

THE EFFECTS OF ALTERING WINDROW WIDTH ON DRYING RATE AND QUALITY

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Abstract: A series of field trials were established in San Bernardino, Tulare, and Northeastern California to compare drying rate and quality of alfalfa cut with an adjustable swather that was set to produce wide (7.0 ft.) and conventional (3.5 ft.) windrows. Wide windrows dried significantly faster saving up to two days curing time, except for the last cutting (fall) in Tulare and Shasta Counties. The drying advantage of wide windrows was greatest during spring and summer and when yields were highest. In the high desert, wide windrows were still advantageous in the fall because of the lack of heavy dew or other precipitation. There was no significant difference in the degree of bleaching or in the quality of the alfalfa hay.

Keywords: Alfalfa (Medicago sativa L.), Harvesting, Haymaking, Curing, Baling

INTRODUCTION

The curing process is one of the last operations of the hay production process, but it is very important. This involves drying alfalfa from a moisture content of approximately 80 percent down to a moisture content suitable for baling (approximately 16 percent or less). In California, this phase of alfalfa production has received far less attention than some of the earlier phases (i.e. variety selection, fertilization, pest control, etc.). The explanation for this lack of emphasis on hay curing in California is due primarily to the favorable drying conditions we are blessed with for most of the year. This is not true in other parts of the country. For example, in Wisconsin the probability of three consecutive dry days in the months of June, July, and August averages 27, 37, and 36 percent, respectively. Because of this incentive, much of the research and advances in hay curing technology have come from the Midwest. However, this does not mean that we in California could not also benefit from accelerated hay curing.

To evaluate the benefits of rapid curing it is helpful to first review the losses that can occur during the curing process. These losses include respiration losses, losses due to rain damage or leaching, leaf loss, and bleaching or loss of color. The alfalfa plant continues to respire after it has been cut until it has dried down to 40 percent moisture or less. Under very poor drying conditions, dry matter losses due to respiration can be as high as 10 percent. Although rain damage is not a constant threat in most of California, it does occur, particularly in the spring and fall, and losses can be extensive. Leaf shatter and leaf loss can also occur while the alfalfa is drying in the windrow, and particularly during mechanical manipulation such as raking or inverting.

Prolonged field curing also results in secondary losses affecting the yield of the subsequent cutting. The extent of the losses depends on the length of curing time. These losses relate to the effects of 1) shading of the alfalfa underneath the windrow, 2) wheel traffic on alfalfa regrowth, and 3) delayed alfalfa irrigation. Research in Nevada showed a yield loss under the windrow of 5, 7, and 18 percent for two, four, and eight day curing times, respectively, compared to removing alfalfa immediately after cutting. Traffic damage to regrowth shoots caused by the baler and bale wagon is greater the longer the time from cutting to baling. Alfalfa is most sensitive to water stress just after cutting. An example of the

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losses that can be experienced from delaying irrigation after a cutting was presented in Irrigation of Alfalfa from the Handbook of Irrigation Technology. When the number of days between cutting and irrigation was 2, 4, and 6 days, the yield decrease compared to irrigating the day after cutting was 11, 14, and 30 percent, respectively. Obviously, yield reductions from all three of these secondary factors are minimized the shorter the hay curing time.

The role of environmental factors in hay drying rate has been evaluated by Rotz and others in both Michigan and in a location near Fresno, California. They found solar radiation to be the weather parameter with the greatest influence on drying rate. Vapor pressure deficit (a combined measurement of temperature and humidity) was also determined to be an important factor. Contrary to what many believed, wind was not found to have a significant influence on drying rate. Wind may play a more significant role in extremely arid and windy regions (such as California's High Desert) and when the alfalfa is laid in a narrow windrow rather than a wide swath.

Swath density was observed to be an important element in hay drying. Studies conducted by Rotz indicated approximately 8 hrs (1 day) more drying time is required for a thick narrow swath compared to a wide thin swath spread over much of the field surface. Similar results were obtained by John Arledge in New Mexico. Apparently, the wide thin swath dries faster than a narrow one since more of the alfalfa is exposed to the solar radiation (the factor having the greatest effect on drying).

Windrow width in California has been determined more by tradition than by any other factor and has probably not received the attention it deserves. Preliminary research was conducted in the high desert in 1989 to study the wide windrow concept in California. Results were encouraging, highlighting the need for further research under varying conditions to better quantify the advantages and disadvantages of using a "wider than normal" windrow. An important factor in this is that self-propelled swathers are now available with wide conditioning rollers and the flexibility of greatly altering windrow width. Because of the encouraging preliminary results and the availability of wide windrow swathers, a series of field trials were established in 1990 to test the wide windrow concept. The objective of these field experiments was to determine the effect of windrow width on alfalfa drying rate, quality, and sun bleach under different environmental and yield situations.

MATERIALS AND METHODS

Windrow width trials were conducted by the authors in four California counties representing different climatic and drying conditions. The counties were San Bernardino County (hot and arid high desert conditions), Tulare County (Southern Central Valley conditions), and Northeastern California (cooler inter-mountain conditions). Trials were conducted in San Bernardino and Tulare counties for three cuttings (a spring, summer, and fall). Trials were conducted in Northeastern California on a summer cutting (Modoc County) and a fall cutting (Shasta County).

Narrow or standard windrows (3.5 feet wide) were compared with wide windrows (7 feet wide). A randomized complete block experimental design was used with six replications where each windrow was an individual plot. The swather used in the San Bernardino County trials was a Case IH Model 8840 with a 16-foot header. A Case IH Model 8840 with a 14 foot header was used in the Tulare County studies. A Hesston Model 8840 and New Holland Model 1499 swathers were used in the Modoc and Shasta County studies, respectively. These swathers were selected because they are equipped with wide conditioning rollers, and the capacity to make a windrow up to eight feet wide by adjusting a lever.

The alfalfa drying rate was determined by weighing sections of windrow laid on trays. The trays consisted of light-weight nylon mesh attached to

half-inch electrical conduit. The weighing frames measured four by four feet for the narrow windrows, and four by eight feet for the wide windrows. The frames were placed under the windrows promptly after cutting using a large specially constructed fork. The windrow was gently lifted using the fork to minimize windrow disturbance, and the tray was slid underneath. The alfalfa was trimmed along the edges of the frame to permit lifting and weighing of the tray with the section of windrow. Trays were weighed twice daily, approximately 10:00 a.m. (after any dew had dissipated) and again at approximately 4:00 p.m., except in Northeastern California, where they were weighed once a day at 5:00 p.m. The windrow sections were weighed for the duration of the curing process using a hanging spring-type scale. Prior to raking and combining windrows, the section of windrow on the trays was collected to determine oven-dry weight. The trays were then reinserted under the raked windrow to continue the drying rate measurements. Prior to baling, the section of the windrow on the trays was again collected to determine oven-dry weight. The bales in each treatment were cored for moisture and/or quality determination.

A hygrothermograph was placed in the field at windrow height to obtain temperature and relative humidity data for the San Bernardino and Tulare County studies. A hygrothermograph was not available for the Northeastern California studies, so temperature and relative humidity data was obtained from the local CIMIS weather station.

RESULTS AND DISCUSSION

A brief description of the weather conditions, the timing of the harvest operations, and any pertinent observations are presented below for each experimental period and location.

San Bernardino County Studies

May 29 - May 31

Cutting Date and Time: 10-11:00 a.m. on May 29

Yield: 1.9 tons/A

Weather: High temperatures for May 29 and May 30 were 82 and 84 degrees, respectively. Lows the morning of the 30th and 31st were near 60 degrees. Relative humidity for the same mornings peaked in the 60's and the minimum relative humidity readings were in the high 20's to 30's. There were strong winds in the afternoon and evening hours the day after cutting and the following day as well. Wind speeds reached approximately 30 mph.

Results and Observations: Wide windrows were ready to rake in the evening the day they were cut, but strong winds precluded raking. Instead, the wide windrows were raked the next morning. The wide windrows dried significantly faster than the conventional windrows, but because of the exceptional curing conditions (warm temperatures, very strong winds, and no dews) both windrow types were ready to bale the second morning after cutting. Although, the wide windrows had cured sufficiently to bale earlier, we needed to wait until the second morning for higher humidity to prevent excessive leaf loss.

August 5 - August 7, 1990

Cutting Date and Time: 7-8:00 a.m. on August 5, 1990

Yield: 1.6 tons/A

Weather: Very warm temperatures without the usual hot,

drying late-afternoon and evening winds. High temperatures were 108 degrees both days. Lows the two mornings after cutting were 75 and 71, respectively. Relative humidities were higher than usual for this time of year due to thunderstorm activity in surrounding areas. Minimum relative humidities were near 30 percent the day of cutting and the following day (relative humidities in the teens are common for this time of year). Maximum relative humidity was 60 percent the morning after cutting and 78 percent the next morning when plots were baled.

Results and Observations: High-desert growers typically bale directly out of the swath rather than raking and combining windrows as is done in other areas. Instead of raking, the edge of the wide windrows was flipped over so that the windrow was narrow enough to fit within the pick-up of the baler. We attempted baling the wide windrows the morning after cutting, but portions of the windrow were still too moist. Delmhorst moisture probe readings indicated moisture levels as high as 20 to 22 (too high to bale safely). Therefore, both the conventional and wide windrows were baled the second morning after cutting. Bales from the conventional windrows had some "slugs" (high moisture areas) and probably should not have been baled until the following day. Under more typical arid and breezy conditions it probably would have been possible to bale the wide windrows the morning after cutting.

October 15 - October 20, 1990

Cutting Date and Time: 11-12:00 a.m. on October 15, 1990

Yield: 1.3 tons/A

Weather: Fall conditions prevailed with moderate temperatures and higher morning humidities (conditions that were more similar to other areas of the state). The temperature reached 90 degrees on October 15 and only reached the low 80's for the next three days, October 16 through 18. Very strong winds (20 to 30 mph) began early morning on the 19th and continued throughout the day. Temperatures this day only reached 74 degrees. Minimum relative humidity for the cutting day and the following day was 17 percent. The minimum relative humidity was slightly higher, 30 to 40 percent for the next three days. The maximum relative humidity was near 90 percent each morning except for the windy morning, October 19, when the maximum relative humidity only reached 69 percent.

Results and Observations: The wide windrows were raked on the morning of the 17th, two mornings after cutting. We tried baling the wide windrows the next day, October 18th, but because of high humidity that morning the alfalfa was still too moist. Conventional windrows were still too green on the bottom to be raked on the 18th. Wide windrow would have been baled on the 19th but excessive winds that day prevented baling of the wide windrows and raking of the narrow windrows. Although wide windrows dried one to one and a half days faster than conventional windrows, both windrows had to be baled on the 20th because of the winds on the 19th.

Tulare County Studies

June 1 - June 7, 1990

Yield: 1.8 tons/A

Cutting Date and Time: Afternoon of June 1, 1990

Weather: Moderately warm temperatures with mild breezes. Hygrothermograph records indicated that temperatures peaked in the mid 80's. Minimum relative humidities each day were below 30% except for June 6, when minimum relative humidity did not fall below 40%.

Results and Observations: Wide windrows were raked on the morning of June 4, whereas the conventional windrows were raked the next day, June 5. Wide windrows were baled the morning of June 6. Conventional windrows were baled on the morning of June 8 after being flipped over to dry the underside. Regrowth was quite vigorous and transpiration was causing high moisture on the underside of the windrows. (The rest of the field was baled on June 9 because the windrows were so wet from the regrowth). Therefore, two days curing time were saved with the wide windrows.

July 26 - July 31, 1990

Cutting Date and Time: Early afternoon on July 26, 1990

Yield: 1.5 tons/A

Weather: Maximum temperatures reached the low to mid 90's. Due to a malfunction with the hygrothermograph, relative humidities are only available July 28, 29, and 30, when the minimum relative humidities were 35, 30, and 25%, respectively.

Results and Observations: The wide windrows were raked on the morning of July 29 and baled the next morning, July 30. The raking and baling of the conventional windrows were delayed one day (i.e. raked and baled on the mornings of July 30 and 31, respectively).

September 18 - September 24, 1990.

Cutting Date and Time: Early afternoon on September 18, 1990

Yield: 0.9 tons/A

Weather: This time period was plagued by clouds, high humidity, and sporadic showers. Minimum relative humidities for the time period were as follows: Sept. 21 - 31%; Sept. 22 - 39%; Sept. 23 - 42%; and Sept. 23 - 42%. Maximum temperatures ranged from the high 70's to the mid 80's.

Results and Observations: It sprinkled as the trays were weighed on the morning of September 21, the morning of September 22, and the afternoon of September 22. There was free moisture on the hay and trays during the morning weighing on September 22.

The wide windrows would have been raked on September 21, but the threat of rain postponed raking until the next day. Conventional windrows were raked on the morning of September 23. Both windrow types were baled on September 24.

Northeastern California Studies

July 2 - July 5, 1990 Quail Valley Ranch - Modoc County

Cutting Date and Time: July 2

Yield: 2.0 tons/A

Weather: High temperatures were in the 70's and minimum temperatures were in the high 30's to 40's. Minimum relative humidities were very low, resulting in fast drying conditions.

Results and Observations: Moisture measurements were made only at the time of cutting, one day after cutting, and three days after cutting. On the third day the hay was raked and no further moisture determinations were made. It was noted that the wide windrows could have been raked on the second day.

October 1 - October 9, 1990 Goose Valley Ranch - Shasta County

Cutting Date and Time: October 1

Yield: 0.9 tons/A

Weather: Maximum temperatures during this time period were in the 60's and 70's. Minimum temperatures ranged from 21 to 44 degrees, with the average low temperature being 33 degrees. Wide temperature swings resulted in heavy dew moisture despite daytime relative humidities that declined as low as the teens.

Results and Observations: There was no significant difference in drying rate for this low-yielding cutting. Both wide and narrow windrows were baled at the same time. A raking treatment was also included in this study. Turning the windrow greatly improved the hay drying rate more than windrow width for this low-yielding fall cutting.

The drying rate information is presented in table two and represented graphically in the figures that follow. The moisture percentages calculated from the weights on the trays is probably slightly lower than the actual moisture content. This is possibly due to the fact that it was difficult to completely oven dry the large amount of alfalfa on the trays. Therefore, there was actually more moisture in the hay than the values indicate and this would be exaggerated at the lower moisture levels (close to the time when the alfalfa was baled). Also, weighing error is greater at the low moisture levels. However, the critical values for comparing windrow types are the higher moisture levels, prior to raking. The drying rate after raking should be similar for both windrow types since they are raked into the same width.

The drying rate differed dramatically between locations. The alfalfa dried significantly faster in the high desert compared to the other locations due to the high temperatures, low daytime humidities, lack of dew, and often windy conditions. As one would expect, mid-summer cuttings dried quicker than spring or fall cuttings in all locations.

Wide windrows dried significantly faster than conventional windrows with the exception of the fall cutting in Tulare and Shasta Counties, when there was no significant difference in drying rate. In general, wide windrows were ready for raking one day sooner than conventional windrows. The ability of the grower to take advantage of the faster drying rate depended on weather conditions at the time when the alfalfa had dried to a

moisture content suitable for baling. For example, wide windrows dried faster for the spring cutting in the San Bernardino County trial. However, since they did not dry twice as fast (a full 24 hrs. faster), baling of the wide windrows had to be delayed until the following day when conventional windrows were just ready to bale.

According to Rotz, wide windrows dry faster because the forage is spread out thinner and more of the alfalfa is exposed to radiant solar energy. Also, moisture movement is not as inhibited in a wide windrow as it is in narrow windrows. Therefore, the greatest advantage for wide windrows occurs during high-yielding cuttings when swath density is greater than it is for low-yielding cuttings. For example, two days curing time were saved on the high-yielding early June cutting in Tulare County compared to no savings on the low-yielding last cuttings in Tulare and Shasta Counties. Also, it appears that for most areas the greatest advantage may occur in the spring, followed by the summer, and somewhat less to no advantage in the fall. The exception to this is the high desert where the advantage of wide windrows still exists in fall, when conditions are more like other areas during the rest of the year. The reason for this difference between seasons is probably two-fold. First, spring cuttings are usually higher yielding than fall cuttings. Secondly, solar radiation is greater in the spring than the fall, thus providing less of an advantage to wide windrows compared to conventional narrow windrows in the fall. Also, there are typically heavier morning dews in the fall. A wide windrow exposes more alfalfa to dews and other forms of precipitation. Hence, the advantage of greater solar radiation exposure with wide windrows may be outweighed by greater exposure to heavy dew or precipitation during the fall in some areas.

Soil moisture may also influence drying rate and alter the comparative advantage of wide thin swaths versus narrow thicker swaths. Just as the wide windrow exposes more of the alfalfa to dew, the wide windrow exposes more alfalfa to soil moisture. Therefore, under high soil moisture conditions a wide windrow may not prove as beneficial.

There are some possible disadvantages of wide windrows for some growers. Wide windrows must be raked before baling so that they can be narrowed to fit within the baler pick-up. This is a disadvantage in the few locations where alfalfa is not usually raked prior to baling. For example, in the high desert most cuttings are not raked, as raked windrows are especially susceptible to being scattered by wind. Another disadvantage to extremely wide windrows is that some growers may not have rakes that can spread wide enough to rake and combine two wide windrows. The solution to this problem may be to narrow the windrow slightly to a width that can be handled by the rake or to purchase rakes that offer a greater extension (i.e. 16 rather than 13 wheel "V" rakes).

There has been some concern that there would be greater sun bleach with wider windrows because more alfalfa is directly exposed to the elements. However, in our research we found no difference in the degree of bleach in wide compared to narrow windrows. A plausible explanation is that while wide windrows expose more alfalfa to the elements, they are usually raked and baled sooner so their exposure time is less. Also, wide windrows are only left wide during the initial drying phase or until they have dried sufficiently to rake. Little sun bleaching occurs during the initial phases of curing, as the waxy cuticle of the plant is largely intact. During the final curing phase, when most bleaching occurs, wide windrows would have been raked and combined and their width is essentially the same as raked conventional windrows.

Only the Tulare County trials were analyzed for quality. There was no significant difference in quality for any of the three cuttings. There was a visual improvement with the wide windrow bales for the first cutting (better leaf retention and less shatter), but the visual difference was not reflected in the NIR quality analysis.

Another factor to consider when evaluating windrow types is the uni-

formity of dry down. We measured average windrow moisture in these trials. However, timing of baling and raking operations is not limited as much by the average windrow moisture content, but rather by the moisture content of the wettest portion of the windrow. Although difficult to measure or quantify, wide windrows did dry more uniformly. Therefore, the difference in average windrow moisture content in the tables may be only 10 to 15 percent lower, but since wide windrows dried more uniformly, they could be raked or baled earlier.

In conclusion, the advantages of more rapid curing are numerous. Wide windrows (seven foot) did dry faster than the conventional windrows (3.5 foot). The advantage was greatest in heavier cuttings and during the spring and summer when solar radiation is greatest. There is nothing "magical" about the seven foot width. A five and a half or six, or even eight foot windrow, may be best under certain conditions. Growers should not let tradition dictate windrow width. They should experiment with different windrow widths to determine the width most suited to their climatic conditions, yield level, and the equipment they have at their disposal.

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Table 1. Windrow moisture content (%) of alfalfa hay cured in conventional versus wide windrows. San Bernardino County (Newberry Springs)

Second Cutting May 29, 1990

Windrow	May 29	May 30	May 31
Width	pm	am pm	am
3.5 ft	60	37*	Impossible to get accurate weights
7.0 ft	47	28	after raking due to strong gusty winds

Both windrows were baled on 5/31.

Fourth Cutting August 5, 1990

Windrow	Aug 5	Aug 6	Aug 7
Width	pm	am pm	am ¹
3.5 ft	46	27 12	10
7.0 ft	18	12 5	8

Wide windrows were slightly too wet to bale on 8/6; both windrows were baled on 8/7.

Sixth Cutting October 15, 1990

Windrow	Oct 15	Oct 16	Oct 17	Oct 18	Oct 19	Oct 20
Width	pm	am pm	am pm	am pm	am pm	am ¹
3.5 ft	71	67 51	*38 23	22 14	Too windy	13
7.0 ft	61	52 25	21 14	10 8	to weigh	12

Both windrows baled on October 20th but wide windrow would have been baled on the 19th, but was not feasible because of strong winds.

¹Moisture determined from core samples of bales rather than weighing trays

* indicates time of raking

Table 2. Windrow moisture content (%) of alfalfa hay cured in conventional versus wide windrows. Tulare County

Second Cutting June 1, 1990

Windrow Width	June 1 pm	June 2 am pm	June 3 am pm	June 4 am pm	June 5 am pm	June 6 am pm	June 7 am
3.5 ft	81	76 66	58 45	37 25	23*17	15 10	17
7.0 ft	77	71 49	41 26	23*14	12 8	7	

Narrow windrow baled 6/8 am; Wide windrow baled 6/6 am.

Fourth Cutting July 26, 1990

Windrow Width	July 26 pm	July 27 am pm	July 28 am pm	July 29 am pm	July 30 am pm	July 31 am
3.5 ft	69	50 27	23 5	13 1	9 *2	9
7.0 ft	70	48 22	21 6	15 *5	13	

Narrow windrow baled 7/31 am; Wide windrow baled 7/30 am.

Sixth Cutting September 19, 1990

Windrow Width	Sept 18 pm	Sept 19 am pm	Sept 20 am pm	Sept 21 am pm	Sept 22 am pm	Sept 23 am pm	Sept 24 am
3.5 ft	73	63 41	39 19	22 11		28* 8	19
7.0 ft	75	61 40	39 22	24 12		22 8	

Both baled 9/24 am.

* indicates time of raking

Table 3. Windrow moisture content (%) of alfalfa hay cured in conventional versus wide windrows. Northeastern California

First Cutting July 2, 1990 Modoc County

Windrow Width	July 3	July 4	July 5
3 ft	46	-	21
7 ft	38	-	21

Swathing and Measurements 3-5 p.m., Raking on July 5th

Fourth Cutting October 1, 1990 Shasta County

Windrow Width	Oct 1	Oct 2	Oct 3	Oct 4	Oct 5	Oct 6	Oct 7	Oct 8	Oct 9	Oct 10
3.5 ft	78	41	30	27	27	30	26	26	-	26
7.0 ft	78	38	31	28	28	30	26	25	-	24
Single windrow rake						15				
Double windrow rake							14			
After baling								12		

Swathing and measurements 3-5 p.m., Raking and baling a.m.

Note: Due to weather, raking was required to dry alfalfa below 24%.

Figure 1. Windrow moisture content of alfalfa hay cured in conventional versus wide windrows. San Bernardino County

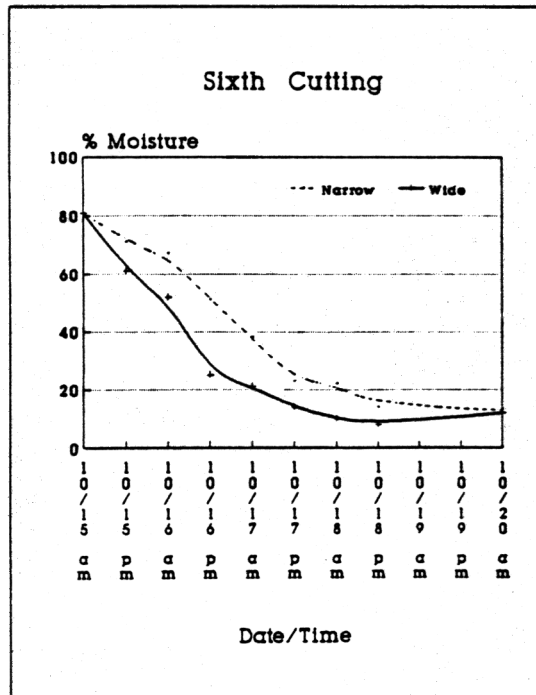
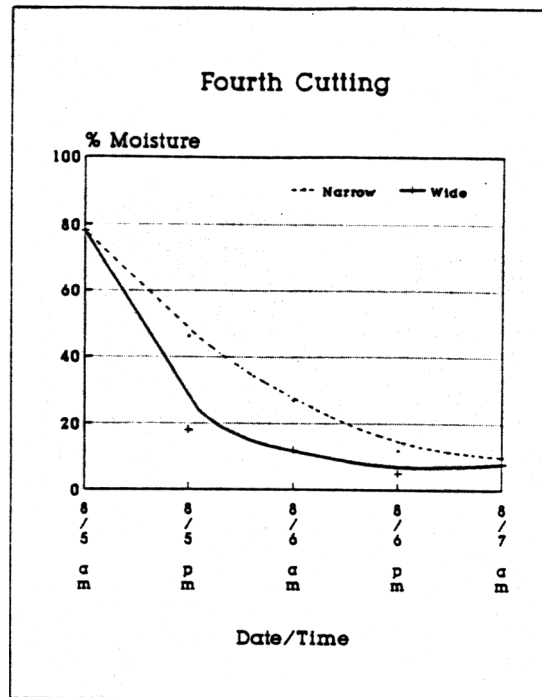
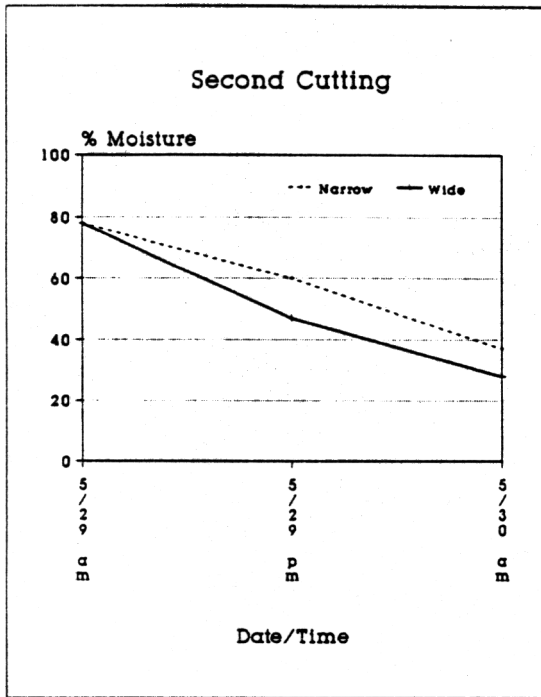


Figure 2. Windrow moisture content of alfalfa hay cured in conventional versus wide windrows. Tulare County

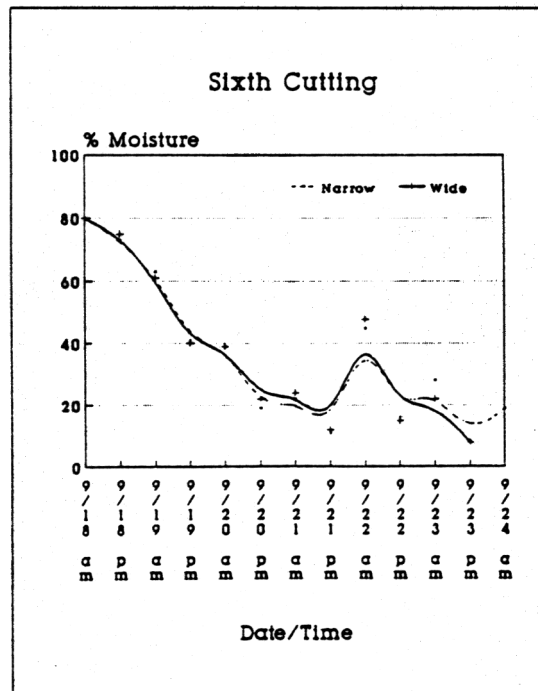
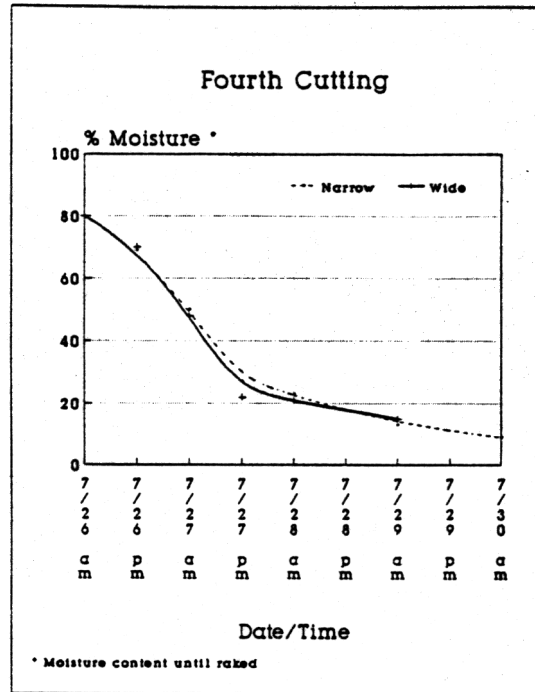
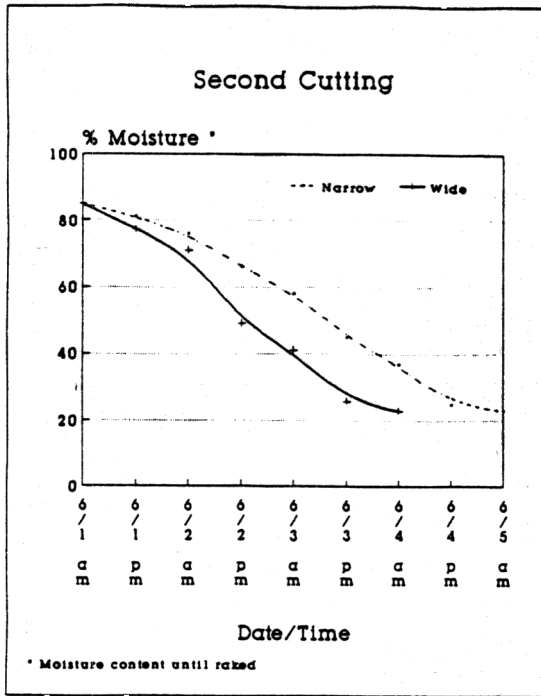


Figure 3. Windrow moisture content of alfalfa hay cured in conventional versus wide windrows. Northeastern California

