f		Contrasts	
		%	grME/Kgb	DM%	DM%	40% DM	75% DM			0-10 hr	10-23 hr	Mean DM	Mean Drt 0-10 hr 10-23
L17	1 None-RC ⁱ	0	0	29	6.5	>23	18.0	45.0	.165	.053	1 vs 2	P<.05	P<.01 NSE
	2 Treated ^h -RC	2	1		4.0	>23	13.5	51.2	.205	.038	3 vs 4	P<.01	P<.01 NS
	3 None Alf ^j	0	0	28	6.0	>23	16.0	46.6	.185	.053	5 vs 6	P<.01	P<.01 P<.05
	4 Treated Alf	2	1		2.0	14	5.75	62.6	.260	.043	1 vs 3	-	NS -
	5 None Bft ^k	0	0	20	12.0	>23	17.0	38.6	.205	.095	1 vs 5	-	P<.01 -
	6 Treated Bft	2	1		5.0	20.0	6.0	52.1	.389	.044	3 vs 5	-	NS -
											2 vs 4	-	P<.01 -
											2 vs 6	-	P<.01 -
											4 vs 6	-	P<.01 -

a,b,c,e See Table 1 for explanation.

^d Mean of 3 replicates.

^f Drt = Drying rate loss of grams water/hr/grDM.

^g Dry Matter content of each species at cutting.

^h Treatment = 5% ME .2M K₂CO₃ + .25% X-77 + .25% OA.

ⁱ RC = Red Clover.

^j Alf = Alfalfa.

^k Bft = Birdsfoot Trefoil.

Another method of expressing speed of moisture removal in this trial is to calculate the time interval between 30 and 60% DM (Table 14), this eliminates the differential effect of initial DM content. Sprayed Alf and Bft required only 5.75 and 6.0 hours to increase from 30 to 60% DM compared to 16.0 and 17.0 hours for their respective untreated controls. Sprayed and unsprayed RC needed 13.5 and 18.0 hours to increase in DM content from 30 to 60%. Thus spray treatment decreased this time interval to 35% of control for Alf and Bft but only to 75% of the control value for RC. This method of expression differentiates between species within a given range of DM content but it does not provide information about species differences during the early and final stages of drying.

When trial L17 was analyzed as a factorial a three-way interaction involving species, chemical or no chemical treatment and weighing period was detected ($P < .01$). Untreated material of each species exhibited a nearly linear increase in DM content over the entire 23 hour trial. However non-parallel trends in the drying of sprayed Alf, Bft and RC were observed (Figure 4). Drying curves for sprayed Alf and Bft were non-linear, increasing much more rapidly in DM content during the first 10 hours than from 10 to 23 hours post cutting. In contrast sprayed RC had a much less pronounced difference between the first 10 and last 13 hours of drying (Figure 4).

Large treatment differences were established during the first 10 hours, therefore mean drying rates, determined as loss

Figure 4. Dry matter content of three legume species during 23 hours of drying with or without chemical treatment at cutting (Trial L17). RC = red clover; Alf = alfalfa; Bft = birdsfoot trefoil; S = sprayed with a solution of 5% ME + .2M K_2CO_3 + .25% X-77 + .25% OA.

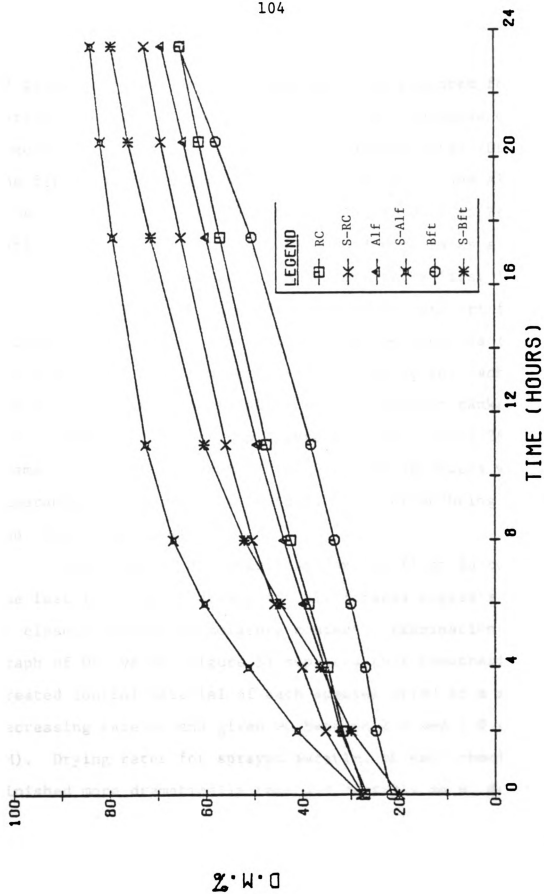


Figure 4.

of grams water per hour per gram DM, were compared for this period to evaluate species differences and response of each species to chemical treatment. Mean drying rates (Drt) during the first 10 hours were similar for control RC and Alf but were less than for control Bft ($0.17, 0.19 < 0.21$ at $P < .01$; Table 14). Spray treatment increased drying rates above respective controls for each species during the first 10 hours ($P < .01$), on the other hand, from 10 to 23 hours Drt for treated forages was less than for their respective controls ($P > .20$ for Alf and RC and $P < .05$ for Bft). Drying rates for each species during the first 10 hours after spray treatment ranked from the slowest to the most rapid were RC (.205) < Alf (.260) < Bft (.389) grams water lost per gram DM ($P < .01$). These values were considerably less during the 10 to 23 hour period being .038, .043 and .044 respectively.

Faster rates of water loss for the first 10 compared to the last 13 hours of drying for all forages suggests that Drt is closely related to moisture content. Examination of a graph of Drt vs WC (Figure 5) supports this hypothesis. Untreated control material of each species dried at a similar but decreasing rate at any given WC between 2.0 and 1.0 (33 to 50% DM). Drying rates for sprayed material of each species diminished more dramatically than did controls as WC decreased. Sprayed Alf had the greatest Drt between WC 2.0 and 0.5 compared to all other treatments and maintained a Drt above controls

Figure 5. Drying rates between water contents of 3.5 and 0.5 for three legume species with or without chemical treatment (Trial L17). RC = red clover; Alf = alfalfa; Bft = birdsfoot trefoil; S = sprayed with solution of 5% ME + .2M K_2CO_3 + .25% X-77 + .25% OA.

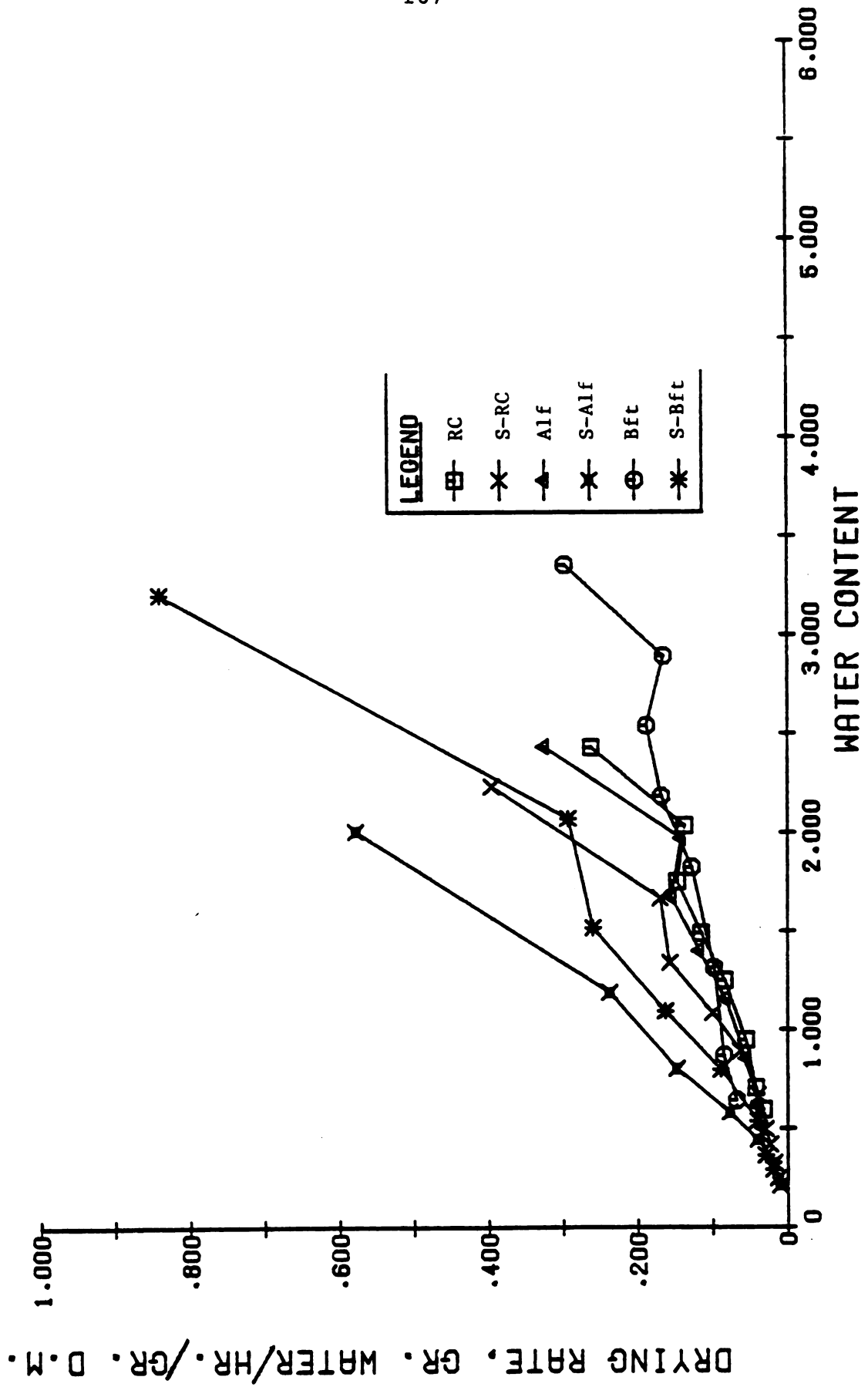


Figure 5.

(all unsprayed forages) throughout this entire range of WC. Sprayed RC had the smallest increase in Drt compared with controls and rates of water loss for sprayed RC because similar to controls at a WC of 0.8. Increases in Drt for treated Bft were intermediate in both amplitude and duration with a WC of between 2.0 and 0.5.

Graphical expression of moisture content at any time post cutting as a % of initial water remaining depicts the relative amounts of moisture lost from each species at a given time. These values are plotted on a semilog scale in Figure 6. Priepke and Bruhn (1970) expressed drying of alfalfa in a chamber held at 36° C and 35% relative humidity in this manner and used the slope of the linear portion of the drying curve to calculate a drying rate constant. Data for L17 plotted this way had non-linear trends for several treatments. This indicates that the relationship between log of % H₂O remaining and time post cutting was not linear. Thus the slope of this line cannot be considered as a total trial "drying rate constant."

Drying rates are dependent on initial DM content of cut forage as is demonstrated in Figure 5. This is contradictory to the assumption made by Priepka and Bruhn (1970) that initial DM content did not have an effect on subsequent drying rates. At the seventh weighing in Trial L17 sprayed Bft attained a % of initial water remaining less than that of

sprayed Alf (Figure 6). On the other hand, rates of water loss per gram of DM were similar for these two treatments during this weighing period (Figure 5) indicating that the use of the slope of % of initial water remaining over time as an estimate of a drying rate constant may lead to erroneous conclusions about the drying rate of forages having different initial DM contents.

These data indicate that chemical treatment significantly increased mean DM and mean Drt during the first 10 hours of drying in the three legume species studied. Effectiveness of spray treatment was less on RC than on Alf or Bft possibly due to 1) interception of spray material by hairs thickly covering leaf and stem surfaces of RC, 2) unmeasured differences in leaf to stem ratios, and 3) different surface area to mass relationships.

The use of time interval to a specified DM%, mean DM or Drt over a given period of time or percentage of initial water remaining to compare drying between forages which have different initial DM contents can be misleading. More useful information can be provided by expressing results as 1) time interval between two specified DM contents, or 2) Drt at a specified WC.

Treatment of brome grass (BG), orchard grass (OG) or a mixture of these two grasses with spray solutions containing ME, K_2CO_3 and X-77 failed to increase mean DM or mean drying rate Drt in four trials ($P > .20$) L12, L26, L32, and L34 (Table 15).

In Trial L12 the addition of 1% crop oil concentrate (COC) to a ME K_2CO_3 , X-77 solution tended to increase ($P < .10$)

Figure 6. Percentage of initial water remaining in three legume species with or without chemical treatment during 23 hours of drying (Trial L17). RC = red clover; Alf = alfalfa; Bft = birdsfoot trefoil; S = sprayed with solution of 5% ME + .2M K_2CO_3 + .25% X-77 + .25% OA.

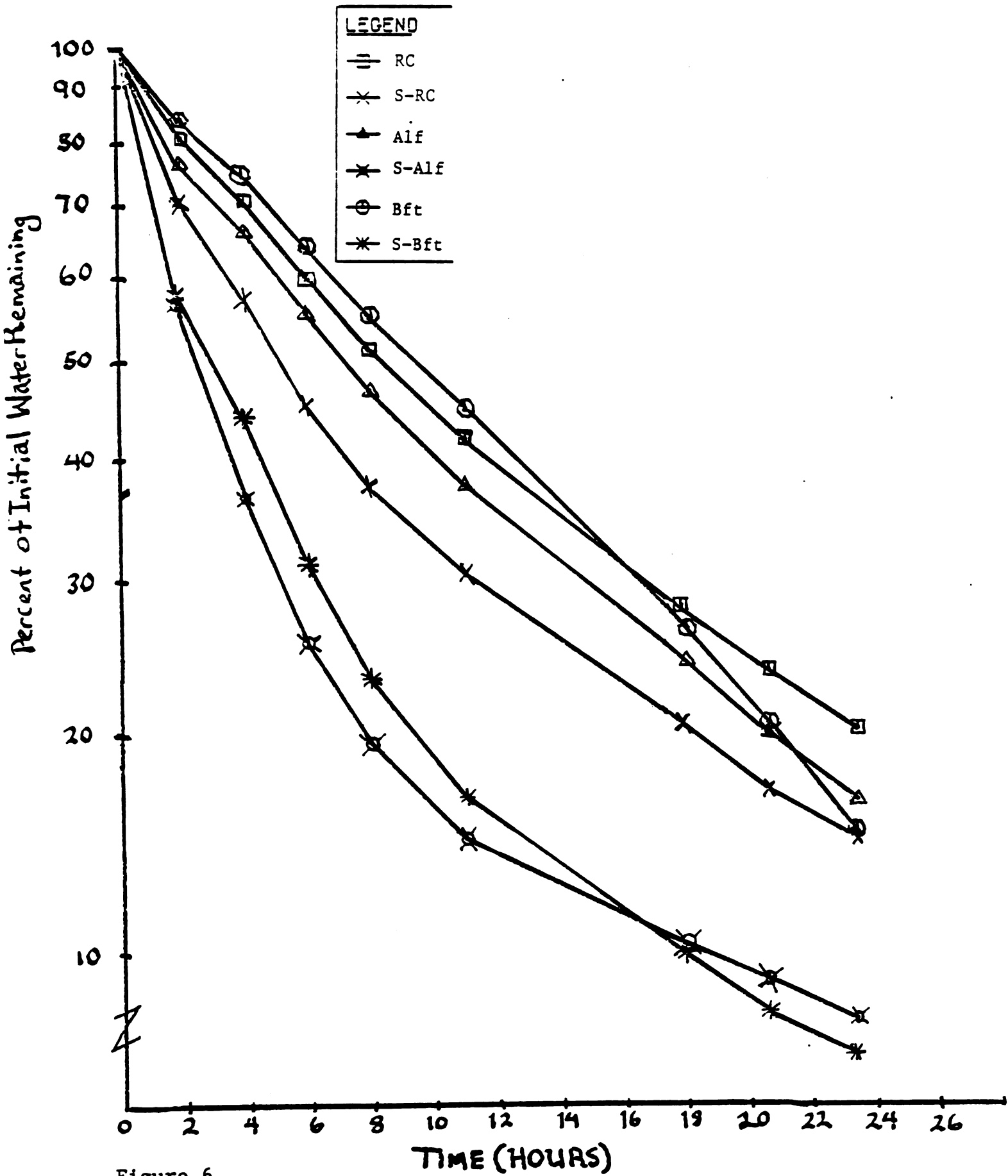


Figure 6.

mean DM of vegetative BG above control while in trial L26 a BG, OG mixture treated with COC alone or in combination with the three component solution had mean DM and Drt values similar to control ($P>.20$).

Brome grass at seed stage (L32) and at a vegetative stage of maturity (L34) had greater initial DM contents than did alfalfa at 20% bloom (L32) or alfalfa at 10% bloom from the same field in trial L34 (39>20, and 23>21% respectively; Table 15). Hours to reach 75% DM were similar for both treated and untreated mature BG and treated Alf (48 hours in L32; Table 15) while untreated alfalfa had reached only 60% DM in 48 hours of drying. Intervals for control BG and sprayed BG and Alf to increase from 40 to 60% DM were also similar, 11.0, 10.5 and 12.5 hours respectively while unsprayed Alf required 16.0 hours. In trial L34 both treated and control BG reached 40% DM one hour before treated Alf and 2 hours before control Alf. Brome grass treatments retained this advantage and reached 75% DM in 33 to 36 hours while treated Alf required 44 hours and control Alf did not reach this DM content in 45 hours. Interval between 40 and 60% was 18.5 and 16.5 hours for control and sprayed BG and 21.0 and 13.0 hours for control and sprayed Alf respectively.

Mean Drt was greater ($P<.01$) for sprayed and unsprayed Alf than for treated or untreated BG (F32 and F34; Table 15). Faster rates of water loss but longer intervals to 40 and 75% DM for Alf are due to the lower initial DM content of Alf compared to BG used in these trials.

Table 15. Measurements of Drying Responses of Bromegrass (BG), Orchard Grass (OG), and Alfalfa (Alf) at Different Maturities or Grown Under Different Conditions to Chemical Treatment.

Trial	ID	Treatment Description and Species	Application Rate %a	Initial ^g DM	Hours to Reach 40% DM ^c	75% DM	Means ^d			Contrasts		
							DM	Drt ^f	Mean	DM	Mean	Drt
L12	1	None Vegetative BG	0	0	5.8	27.4	54.4	.112	1 vs 2	NS ^e		NS
	2	Treated ^h Vegetative BG	2	1	7.5	28.6	52.7	.107	1 vs 3	P<.10		NS
	3	Treated ^h + 1% COC ⁱ Vegetative BG	2	1	5.3	22.4	58.5	.100				
L26	1	None Vegetative BG + OG	0	0	13.5	>29	38.8	.157	1 vs 2	NS		NS
	2	Treated ^h Vegetative BG + OG	2	1	16.5	>29	35.5	.161	2 vs 3	NS		NS
	3	Treated ^h + 1% COC Vegetative BG + OG	2	1	14.0	>29	37.8	.166	3 vs 4	NS		NS
	4	1% COC Vegetative BG + OG	2	0	15.0	>29	37.2	.164				
L32	1	None, Mature BG	0	0	0	48	58.8	.034	1,2 vs 3,4	P<.01		P<.01
	2	Treated ^h , Mature BG	2	1	0	48	59.4	.034	1 vs 2	NS		NS
	3	None, Alf 20% Bloom	0	0	24.0	>48	37.8	.084	3 vs 4	P<.05		P<.01
	4	Treated ^h , Alf 20% Bloom	2	1	14.5	48	48.4	.109				
L34	1	None, Vegetative BG	0	0	8.1	32.7	54.5	.100	1,2 vs 3,4	P<.05		P<.01
	2	Treated ^h , Vegetative BG	2	1	8.8	36.0	53.7	.099	1 vs 2	NS		NS
	3	None, Alf 10% Bloom	0	0	11.0	>45	45.3	.112	3 vs 4	P<.20		NS
	4	Treated ^h , Alf 10% Bloom	2	1	9.7	43.8	51.2	.120				

Table 15. Continued.

Trial ID	Treatment Description and Species	Application Rate % ^a grVE/kg ^b	Initial ^c DM	Hours to Reach 40% DM ^c	75% DM	Means ^d		Contrasts	
						DM	Drt ^f	Mean DM	Mean Drt
L11	1 Control Field Alf	0	26.5%	11.2	>33	47.2	.087		
Fall	2 Treated ^h Field Alf	2		6.4	24	56.5	.105	1 vs 2	P<.01
	3 Control Greenhouse Alf	0	18.2%	24.2	>33	32.3	.128	3 vs 4	P<.01
	4 Treated ^h Greenhouse Alf	2		11.9	>33	46.8	.159		
L16	1 Control Field Alf	0	14.2%	39	>44	29.0	.138		
Spring	2 Treated ^h Field Alf	2		14	>44	47.0	.184	1 vs 2	P<.01
	3 Control Greenhouse Alf	0	16.3%	16	40	46.9	.147	3 vs 4	P<.05
	4 Treated ^h Greenhouse Alf	2		12	28	54.2	.153		NS

^{a,b,c,d,e} See Table 1 for explanation.

^{f,g,h} See Table 14 for explanation.

ⁱ OOC = crop oil concentrate.

Because of these differences in initial DM content drying rates at a given WC can provide a more meaningful comparison of actual species differences. Between WC 3.0 (25% DM) and 0.5 (6.7% DM) BG generally had greater drying rates than did untreated Alf (L32 and L34, Table 16). Spray treatment of Alf increased drying rates at any given WC between 3.0 and 0.5 resulting in values similar to those for BG (Table 16).

Chemical treatment of BG or BG OG mixtures at two maturities did not consistently increase mean DM or Drt above controls, while treatment of alfalfa was effective in increasing drying at both maturities. Lack of effectiveness for chemical treatment of the two grasses studied may be due to differences in the cuticular wax structure and composition of alfalfa and the grasses.

At a given WC, BG dried more rapidly than did untreated alfalfa while sprayed Alf dried at a rate similar to BG. These data suggest that spray treatment of alfalfa, grass mixtures would tend to equalize drying rates of the two species and provide a more uniformly dried product for baling.

In two trials spraying alfalfa grown under "greenhouse" or field conditions with a solution of ME, K_2CO_3 and an emulsifier, increased mean DM and generally increased drying rates above respective untreated controls ($P < .05$ in L11 and L16; Table 15). Initial DM content of fall grown field and "greenhouse" grown alfalfas were 26.5 and 18.2% respectively while spring grown field and "greenhouse" alfalfas were 14.2 and 16.3% DM (Table 15).

Table 16. Drying Rates of Brome Grass, Orchard Grass and Alfalfa at Given Water Contents Between 5.0 to 0.5.

Treatment		Drying Rate ^h at WC ^c					
Trial ID ^a & Species		5.0 (17% DM)	4.0 (20% DM)	3.0 (25% DM)	2.0 (33% DM)	1.0 (50% DM)	0.5 (67% DM)
L32	1 BG	-	-	-	-	.05	.02
	2 S ^d -BG	-	-	-	-	.05	-
	3 Alf	-	-	.11	.06	.03	.01
	4 S-Alf	-	-	.26	.13	.05	.01
L34	1 BG	-	-	-	.17	.07	.04
	2 S-BG	-	-	.31	.18	.07	.03
	3 Alf	-	-	.28	.12	.05	.01
	4 S-Alf	-	-	.35	.17	.06	.03
L16	1 Field Alf	.30	.14	.12	.075	-	-
	2 S-Field Alf	.80	.51	.28	.16	.075	.015
	3 GH ^e Alf	-	.41	.19	.13	.10	.03
	4 S-GH Alf	-	.54	.30	.16	.10	.025
L11	1 Field Alf	-	-	-	.10	.06	.03
	2 S-Field Alf	-	-	-	.19	.085	.03
	3 GH Alf	-	.18	.12	.10	.05	-
	4 S-GH Alf	-	.33	.26	.20	.085	.03

^aSee Table 14 for treatment description.

^bDrying rate = loss of grams water/hr/gram DM.

^cWC = Water content grams water/grams DM.

^dS = Sprayed with 5% ME .2M K₂CO₃ + .25% X-77 + .25% OA.

^eGH = Greenhouse.

To eliminate initial DM as a complication in interpretation of the data Drt at given WC were calculated and are presented in Table 16. Drying rates were similar for sprayed material from either environment from a WC of 2.0 to 0.5 (L11) and from 4.0 to 0.5 (L16). Control alfalfa from both environments dried at similar rates between WC 2.0 and 0.5 in L11 while in L16 control field material dried at a much slower rate than untreated "greenhouse" alfalfa from a WC of 4.0 to 2.0 (Table 16). Faster drying of control greenhouse alfalfa than field grown alfalfa in L16 may have been due to its higher leaf to stem ratio and smaller stem length (Table 17), while equalization of Drt at a given WC by spray treatment may indicate that differences in epicuticular wax layers may have a greater effect on rate of moisture removal than differences in plant morphology.

Low temperature, low relative humidity and long photo period have all been shown to increase epicuticular wax production (Wilkinson and Kasperbauer, 1980, and Pallard and Kozlowski, 1980). None of these environmental factors were well standardized or monitored in these trials making interpretation of the results highly speculative.

Data from these trials do indicate that the use of field or greenhouse grown alfalfa for laboratory drying trials can result in similar responses to chemical treatment, validating the use of greenhouse grown alfalfa as a model for screening chemicals to hasten drying.

Table 17. Characteristics of Alfalfa Grown Under Greenhouse and Field Conditions

Trial ID	Growth Environment	Stem Length	% Bloom	Leaf to Stem Ratio		Initial DM%	
				Fresh Basis	DM Basis	Leaf	Stem
L11	1,2 Field Growth 8/25/81 to 10/23/81	-	None	-	-	-	-
	3,4 Greenhouse 9/4/81 to 10/23/81	-	10%	-	-	-	-
L16	1,2 Field Growth 4/15/81 to 5/29/81	60 cm	10%	0.7:1	0.8:1	19.3	16.0
	3,4 Greenhouse 5/9/81 to 5/29/81	20 cm	10%	1.1:1	1.3:1	19.9	16.3

Further trials examining drying of forages grown and dried under different, controlled environmental conditions could help explain differences in drying time to baling for the first and subsequent cuttings of alfalfa during the growing season, and deserves further study.

Drying of Alfalfa in Swaths or Windrows Under Variable Field Weather Conditions

In two trials alfalfa drying in 2.2 meter-wide swaths attained greater mean DM content than did material in 1.0 meter-wide windrows ($P < .05$; in F3) and ($P < .01$ in F9; Table 18). Spray treatment of swaths or windrows failed to increase mean DM above respective untreated controls in both trials ($P > .20$). This lack of treatment effectiveness may have been due to low solution application rates in F3 and to light rain showers 4 hours post cutting in F9.

Swathed alfalfa had reached 32% DM at the last weighing before rain while windrows were only 26% DM in F9. A total of .68 cm rain fell during the afternoon and first night decreasing DM content of both swaths and windrows to 25%. Drying conditions were favorable the second day and swathed treatments reached 55 to 57% DM while windrows reached only 45% DM. During the second night the drier swathed forage picked up more moisture from dew than did windrows reducing the DM content to 47 and 44% respectively. Final DM content of swaths were greater than for windrows (70 to 75% 65 to 66% DM), at 49 hours post cutting. Drying rates for swaths were consistently greater

Table 18. Measures of Drying for Chemically Sprayed and Unsprayed Alfalfa That Was Left in a Swath or Windrow After Mowing.

Trial	ID	Treatment Description	Application Rate		Starting Date ^h & Weather ^g	Hours to Reach ^h		Mean ^d		DM	Contrasts--Mean DM	
			%a	grME/kgb		40% DM	75% DMC				1 vs 3,4	2 vs 5
F3	1	Untreated swath ^f	0	0	6/24/81	20	47	51.5	2,5 vs 1,4	P<.05		
	2	Untreated windrows	0	0	29° C	22	>48	45.5	2 vs 5	NS		
	3	10% ME .2M K ₂ CO ₃ + .25% X-77-swath	2	1	0.0 cm	20	>48	51.7	1 vs 3,4	NS		
	4	20% ME .4M K ₂ CO ₃ + .5% X-77-swath	1	1		20	48	50.3				
	5	20% ME .4M K ₂ CO ₃ + .5% X-77-windrow	1	1		25	>48	39.6				
F9	1	Untreated Swath	0	0	7/29/81	24	>49	43.4	1,3 vs 2,4	P<.01 ^o		
	2	Untreated Windrow	0	0	25° C	28	>49	38.2	1 vs 3	NS		
	3	5% ME .2M K ₂ CO ₃ + .25% X-77			0.68 cm				2 vs 4	NS		
	4	5% ME .2M K ₂ CO ₃ + .25% X-77	2	1	84% 12.5 kph	24	49	44.5				
		+ .25% OA Windrow	2	1		28	>49	38.0				

a,b,c,e see Table 1 for explanation.
d Mean of 5 replicates.
g,h see Table 2 for explanation.
r swath 2.0 to 2.3 meters wide.
s Windrows 1.0 meter wide.

than for windrows on each day and mean rates of water loss for the entire trial were significantly greater for swaths ($P < .01$ in F9; Table 19).

These results support the findings of Thierstein (1966), Barrington and Bruhn (1970) and Dale (1979) who reported that drying of windrowed forages was slower than for swathed material. Less exposed surface area for interception of solar radiation and increases in relative humidity within bulked forage appear to be two important factors limiting plant drying in windrows. The generally lower moisture content and larger exposed surface area of swaths may explain why swaths absorbed larger amounts of dew or rain.

In another trial (F18) initial drying of swaths treated with ME, K_2CO_3 emulsions and untreated control swaths was compared to redrying of the same forage after .25 cm rain (Table 13). Rain at 41 hours post cutting reduced the DM content of treated swaths from an average of 53% down to 46% and reduced DM of untreated material from 45 to 37%. Treated swaths maintained a DM content greater than control throughout the trial and at trial termination (74 hours post cutting) the treated swaths ranged from 68 to 78% DM compared to 58% for the untreated control.

Drying rates were much greater for treated swaths during the first day of drying but decreased below rates for control swaths the second day (Table 19) due to the much higher DM content of the treated material. During the second night .25 cm rain fell. Drying rates the third day were again greater for treated swaths (averaging $.172 > .164$ for treated and control

Table 19. Drying Rates of Alfalfa Before and After Dew and Rain in Two Field Trials.

Trial	Structure ^a	ID ^b	Drying Rates			Mean ^e
			First Day	Second Day	Third Day	
			-----Change in gm water/hr/gr DM -----			
F9	Swath	1	.601	.269 ^c	.126	.162 ^x
	Sf-Swath	3	.611	.264 ^c	.124	.175 ^x
	Windrow	2	.368	.234 ^c	.135	.140 ^z
	S-Windrow	4	.257	.231 ^c	.14	.127 ^z
F18	Swath	1	.385	.132	.164 ^d	.167 ^x
	Sf-Swath	2	.589	.129	.171 ^d	.226 ^z
	S-Swath	3	.510	.120	.176 ^d	.201 ^z
	S-Swath	4	.502	.105	.171 ^d	.194 ^z

^aStructure of hay during drying; 2.2 meter wide swath or 1.0 meter wide windrow.

^bSee Table 13 for Treatment Descriptions.

^cDrying rates after .68 cm rain.

^dDrying rates after .25 cm rain the previous night.

^eMean of 5 replicates at 8 (F9) or (10) periods of measurement.

^fS = Sprayed.

^{x,z}Means with different subscripts within a trial differ (P<.01).

swaths respectively) which suggests that the larger amount of moisture picked up by treated swaths was more easily removed than was the original intracellular water still contained in the untreated control.

Treatment differences established during the early stages of drying, following chemical treatment, were maintained during and after light rains in the latter stages of drying. The lack of an increase in drying rates from chemical treatment in F9, where rain occurred before large treatment differences were established, may have been due to washing away or dilution of the chemicals and reversal of treatment effects similar to those reported for treated and subsequently washed grapes Grncorevic (1963). This idea would suggest that the treatment of alfalfa with ME, K_2CO_3 emulsions shortly before a heavy dew or when rain is likely to fall that same day, should not be recommended.

Apparent Respiration Losses During Field Drying

Respiration loss during drying was considered as the difference in the initial amount of DM on a screen and the amount of DM present at the final weighing during a trial. Values for 10 untreated control forages ranged from a loss of 22.4% to an increase of 3.2%. Figures for material treated with ME and K_2CO_3 ranged from losses of 14.3 to increases of 14.9% (Table 20).

Table 20. Apparent Respiration Losses During Drying in Eight Field Trials.

Trial	ID	Treatment Description	Hours to 60% DM	Mean DM	% Change in DM from Initial ^f
F7	1	None	22.5	48.0	-6.5
	2	5% ME .2M K ₂ CO ₃ + .25% X-77	5.5	54.8	+3.5
	3	10% ME .2M K ₂ CO ₃ + .25% X-77	5.0	59.9	+6.7
	4	15% ME .2M K ₂ CO ₃ + .25% X-77	4.5	59.1	+3.4
F9a	1	None - Swath ^b	47.0	43.4	+3.29
	2	Treated* - Swath	46.0	44.5	0.0
	3	None Windrow ^c	48.0	38.2	- .59
	4	Treated Windrow	48.0	38.0	+1.29
F10	1	None	9.5	44.2	-7.9
	2	10% ME .4M K ₂ CO ₃ + .25% X-77	5.5	55.3	+3.2
F13	1	None lightd crimp	26.0	41.9	-22.4
	2	None heavy ^e crimp	28.0	39.1	-14.1
	3	Treated ^g light crimp	24.0	46.8	-14.0
	4	Treated heavy crimp	25.0	48.2	- 9.27

Table 20. Continued.

Trial	ID	Treatment Description	Hours to 60% DM	Mean DM	% Change in DM from Initial ^f
F26	1	None	32.0	42.3	- 9.5
	2	.2M K ₂ CO ₃	28.0	49.6	- 4.3
	3	.2M K ₂ CO ₃ + .25% X-77	29.0	48.1	-10.0
	4	.2M K ₂ CO ₃	28.5	49.8	- 8.5
	5	2% ME .2M K ₂ CO ₃ + .25% X-77	28.0	47.8	-14.3
F27	1	None	27.0	44.0	- 8.6
	2	.2M K ₂ CO ₃ + .1M NaOH	26.0	46.9	- 7.6
	3	.2M K ₂ CO ₃	24.0	52.0	- .16
	4	.2M K ₂ CO ₃ + .1% X-77 + .1% OA	26.5	45.8	- 9.4
	5	2% ME .2M K ₂ CO ₃ + .25% X-77	25.5	47.6	-13.5
F34	1	None	25.5	51.0	-14.7
	2	.2M K ₂ CO ₃	7.0	56.3	- 9.8
	3	.2M K ₂ CO ₃	6.0	56.9	- 8.6
	4	5% ME	6.0	57.5	- 3.5
	5	5% ME .2M K ₂ CO ₃ + .25% X-77	5.0	58.8	- 3.4

Table 20. Continued.

Trial	ID	Treatment Description	Hours to 60% DM	Mean DM	% Change in DM from Initial ^f
F35	1	None	5.5	59.1	+ 1.8
	2	4% ME .2M K ₂ CO ₃ + .25% X-77	3.0	67.8	+12.17
	3	4% ME .2M K ₂ CO ₃ + .25% X-77	3.8	61.8	+14.9
	4	8% ME .2M K ₂ CO ₃ + .25% X-77	4.2	64.1	+ 3.5

^aRain .68 cm.^bSwaths 2.3 meters wide.^cWindrows 1.0 meters wide.^dLight crimp averaged 2.4 breaks per stem.^eHeavy crimp averaged 4.3 breaks per stem.^fMean percentage gain (+) or loss (-) of Dry Matter during drying for 4 or 5 replicates per treatment.^g5% ME .2M K₂CO₃ + .25% X-77.

Average losses in these eight trials were 7.7% for untreated hay and 3.1% for forage sprayed with emulsified ME and K_2CO_3 . In three trials respiration loss for K_2CO_3 treated Alf averaged 6.5% while losses for respective controls averaged 10.9%.

In F34 (Table 20) apparent respiration losses were reduced by one third for K_2CO_3 treatments while ME alone and in combination with K_2CO_3 decreased losses by two thirds. In this trial respiration losses were related to mean DM content indicating that the greater effectiveness of ME in hastening drying may diminish respiration loss to a greater extent than K_2CO_3 treatment.

Apparent respiration loss measured in 28 cases regressed with interval to 60% DM yielded the equation $\hat{y} = 4.3 + -.503x$ with a correlation of $-.60$, $P < .01$.

Dale (1979) reported that high environmental temperature increased respiration losses more than did slow rate of drying. Forage allowed to dry in the shade or over a wet puddle had lower respiration losses than forage dried more quickly in direct sunlight. Increased drying rates after chemical treatment could reduce both time to reach 60 to 65% DM and swath temperature during this interval. Dale (1979) found lower respiration losses in windrowed than swathed hay. While this is consistent with her findings on the effects of solar radiation our data on respiration losses from F9 comparing swaths and windrows were variable and show no consistent trend.

Leaching losses due to rain at 4 hours (F9) and at 30 hours post cutting in Dale's research cannot be separated from respiration losses and may be responsible for our different findings.

Dry Matter Losses from Mowing and Raking as a Function of Chemical Treatment and Method of Estimation

Estimation of DM losses after mowing and raking by hand picking leaf and stem fragments from a given area were twice as large as estimates of field raking loss alone as determined by vacuuming up material left on the ground (F35; Table 21). Either method gave values lower than the 3 to 11% losses reported by Barrington and Bruhn (1970) or the 5 to 20% DM losses from mowing and raking reported by Keener et al. (1973).

Trial F35 was conducted in a pure stand of second cutting alfalfa which had experienced extensive leaf hopper damage. Our low values for raking loss may have been due to the short time of field exposure to reach 60 to 65% DM, 4 hours for treated and 6 hours for control, and to the relatively slow speed of 3.5 mph at which the hay was raked. In addition insect damage resulted in a high initial DM content (35%) and could have changed relative drying rates of leaves and stems, providing more uniformly dry material at raking.

Because the hand picking method includes mowing losses it would be expected to give greater values than the estimate of raking losses alone as calculated by difference using the vacuum pick up method.

Table 21. Dry Matter Losses from Mowing and Raking as Estimated by Two Methods.

Treatment Description		Mean ^a grams DM Loss/Sq Meter	Mean Loss Kg/Ha	Mean Loss as % of Total Yield ^b
Hand Pick-Up ^c Method:	None	8.1	81	2.45
	4% ME .2M K ₂ CO ₃ + .25% X-77	8.7	87	2.63
Vacuum ^d Method:	None	3.6 ^d	36	1.09
	4% ME .2M K ₂ CO ₃ + .25% X-77	4.6 ^d	46	1.39
Estimated Mowing Loss ^e	None	4.5	45.0	1.36
	4% ME .2M K ₂ CO ₃ + .25% X-77	4.1	41.0	1.24

^aMean of three replicates.^bYield of 3306.1 kg DM/HA was calculated from mean of 3 yield estimates.^cLeaf and stem fragment dislodged from the plant during mowing and raking were picked up by hand.^dAn estimate of mowing losses and residual trash of 21.5 grams was subtracted from each value.^eFrom the difference of these two methods.

Estimates of mowing losses calculated by subtracting the vacuumed estimate from the hand picked estimate were 1.2 to 1.4%.

Slightly greater mechanical losses were detected for the sprayed alfalfa by both methods. If this difference is expressed as a ratio of losses for sprayed hay to losses for control, values of 1.07:1 for hand picked and 1.28:1 for vacuum methods are obtained.

These results, preliminary in nature, indicate that treatment of alfalfa with ME, K_2CO_3 emulsions can decrease the interval between cutting and raking without causing excessive leaf losses like those reported by Sheperd (1959) after desiccation of alfalfa with contract herbicides.

Changes in Amounts of Dry Matter, Bale Temperatures, and
Analytical Values of Baled Hay During Storage As A
Function of Dry Matter Content and Chemical Treatment

Hay reached an average of 78% DM in 11, 25 and 50 hours in trials F10, F34 and F20 respectively while unsprayed hay baled at these same times post cutting had reached an average of only 66% DM (Table 22).

Dry matter losses during 25 to 51 days of storage were greater for control than for bales of sprayed hay, averaging 9.5 and 5.8% respectively. Mean bale temperatures were also greater for control than treated forage ($34.1 > 31.9^\circ \text{C}$ at

Table 22. Interval From Cutting to Baling, Dry Matter Content at Baling, Bale Temperatures and Dry Matter Losses During Storage for Five Field Trials.

Trial ID	Treatment			Description baling hr	DMT at baling	Days in storage	Bale Temp.		DM ^h loss	Visual observa- tions	
	MEa	K ₂ CO ₃	b				Peak °C	Mean °C			
F10	1	0	0	0	11.0	65	25 ^f	46	34s	7.6	Brown, patchy white mold
	2	1.5	2	.25	2	77	25 ^f	41	32 ^t	1.9	Green, no mold
F20	1	0	0	0	50.0	65	33 ^f	46 ^x	33q	10.2	Brown, white surface mold
	2	2.0	2	.25	4	79	33 ^f	27z	14 ^r	7.1	Green, no mold
F34	1	0	0	0	24.5	68	51 ⁸	50	37 ^x	10.4	Brown, patchy white mold
	2	0	0	0	30.0	79	51 ⁸	37	27z	5.3	Green, no mold not dusty
	3	0	.2	0	4.4	80	51 ⁸	36	28 ^z	4.6	Green, no mold not dusty
	4	2.8	0	.5	2.8	79	51 ⁸	36	26z	5.7	Green, no mold not dusty
	5	2.8	.2	.5	2.8	78	51 ⁸	35	28	-0.8	Green, no mold not dusty
F31	1	0	0	0	48.0	81	32 ^f	-- ⁱ	--	-0.4	Green, no mold not dusty
	2	j	.2	.25	j	78	32 ^f	--	--	-2.3	Green, no mold very dusty
	3	0.3	.2	.25	1.5	82	32 ^f	--	--	-0.9	Green, no mold somewhat dusty
	4	0.6	.2	.25	3.0	82	32 ^f	--	--	-1.1	Green, no mold somewhat dusty

Table 22. Continued.

Trial ID	Treatment		Description	Time to baling hr	DMT at baling	Days in storage	Bale Temp.		DMh loss	Visual observa- tions
	MEa	K ₂ CO ₃ ^b	EMC % ^d				Peak °C	Mean °C		
F35	1	0	0	0	7.5	38g	43	32s	3.9	Color mostly green, brown and some white surface mold on bottom bales
	2	1.2	.2	.5	3.0	6.0	77	38g	29	
									24	2.9
										Brown dusty white surface mold on bottom bales

a,b,c,d See Table 10 for explanation.

e % DM = units DM ÷ units total sample weight.

f Stored under roof in open sided polebarn.

g Stored under roof in enclosed barn.

h DM = actual weight of dry matter; loss is % of initial DM weight.

i Temperatures not measured.

j Application rates not measured but lower than ID 3 trial F31.

q,r All values with different superscripts in the same trial are different (P<.10).

s,t All values with different superscripts in the same trial are different (P<.05).

x,z All values with different superscripts in the same trial are different (P<.01).

P<.10 in trial F10; 33.0>13.8° C at P<.05 in F20; and 36.7>28.0° C at P<.01 in trial F34, Table 22).

Control bales stored at 64 to 68% DM developed patches of white mold and turned brown in color during storage while treated bales stored at 77 to 79% DM did not mold and retained green color in the three trials.

Both treated and control hay increased in DM content during storage attaining approximately equal DM content, ranging from 78 to 90% at the end of storage. Ash, fiber fractions, crude protein (CP) and Acid detergent fiber (ADF) bound nitrogen (N) usually increased during storage. Magnitude of these increases was generally greatest for control bales indicating larger losses of non-fibrous constituents had occurred during storage of the wetter control bales. A large reduction in water soluble carbohydrate (Soly CH₂O) concentration occurred during storage in both treated and control bales in F10 but Soly CH₂O decreased only in control bales in trial F20 (Table 23).

These data suggest that fiber fraction and CP were relatively stable during heating up to 50° C while reductions in Soly CH₂O concentration of 34 to 56% occurred in bales that attained 40° C and had mean temperatures of 30° C.

These results are consistent with the work of Nelson (1966) who reported DM losses of 8 and 11% for hay baled at 73 and 61% DM respectively, and Fetenstine (1971) who found

Table 23. Analytical Values for Control and Sprayed Alfalfa at Baling and After Storage.

Trial	Control			Treated ^h		
	Initial	Final	Difference	Initial	Final	Difference
F10						
DM	64.9	82.6	17.7	76.8	84.7	7.9
Ash ^a	7.98	8.04	.06	8.25	9.0	.75
ADF ^{ab}	35.4	41.0	5.6	34.2	39.0	4.8
CW ^{ac}	50.0	57.2	7.2	46.4	53.3	6.9
Hemicellulose ^a	14.7	16.4	1.7	12.3	14.3	1.6
% CP ^{ad}	16.9	18.9	2.0	16.9	18.6	1.6
ADF-N ^e , as % of total N	12.07	11.99	-0.08	10.77	11.55	0.78
Soly CH ₂ O ^{af}	7.57	4.12	-3.45	5.95	3.32	-2.63
IVDMD ^g	59.67	56.39	-3.28	58.27	57.39	- .88
F20						
DM	64.6	78.6	14.0	76.3	77.9	1.6
Ash ^a	8.56	10.03	1.47	7.93	8.11	0.18
ADF ^{ab}	29.1	34.1	5.0	28.6	29.1	0.5
CW ^{ac}	41.8	52.5	10.7	41.7	43.1	1.4
Hemicellulose ^a	12.8	18.4	5.6	13.1	14.0	0.9
% CP ^{ad}	18.8	20.4	1.6	17.6	18.6	1.0
ADF-N ^e /N %	8.05	11.90	3.9	7.11	7.80	0.69
Soly CH ₂ O ^{af}	11.00	6.65	-4.35	11.89	13.17	1.28
IVDMD ^g	68.1	64.8	-3.3	67.3	66.0	-1.3

Table 23. Continued.

Trial	Control			Treated ^h		
	Initial	Final	Difference	Initial	Final	Difference
F35						
DM	74.9	85.1	10.2	77.2	83.3	6.1
Ash ^a	7.20	8.72	1.52	6.97	7.27	.30
ADF ^{ab}	33.4	33.2	- .2	31.2	32.2	1.0
CW ^{ac}	48.3	55.0	6.7	50.1	52.1	2.0
Hemicellulose ^a	14.9	21.8	6.9	18.9	19.9	1.0
% CP ^{ad}	17.1	19.3	2.2	15.9	16.1	.2
ADF-N ^e /N %	8.35	9.15	.8	8.30	8.16	- .14
Soly CH ₂ O ^{af}	7.8	8.1	.3	8.5	6.6	-1.9
IVDMD ^{ag}	65.4	62.8	-2.6	63.8	62.9	-0.9

^aExpressed as % of DM.

^bADF = acid detergent fiber.

^cCW = cell walls.

^dCP = crude protein N x 6.25.

^eN = nitrogen.

^fSoly CH₂O = water soluble carbohydrate.

^gIVDMD = in vitro dry matter disappearance.

^hSee Table 22 for treatment description.

that Soly CH₂O concentration in alfalfa decreased with increasing temperatures from 27 to 70° C while cellulose and hemicellulose were not degraded by temperatures in this range. This author also reported no loss of CP in heated alfalfa but found increases in fiber bound N.

In the previously described trials all hays were baled at the same time but in trials F31, F34 (treatments 2 to 5) and F35 the experimental hays were all baled at the same DM.

Interval from cutting to baling at 78 to 82% DM averaged 39 hours for 2 untreated hays and 24.5 hours for 4 treated hays (F31 and F34, Table 22). In trial F34 ME + EM and K_2CO_3 treatments alone were less effective in reducing hours to baling than the 3 component solution (Control, $30.0 > ME + EM$, $28.0 > K_2CO_3$, $26.5 > ME + EM + K_2CO_3$, 24.5 hours; Table 22).

Dry matter loss and mold development during storage were not detected for any treatment in F31 but all sprayed hays (groups 2, 3, and 4) were dusty while control bales were not. Losses of DM for sprayed and unsprayed hay baled at 78 to 79% DM in F34 (groups 2 to 5) were small and generally similar between treatments while no differences in mean temperature, peak temperature or visual quality measurements were observed (Table 22).

Analytical values were similar for control and sprayed hay when baled at about equal DM contents (77 to 82%; F31 and F34; Table 24). Small increases in fiber fractions and CP as a % of DM occurred during storage. Magnitude of these changes was not related to chemical treatment at cutting. Increases in fiber bound N were also small with the exception of control number 2 in trial F34 where ADF/N increased from 8.1 to 13% of total N.

Table 24. Analytical Values for Unsprayed and Sprayed Alfalfa as Baled at 77 to 82% Dry Matter and Changed During Storage.

Trial	Control		Treated ^h									
	Initial	Final Difference 1 _f	Initial	Final Difference 2 _f	Initial	Final Difference 3 _f	Initial	Final Difference 4 _f	Initial	Final Difference 5 _f		
F31												
DM	81.2	87.4	6.2	77.6	88.1	10.5	82.1	89.5	7.4	81.6	89.2	7.6
Ash ^a	7.79	8.05	.26	8.22	8.31	.09	7.42	7.90	.48	7.80	8.50	.7
ADF ^{ab}	29.3	33.1	3.8	30.2	33.7	3.5	30.0	33.0	3.0	30.7	34.8	4.1
CW ^{ac}	41.2	46.8	5.6	46.3	49.6	3.3	42.3	49.5	7.2	44.5	52.4	7.9
Hemicel- lulose ^a	11.9	13.7	1.8	16.1	15.9	-0.2	12.3	16.5	4.2	13.8	17.6	3.8
% CP ^{ad}	16.7	16.5	- .2	16.8	17.9	1.1	16.4	16.9	.5	16.2	16.5	.3
ADF-N ^e /N %	12.1	9.0	-3.1	10.7	10.7	0.0	10.2	11.8	1.6	11.2	10.7	- .5
Soly CH ₂ O ^{af}	10.2	9.1	-1.1	7.5	7.1	-0.4	8.4	7.1	-1.3	8.5	6.9	-1.6
IVDM ^{ag}	64.7	65.6	0.9	64.4	64.4	0.0	60.7	63.8	1.1	62.9	63.1	0.2

Table 24. Continued.

Trial	Control					
	1			2		
	Initial	Final	Difference	Initial	Final	Difference
F34						
DM	68.2	82.8	14.6	79.0	83.1	4.1
Ash ^a	7.57	8.22	.65	7.56	8.07	.51
ADF ^{ab}	29.8	36.7	6.9	30.1	35.0	4.9
CW ^{ac}	48.9	54.8	5.9	45.6	49.5	3.9
Hemicel- lulose ^a	19.1	18.1	1.0	15.6	14.5	-1.1
% CP ^{ad}	17.7	17.0	1.0	17.0	18.4	1.4
ADF-N ^e /N %	8.90	14.27	5.37	8.14	13.02	4.88
Soly CH ₂ O ^{af}	9.2	4.7	-4.5	8.2	4.00	-3.8
IVDMD ^{ag}	61.5	58.3	-3.2	67.5	64.1	-3.4

Table 24. Continued.

Trial	Treated ⁿ											
	3					4					5	
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
F34												
DM	79.6	83.3	3.7	79.1	83.9	4.8	78.2	83.8	5.6			
Ash ^a	8.93	9.83	.9	7.87	8.58	.71	7.13	7.88	.75			
ADF ^{ab}	32.9	32.4	-.5	30.9	32.9	2.0	33.6	33.2	-.4			
CW ^{ac}	46.0	49.1	3.1	45.8	49.7	3.9	50.1	49.7	-.3			
Hemicel- lulose ^a	13.1	16.7	3.6	14.9	16.8	1.9	16.5	16.5	0.0			
% CP ^{ad}	18.1	18.2	.1	17.7	18.9	1.2	16.6	18.2	1.6			
ADF-N ^e /N %	7.52	10.45	2.93	9.22	8.85	-.37	10.33	10.08	-.25			
Soly CH ₂ O ^{af}	7.5	7.1	-.4	8.61	6.1	-2.5	7.1	6.2	-.9			
IVDMD ^{ag}	65.5	63.7	-1.8	66.9	61.6	-5.3	61.2	61.2	0.0			

^aExpressed as % of DM.^bADF = acid detergent fiber.^cCW = cell walls.^dCP = crude protein N x 6.25.^eN = nitrogen.^fSoly CH₂O = water soluble carbohydrate.^gIVDMD = in vitro dry matter disappearance.^hSee Table 21 for treatment description.

Hay was baled at 75 to 77% DM in trial F35 to determine if chemical treatment applied at cutting would influence changes in quality of hay baled at a DM content generally accepted to be the lower limit for safe storage without excessive heating and DM loss (Hodgson, 1948).

Interval from cutting to baling at 75 to 77% DM was only 6.0 hours for sprayed and 7.5 hours for control alfalfa in F35, this short interval was due to extensive leaf hopper damage which resulted in an initial DM content above 30%.

Mean bale temperatures were greater for control bales ($32.4 > 23.4$ at $P < .05$ in F35; Table 22). Dry matter losses were small for both treatments but were slightly greater for the wetter control bales ($3.9 > 2.9\%$; Table 22). Increases in ash, cell walls and CP were also greatest in control bales (Table 23). On the other hand treated bales were brown and dusty when opened while control bales were primarily green and not dusty.

In conclusion, alfalfa sprayed with the three component solution had a higher DM% than unsprayed alfalfa baled at the same time in three trials. Mean bale temperatures, DM loss and increases in concentration of Ash, fiber, CP and ADF-N were greater for these control bales than for the drier sprayed hay. Water soluble carbohydrate concentration decreased dramatically in two trials where bale temperature during storage averaged greater than 30°C , thus increases in fiber fractions and CP expressed as a % of DM may in large part be due to losses of Soly CH_2O during heating.

Hours from mowing to baling at a DM of 75 to 82% were greater for unsprayed control hay in 3 trials while analytical values for the resulting hay at baling, bale temperatures, DM loss, and changes in visual and analytical quality measurements during storage were usually similar for these control and sprayed forages.

SUMMARY

The present research extended previous investigations of chemical treatments that hasten forage drying, and clarified several questions brought up by the investigations of Tullberg and Angus (1972 and 1978), Tullberg and Minson (1978) and Wieghart et al. (1980). In addition several new areas of investigation were identified.

Drying of alfalfa was hastened by the use of spray solutions containing carbonates or other salts of the alkali metal group and was influenced by both the cation present and solution pH. Effectiveness was generally enhanced as cationic radius increased ($\text{Li} < \text{Na} < \text{K} < \text{Rb} < \text{Cs}$) and as pH increased for solutions containing potassium salts.

Potassium and sodium carbonate are readily available, relatively inexpensive, non caustic and both produced satisfactory increases in drying. The greater effectiveness of K_2CO_3 prompted us to use it in experimental studies while cost effectiveness of these two compounds will need to be determined in future studies. Drying hastened by use of K_2CO_3 solutions was not enhanced by additions of surface active agents or by application of solution volumes greater than 2% of fresh forage weight. Results from drying trials utilizing K_2CO_3 were variable, sometimes showing dramatic

increases in drying after spraying with K_2CO_3 and sometimes showing little advantage for use of this compound. Reason for this variability is not apparent.

Methyl esters of long chain fatty acids (ME) have previously been shown to increase drying rates (Drt) of cut alfalfa (Wieghart et al., 1980). In the present studies ME added to K_2CO_3 solutions usually increased mean Drt and DM compared to use of either component alone. Responses to spray treatments with emulsified ME and K_2CO_3 appeared to be additive, and variability of response was also reduced. Effectiveness of applied ME was increased when an emulsifier was added or when liquid application rates were increased. The minimum effective application of ME in K_2CO_3 solutions was approximately 0.5 gr ME/kg while increasing application rate of ME above this amount increased drying, reaching a maximum of 1 to 3 gr ME/kg.

Drying rates for both control and treated forages diminished over time and as WC decreased. Potassium carbonate increased Drt primarily during the early stages of drying while ME increased Drt over a longer interval and maintained an increased Drt above control until WC reached at least 0.5 (67% DM). Spray treatment with the three component solution increased Drt primarily during the first 8 to 12 hours after treatment compared to untreated controls but Drt appeared to be more closely related to WC than to time after treatment.

The three component solution consistently increased Drt of alfalfa in the laboratory down to a WC of 0.5. Treatment differences in DM content established during the initial period when Drt was increased by chemical treatment, were usually maintained during the final stages of drying. Reductions in field drying time required to reach 80% DM of 10 to 24 hours were demonstrated in several trials.

Treatment of different forage species with the three component solution influence Drt to different extents. Drying rate at a given water content (WC) was greatest for treated Alf > treated Bft > treated RC, while Drt of two temperate forage grasses, brome grass (BG) and orchard grass (OG), was not affected by chemical treatment. Grasses had higher initial DM content and at a given WC had more rapid rates of water loss than did unsprayed alfalfa. Spray treatments tended to equalize Drt of Alf and BG. Sprayed alfalfa of different maturities or grown under field or "greenhouse" conditions dried more rapidly than did respective controls. These results indicate that the three component solution can hasten drying of alfalfa grown under different environments and of different maturities.

Field application of the three component solution increased mean DM under a wide range of environmental conditions. Drying of alfalfa was more rapid when swathed than when placed in a windrow. Swathed alfalfa or sprayed alfalfa was usually

drier at the end of the day or at the onset of rain, than was windrowed or untreated alfalfa. This drier forage picked up more moisture from dew or rain than did windrowed forage or untreated control swaths. Swaths or treated swaths attained a greater DM content during early drying than did windrowed or untreated alfalfa. This greater DM content was maintained after dew or light rain.

Dry matter loss from continued respiration during drying was generally less for sprayed alfalfa than for untreated control. Methyl esters appear to be more effective than K_2CO_3 in reducing respiration loss and this may be related to increases in Drt when ME were included in the spray solution. Mechanical losses of DM from mowing and raking were slightly greater for sprayed than unsprayed alfalfa but losses of DM during these operations were less than some reported values for unsprayed alfalfa.

Alfalfa sprayed with the three component solution had attained a greater DM% than untreated control when both were baled at the same time. Bale temperatures, DM loss, and changes in visual and analytical quality measurements during storage were greatest for these control bales. Interval to baling at a DM% "safe" for storage was substantially reduced by spray treatments while analytical values of treated and untreated forage at baling, bale temperatures and changes in visual and analytical quality measurements during storage were usually similar.

The present research has demonstrated that the length of exposure time for alfalfa sprayed with the three component solution can be reduced under a variety of conditions without a reduction in quality of the final product after harvest and storage. Thus the use of this technique in alfalfa harvesting systems in the midwestern United States should increase the quality of harvested alfalfa by reducing the likelihood of exposure to adverse weather during field drying.

New areas with potential for further research have been identified and include 1) study of cost effectiveness of spray treatments containing sodium or potassium carbonate alone or in combination with emulsified ME, 2) tests to determine the effectiveness of the three component solution on drying of temperate and tropical grasses and legumes, 3) measurement of rates of drying as influenced by environmental conditions during plant growth and during drying, 4) development of field application systems to obtain more complete coverage with small volumes of water, and 5) long term field studies evaluating savings in harvested nutrients per Ha, animal intake and production, and cost effectiveness of utilizing chemical treatments to hasten drying in commercial farm operations.

REFERENCES CITED

REFERENCES CITED

- Ajibola, O., R. Koegel, and H. D. Bruhn. 1980. Radiant energy and its relation to forage drying. Transactions of Amer. Soc. Agric. Engin. 23:1297.
- Audus, L. J. 1964. The physiology and biochemistry of herbicides. Academic Press, London and N. Y.
- Bagnell, L. O., W. F. Miller, N. R. Scott. 1970. Drying of the alfalfa stem. Transactions of the ASAE 13:232.
- Barrington, G. P. and H. D. Bruhn. 1970. Effect of mechanical forage harvesting devices on field curing rates and relative harvesting losses. Transactions ASAE 13:874.
- Bleckman, C. A. 1980. Cuticular ultrastructure of *prosopis velutina* and *Acacia-Greggi* leaflets. Botanical Gazette 141:1.
- Blair, E. H., H. L. Mitchell, R. E. Sliker. 1953. Industrial and engineering chemistry. Industrial Ed. 45:1104.
- Boyd, M. M. 1959. Hay conditioning methods compared. Ag. Eng. 40:663.
- Bruhn, H. D. 1959. Performance of forage conditioning equipment. Ag. Eng. 40:667.
- Byers, G. L., D. G. Routely. 1965. A study of factors affecting the release of moisture from cut alfalfa. Proc. 9th Int. Grasslands Cong. Sao Paulo 1:595.
- Chambers, T. C. and J. V. Possingham. 1963. Studies of the fine structure of the wax layer of sultana grapes. Aust. J. Biol. Sci. 16:818.
- Clark, B. J. and P. McDonald. 1977. The drying pattern of grass swaths in the field. J. Brit. Grassland Soc. 32:77.
- Coitti, A. and A. Cavallero. 1980. Haymaking losses in cocks foot-Lucerne mixtures in relation to conditioning and degree of drying at harvest. European Grassland Federation, Proceedings of Symposium No. 11, Brighton UK. P. 214.

- Dale, J. G. 1979. Simulation of alfalfa harvest losses. MS Thesis. Purdue University.
- Dubois, M., K. Gilles, J. K. Hamilton, P. A. Rebers and F. Smith. 1951. A colorimetric method for the determination of sugars. *Nature*. 168:167.
- Eglinton, G. and R. J. Hamilton. 1967. Leaf epicuticular waxes. *Science* 156:1322.
- Eglinton, G., A. G. Gonzalez, R. J. Hamilton and R. A. Raphael. 1962. Hydrocarbon constituents of the wax coatings of plant leaves: a taxonomic survey. *Phytochemistry* 1:89.
- Fairbanks, G. E., G. E. Thierstein. 1966. Performance of hay conditioning machines. *Transactions ASAE* 9:182.
- Festenstine, G. N. 1971. Carbohydrates in hay on self heating to ignition. *J. Sci. Food. Agric.* 22:231.
- Fisher, R. A. 1968. Stomatal opening: role of potassium, active uptake by guard cells. *Science* 160:784.
- Gallander, J. F. and A. C. Peng. 1980. Lipid and fatty acid composition of different grape types. *Amer. J. Enology and Viticulture* 31:24.
- Green, R. M. 1975. Microclimate and resistances to water loss in the hay swath. Grassland Research Institute annual report, p. 70.
- Green, R. M. and B. M. Jagger. 1977. Microclimate, energy exchange and water loss from the hay swath. Grassland Research Institute annual report, p. 74.
- Green, R. M., J. L. Prickett, and J. Bennett. 1976. Microclimate, energy exchange and water loss from the hay swath. Grassland Research Institute annual report, p. 77.
- Grncarevic, M. 1963. Effect of various dipping treatments on the drying rate of grapes for raisins. *Amer. J. Enology and Viticulture* 14:230.
- Grncarevic, M. and F. Radler. 1971. A review of surface lipids of grapes and their importance in the drying process. *Amer. J. Enology and Viticulture* 22:80.
- Hall, D. M. 1966. A study of the surface wax deposits on apple fruit. *Aust. J. Biological Sci.* 19:1017.
- Hall, D. M. and R. L. Jones. 1961. Physiological significance of the surface wax on leaves. *Nature* 191:95.

- Hall, G. E. 1964. Flail conditioning of alfalfa and its effect on field losses and drying rates. Transactions of the ASAE 7:435.
- Harris, C. E. 1975. Effect of chemical desiccants on the drying rate and respiration of perennial ryegrass leaves. Grassland Research Institute annual report.
- Harris, C. E. 1979. Water loss from isolated plant parts under controlled conditions. Grassland Research Institute annual report.
- Harris, C. E., R. Thain and H. I. M. Sarisalo. 1974. Effectiveness of some mechanical, thermal and chemical laboratory treatments on the drying rate of leaves and stem internodes of grass. J. Agri. Sci. 83:353.
- Harris, C. E. and J. N. Tullberg. 1980. Pathways of water loss from legumes and grasses cut for conservation. Grass and Forage Sci. 35:1.
- Hayward, H. E. 1938. The structure of economic plants. McMillan Co., New York.
- Hodgson, R. E., R. E. Davis, W. H. Hosterman and T. E. Hienton. 1948. Storage of forage, p. 161 in Grass-Yearbok of Agriculture. 1948. Washington, D. C.
- Hoglund, C. R. 1964. Michigan Agr. Exp. Econ. Report 947, p. 16.
- Holloway, P. J. 1969. Chemistry of leaf waxes in relation to wetting. J. Sci. Food and Agric. 20:124.
- Honig, H. 1980. Mechanical and respiration losses during pre-wilting of grass. European Grassland Federation, Proceedings of Symposium No. 11. Brighton UK, p. 201.
- Jeffree, C. E., E. A. Baker, and P. J. Holloway. 1975. Ultrastructure and recrystallization of plant epicuticular waxes. New Phytol. 75:539.
- Johns, G. G. 1972. Water use efficiency in dry land herbage production. J. Aust. Inst. Agric. Sci. 38:135.
- Jones, L. 1973. Water loss from isolated plant parts under controlled conditions. Grassland Research Institute annual report.
- Jones, L. and J. C. Prickett. 1977. Water loss from the swath. Grassland Research Institute annual report.

- Jones, T. N. and L. O. Palmer. 1932. Field curing of hay as influenced by plant physiological reactions. *Ag. Engin.* 13:199.
- Keener, H. M., W. L. Roller and W. E. Gill. 1973. Expected forage quality and quantity for different harvesting systems in Ohio. *Proceedings of the third alfalfa symposium, Wooster, Ohio.*
- Kennedy, W. k., W. H. Hesse and C. M. Johnson. 1954. Effect of herbicides on the drying rate of hay crops. *Agronomy J.* 46:199.
- Klinner, W. E. 1975. Design and performance characteristics of an experimental crop conditioning system for difficult climates. *J. Agr. Eng. Res.* 20:149.
- Klinner, W. E. 1976. Mechanical and chemical field treatment of grass for conservation. *Annual Conf. Inst. Agr. Eng. Report No. 21, London.*
- Klinner, W. E. and G. Shepperson. 1975. The state of hay making technology. A Review. *J. Brit. Grassland Soc.* 30:259.
- Krutz, G. W. and D. A. Holt. 1979. For fast field drying of forage crops. *Ag. Eng.* 60:16.
- Leshem, Y., R. Thaine, C. E. Harris and R. J. Canaway. 1972. Water loss from cut grass with special reference to hay-making. *Ann. Appl. Biol.* 72:89.
- Nelson, L. F. 1966. Spontaneous heating and nutrient retention of baled alfalfa hay during storage. *Transactions of ASAE* 9:509.
- Nagarajah, S. 1979. The effect of potassium deficiency on stomatal and cuticular resistance in tea leaves (*Camellia sinensis*). *Physiol. Plant* 47:91.
- O'Toole, J. C. and R. T. Cruz. 1979. Leaf rolling and transpiration. *Plant Sci. Letters* 16:111.
- Pallardy, S. G. and T. T. Kozlowski. 1980. Cuticle development in the stomatal region of populus clones. *New Phy.* 85:363.
- Pederson, T. T. and W. F. Buchele. 1960. Drying rate of alfalfa hay. *Ag. Eng.* 41:86.
- Pederson, T. T. and W. F. Buchele. 1960. Hay in a day harvesting. *Ag. Eng.* 41:172.

- Person, N. K. and J. W. Sorensen. 1970. Comparative drying rates of selected forage crops. Transactions ASAE 13:352.
- Petrucchi, V., N. Catata, H. R. Bolin, G. Fuller and A. G. Stafford. 1974. Use of oleic acid derivatives to accelerate drying of Thompson seedless grapes. J. Amer. Oil Chem. Soc. 51:77.
- Philipsen, P. J. J. 1969. Methods of drying and changes in the crop especially after killing the standing crop by thermal treatment. European Grassland Federation Proc. of 3rd General Meeting. Braunschwig p. 77.
- Priepke E. H., and H. D. Bruhn. 1970. Altering physical characteristics of alfalfa to increase the drying rate. Transactions of the ASAE 13:827.
- Schieferstein, R. H. and W. E. Loomis. 1956. Wax deposits on leaf surfaces. Plant Phys. 31:240.
- Schonherr, J. 1976. Water permeability of isolated cuticular membranes: the effect of pH and cations on diffusion, hydrodynamic permeability and size of polar pores in the cutin matrix. Planta 128:113.
- Schukking, S. and J. Overvest. 1980. Direct and indirect losses caused by wilting. European Grassland Federation, Proceedings of Symposium, No. 11, Brighton U. K., p. 210.
- Sheperd, J. B., H. G. Wiseman, R. E. Ely, C. G. Melin, W. J. Sweetman, C. H. Gordon, L. G. Schoenleber, R. E. Wagner, L. E. Campbell, G. D. Roane and W. H. Hosterman. 1954. Experiments in harvesting and preserving alfalfa for dairy cattle feed. USDA Tech. Bull. No. 1079.
- Shepherd, W. 1959. The effect of a chemical desiccant on the speed of curing hay. J. Aust. Inst. Ag. Sci. 25:218.
- Shepherd, W. 1964. Paths and mechanisms of moisture movement in detached leaves of white clover. I. Losses of petiole moisture direct from petioles and via laminae. Annals of Bot. 28:207.
- Shepherd, W. 1965. Air speed effects during drying of harvested pasture material. Aust. J. Ag. Res. 16:385.
- Sitte, P. and R. Rennier. 1963. Investigation of cuticular cell wall layers. Planta 60:19.

- Spray Systems Co. 1977. Spray Manual Catalog 36, Agricultural spray nozzles and accessories, p. 3.
- Stafford, A. E., G. Fuller and H. R. Bolin. 1980. Loss of fatty acid esters from grape surfaces during drying. J. Amer. Oil Chem. Soc. 57:70.
- Stalfet, M. G. 1957. The water output of the guard cells of the stomata. *Physiologica Plantarum* 10:752.
- Sullivan, J. T. 1973. Chemistry and Biochemistry of Herbage. Vol. III, Chapter 27, Butler, G. W. and D. G. Bailey, eds. Academic Press, New York.
- Thaine, R. and C. E. Harris. 1973. Short note: formic acid as a desiccant for grass leaves. J. Agr. Sci. 80:349.
- Tinnimit, P. and J. W. Thomas. 1976. Forage evaluation using various laboratory techniques. J. Animal Sci. 43:1058.
- Tullberg, J. N. and D. E. Angus. 1972. Increasing the drying rate of lucerne by the use of chemicals. J. Aust. Inst. Agr. Sci. 38:214.
- Tullberg, J. N. and D. E. Angus. 1978. The effect of potassium carbonate solution on the drying of lucerne. 1. Laboratory studies. J. Agr. Sci. 91:551.
- Tullberg, J. N. and D. J. Minson. 1978. The effect of potassium carbonate solution on the drying of lucerne. 2. Field studies. J. Agr. Sci. 91:557.
- Turner, N. C. 1970. Speeding drying of alfalfa hay with fusicoccin. Agronomy J. 62:538.
- Turner, N. C. and G. Antonio. 1969. Fusicoccin: a fungal toxin that opens stomata. Nature 223:1070.
- Vijaya, Raghavan, G. S. and W. K. Bilanski. 1974. Effects of alfalfa stem-leaves moisture difference on leaf loss during harvest. Canadian Ag Engin. 16:10.
- Wieghart, M., J. W. Thomas and M. B. Tesar. 1980. Hastening drying rate of cut alfalfa with chemical treatment. J. Anim. Sci. 51:1.
- Wilkins, R. J. and R. M. Tetlow. 1972. Water loss in conservation systems: field studies. Grasslands Research Institute annual report.

- Wilkinson, R. E. and M. J. Kasperbauer. 1980. Effect of light and temperature on epicuticular fatty acids and fatty alcohols of tobacco. *Phytochemistry* 19:1379.
- Winkler, A. J., J. A. Cook, W. M. Kliever and L. A. Lider. 1974. *General Viticulture*. Univ. of California Press, Ltd., p. 633.
- Zimmer, E. 1973. New methods in fodder conservation. *Vaxtodling* 28:90.

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