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dissertation entitled

PREDICTING FIRST-CUT ALFALFA YIELD FROM WINTER WEATHER
AND EVALUATING ALTERNATIVE FORAGE PRODUCTION SYSTEMS

presented by

John Calvin Durling

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Crop & Soil Sciences

Alan B. Holmes
Major professor

Date November 15, 1994

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**PREDICTING FIRST-CUT ALFALFA YIELD FROM WINTER WEATHER AND
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John Calvin Durling

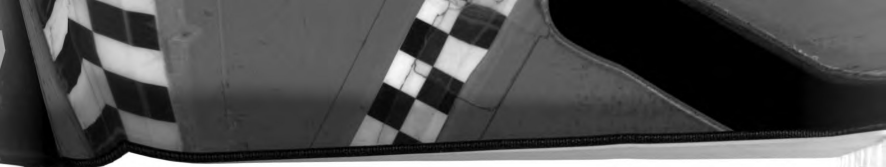
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ABSTRACT

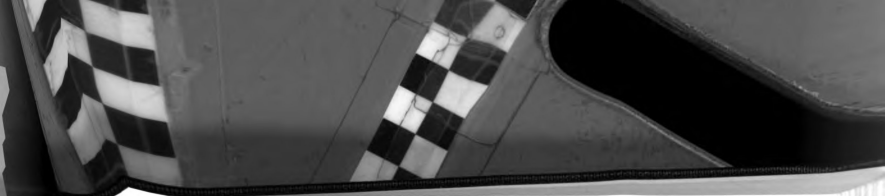
PREDICTING FIRST-CUT ALFALFA YIELD FROM WINTER WEATHER AND EVALUATING ALTERNATIVE FORAGE PRODUCTION SYSTEMS

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Reliable predictions of first-cut alfalfa (*Medicago sativa* L.) yield could assist producers in the northern sections of the USA in forecasting forage availability and in deciding whether to replace an existing stand. Mathematical models, developed using regression analysis of first-cut alfalfa yields on antecedent over-winter weather data from E. Lansing, MI, between 1972 and 1988, explained 65-76% of yield variability. Models included either winter temperature cycles (based on fluctuations of daily mean temperature in winter) or winter degree days, and spring growing degree days. Winter temperature cycles and winter degree days were negatively correlated with yield while spring growing degree days were positively correlated with yield. Validation predictions averaged $\pm 15\%$ of measured yields in 1989 to 1992 but 33% above measured yields in 1993 when conditions not included in the models (i.e., extremely wet soil in fall and spring) were major yield determinants.

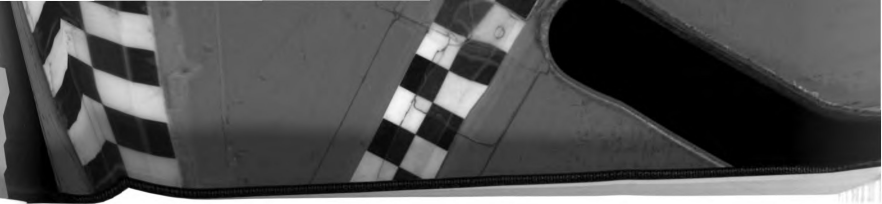
In years when alfalfa stands are injured and first-cut yield decreases are predicted, producer interest is increased in double cropping first-cut alfalfa with corn (*Zea mays* L.) silage. Simulation was used to evaluate and compare corn silage following first-cut alfalfa with



single-crop corn silage and 4-cut alfalfa systems over 26 years of south central Michigan weather conditions. Model validation was done using two years of independent E. Lansing, MI field data. The alfalfa/corn silage double-crop system was less profitable than single-crop corn silage and/or 4-cut alfalfa in 22 of the 26 years. In sensitivity analyses using forage prices representing historical extremes, varied first-cut dates, and realistic changes in forage yields, the maximum number of years in which the double-crop system was more profitable than both single-crop and four-cut alfalfa was 7 of 26.

Comparative breakeven analysis as a tool for making an economic comparison of a single crop and a double-crop alternative is presented. Comparative breakeven analysis is illustrated through a comparison of single-crop corn silage and double-crop corn silage following first-cut alfalfa.

Management practices for reducing winter injury to alfalfa are described. A method for assessing yield loss due to alfalfa stand reduction is presented and illustrated.



DEDICATION

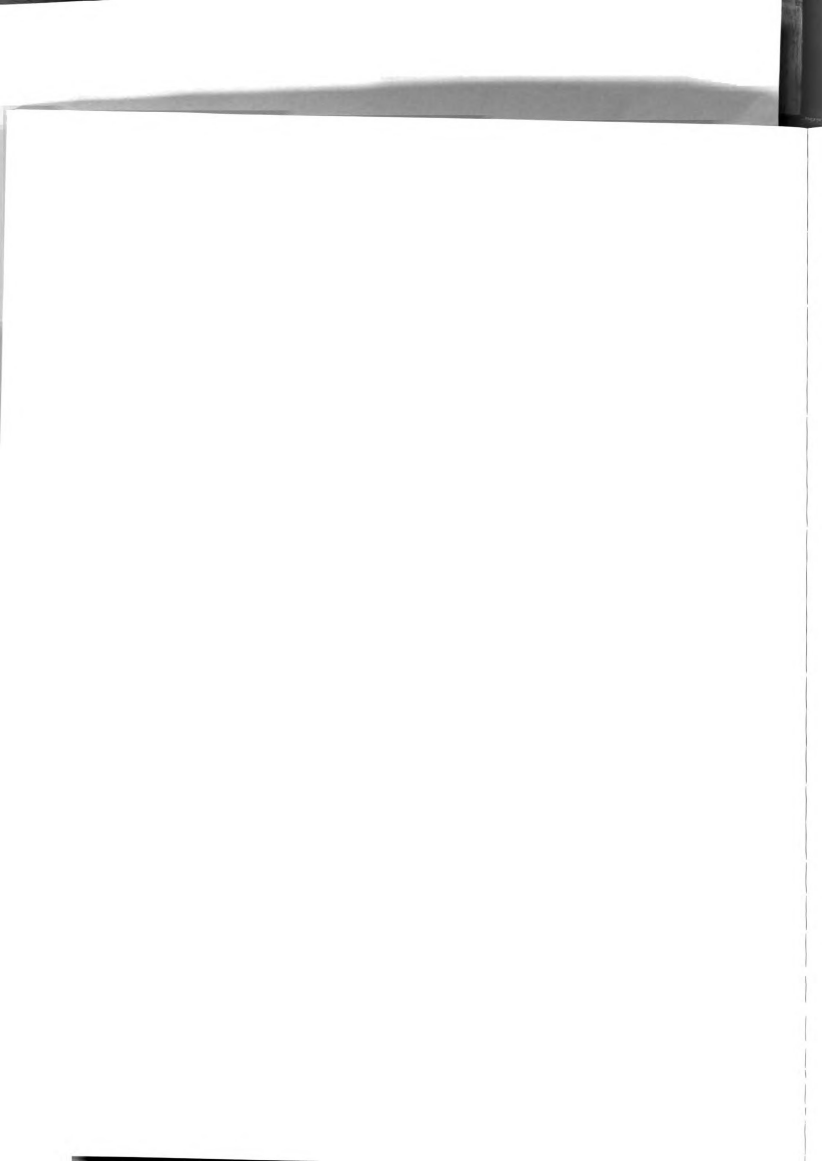
To my wife Lori and to our children Taylor, AnnaLiese,
and Esther.

ACKNOWLEDGMENTS

I want to express my sincere appreciation to Dr. Oran B. Hesterman for guidance in the course of this investigation and manuscript preparation. Moreover, I want to express my appreciation for the rewarding career opportunities that I've experienced under his supervision.

I also want to thank Drs. C.A. Rotz, G.D. Schwab, and M.L. Vitosh for their critical reviews of this manuscript and the faculty, students, and staff with whom I've worked for their camaraderie and support.

Acknowledgment is made to the Michigan Agricultural Experiment Station for support of this research.



PREFACE

Chapters one and two of this dissertation are written in the style required for publication in the *Journal of Production Agriculture*. Chapter one has been accepted for publication in the *Journal of Production Agriculture*. Chapter three is written in the style of an Extension publication and chapter four was published in 1991 as Michigan State University Extension Bulletin E-2310.

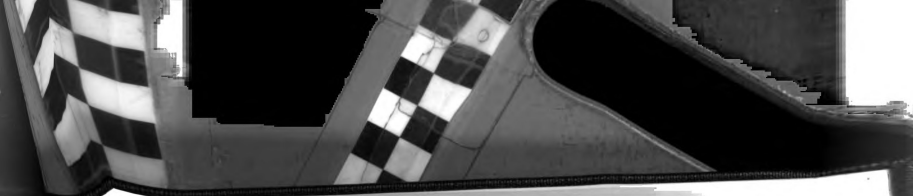


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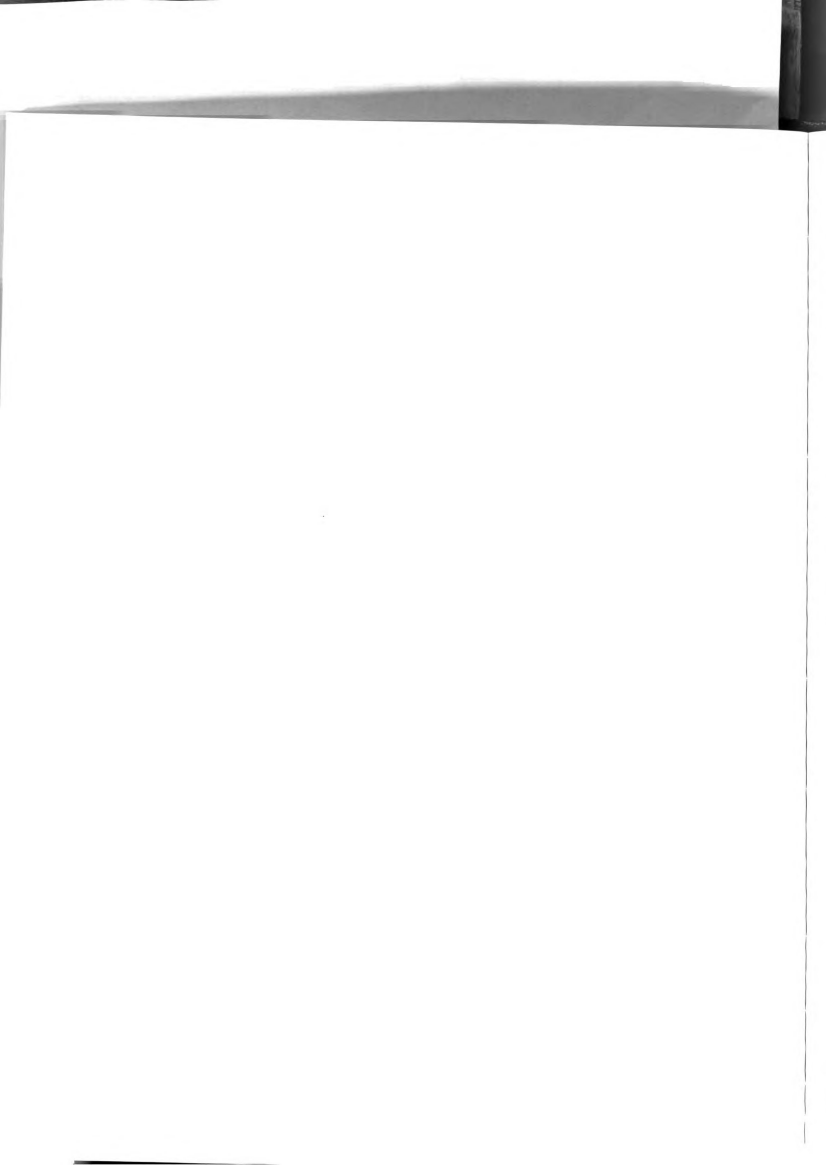
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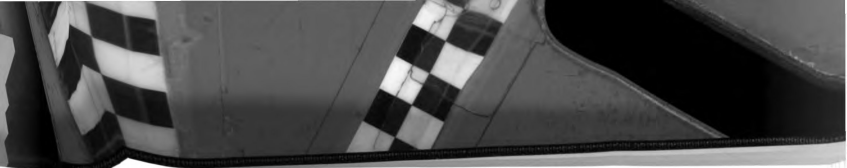
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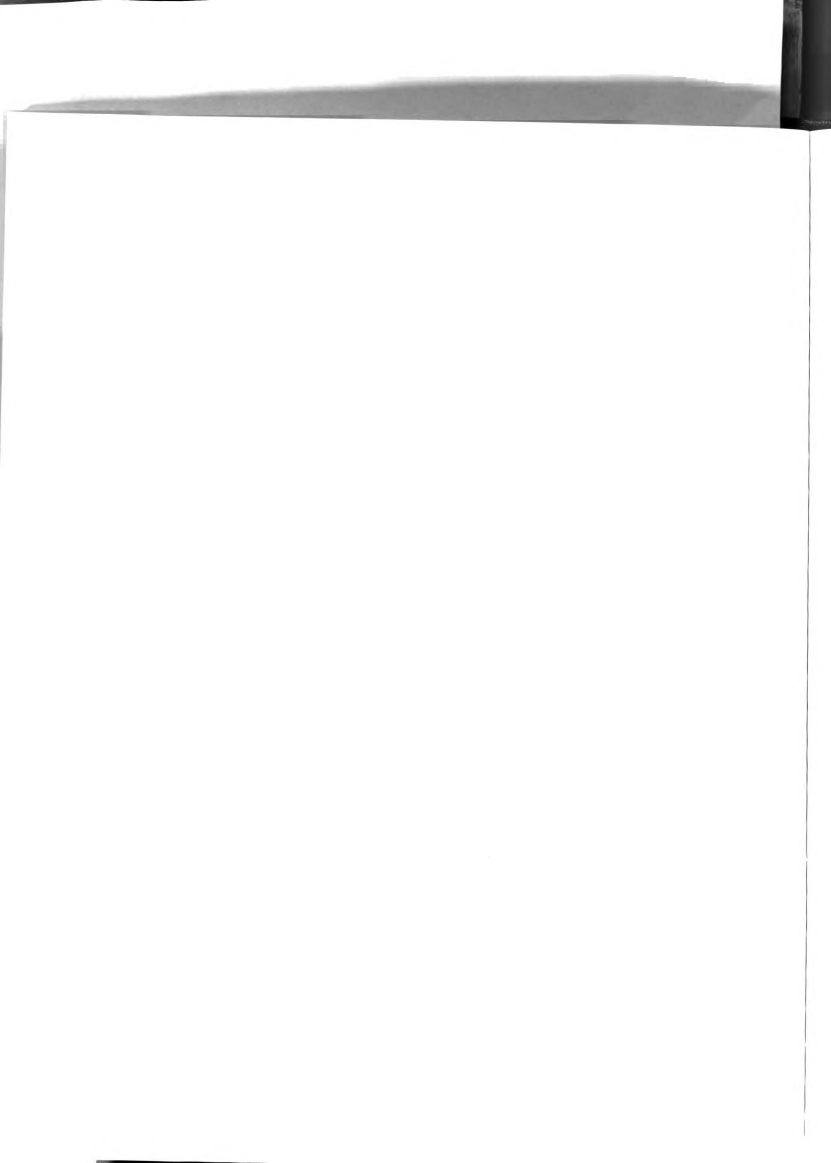
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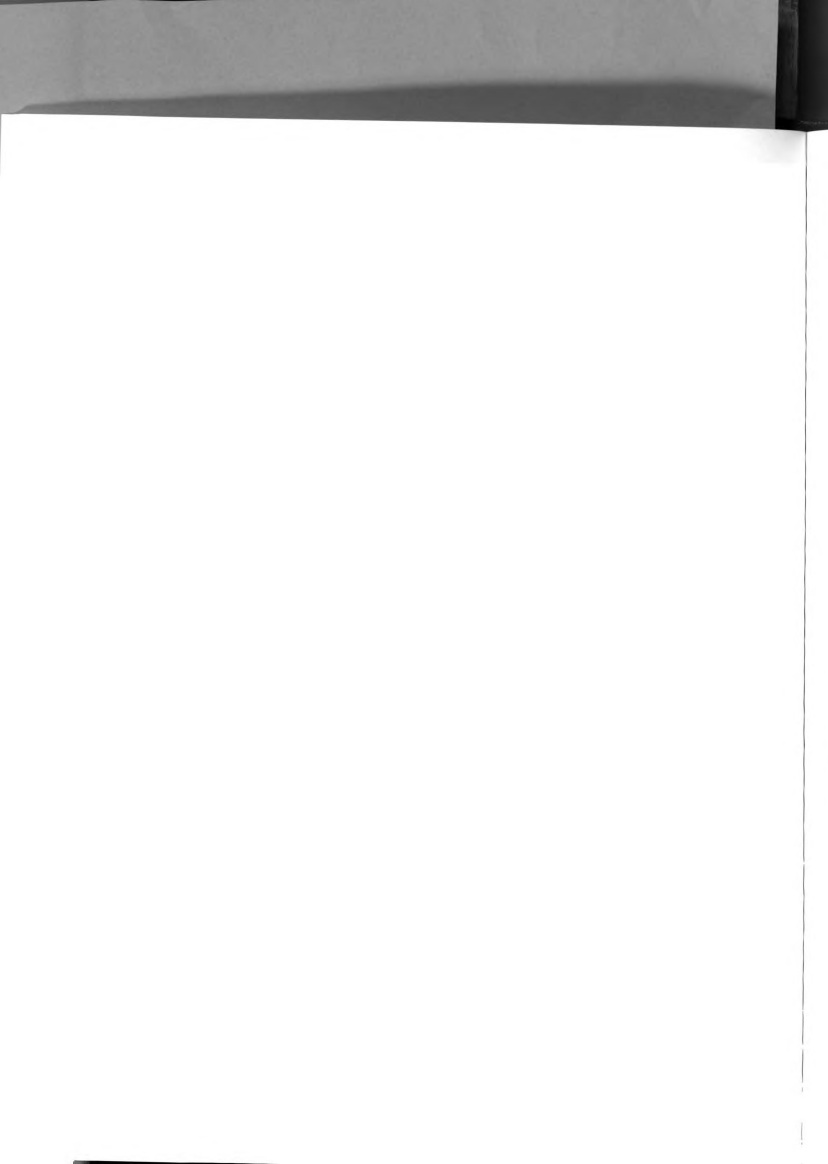


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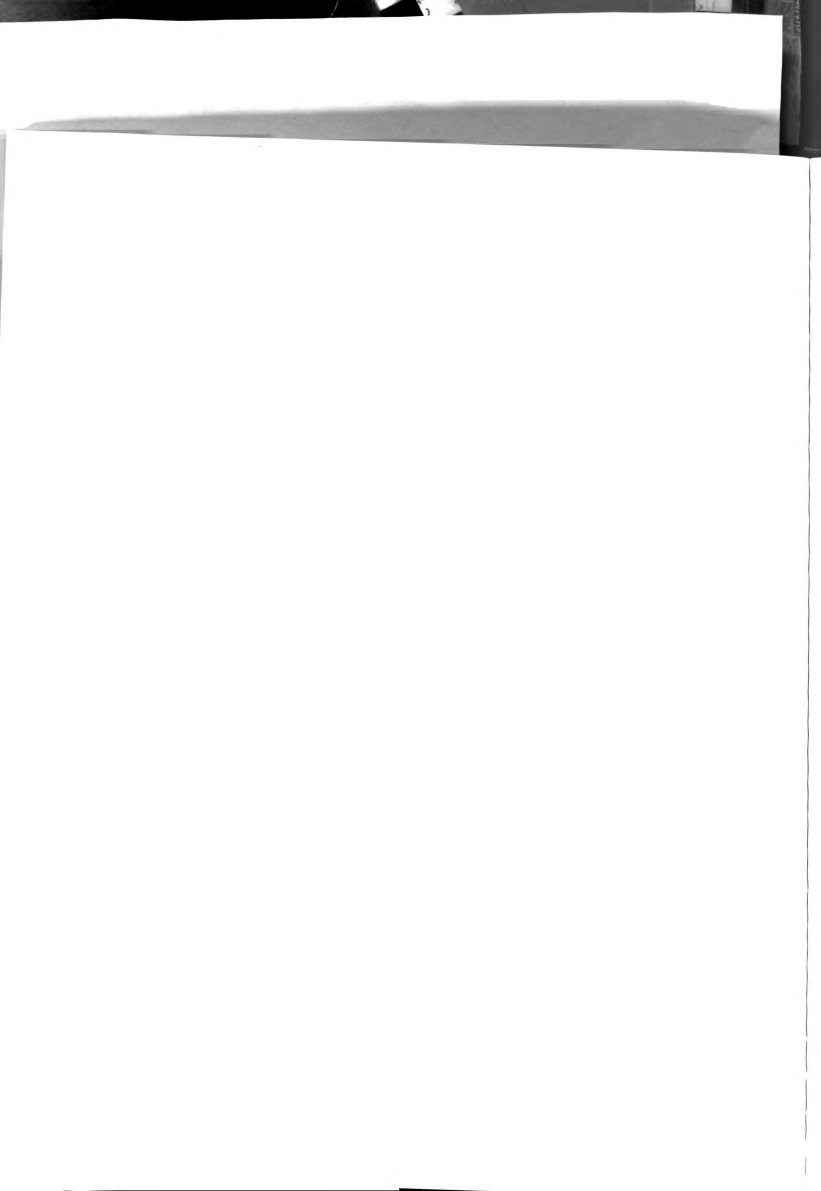
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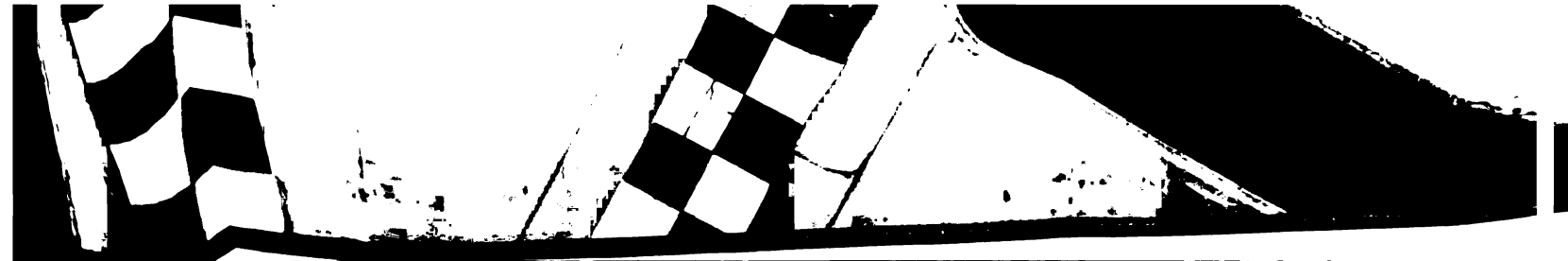
CHAPTER ONE

PREDICTING FIRST-CUT ALFALFA YIELDS FROM PRECEDING WINTER WEATHER CONDITIONS

ABSTRACT

In the northern USA, reliable predictions of first-cut alfalfa (*Medicago sativa* L.) yields could assist producers in forecasting forage availability for the coming season and in deciding whether to replace an existing stand. A mathematical model using over-winter weather variables was developed for predicting first-cut yield of moderately winter-hardy alfalfa cultivars. Models for the second year, third year, and combined second and third years after seeding were developed using regression analysis of first-cut yields on antecedent over-winter weather data from E. Lansing, MI between 1972 and 1988. Models explained 76% of variability for second year data, 69% for third year data, and 65% for combined data. The three models used either winter temperature cycles (based on fluctuations of daily mean temperature) or winter degree days and spring growing degree days to predict yield. Winter temperature cycles and winter degree days were negatively correlated with yield while spring growing degree days were positively correlated with yield. Validation predictions averaged $\pm 15\%$ of measured yields in 1989 to 1992 and 33% above measured yields in 1993 when conditions not included in the models (i.e., extremely wet fall and spring soil conditions) were major yield determinants. Models like those developed in

this study may provide an alfalfa management tool for producers, Extension workers, and consultants. These models also may improve the simulation of winter injury in existing alfalfa growth models. Care must be exercised, however, in using any model developed at a single location to predict crop yields in other (especially dissimilar) locations.



INTRODUCTION

In the early spring following a severe winter, alfalfa (*Medicago sativa* L.) producers would like to be able to predict first-cut yield to adjust for possible forage shortfalls or to decide whether to maintain or replace a stand (Suzuki, 1973). Such predictions are more important in areas where winters vary in severity and amount of snow cover. A model for predicting first-cut yield based on over-winter (fall, winter, and spring) weather conditions could provide an effective decision aid for producers. First-cut (spring) yields of alfalfa are largely determined by plant response to fall, winter, and spring environmental conditions; sublethal and/or lethal plant injury will decrease yield.

Winter hardiness establishes the potential of a crop to survive the winter. A major component of winterhardiness is cold hardiness, or the capacity of a plant to survive the effects of freezing temperature. Cold hardiness is developed in alfalfa in response to decreasing temperatures and daylengths during the fall (Tysdale, 1933). Warm periods during the winter may cause alfalfa regrowth, resulting in a reduction of stored food reserves and a loss of cold hardiness (Dexter, 1941). With reduced food reserves, subsequent rehardening may not be complete.

Frost heaving, or a lifting of plants caused by ice formation and accumulation in the soil, is another type of injury associated with temperature fluctuations. Frost



heaving may mechanically injure alfalfa roots and expose crowns and roots to desiccation and freeze damage. Lifted plants also may be cut below the crown when harvested. Portz (1967) observed that frost heaving was positively correlated with soil moisture and with temperature fluctuations.

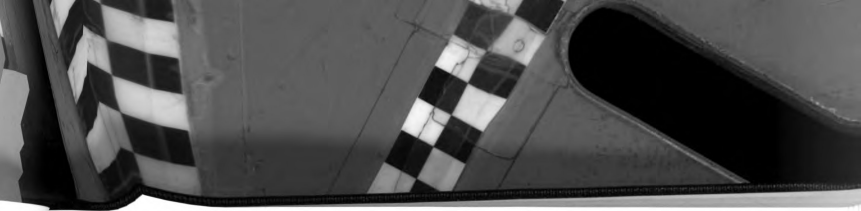
Persistent ice sheeting is another environmental condition that can injure or kill alfalfa during winter. Ice-encased plants may be smothered by metabolic byproducts (e.g., CO_2 , ethanol, and methanol) or may be injured when exposed to cold air due to the low insulation value of ice. Snow cover, however, is usually beneficial to alfalfa, offering protection from extremely cold and fluctuating temperatures. In an exceptionally cold Michigan winter, soil covered with vegetation and a layer of snow was 25°F warmer than a bare soil at 3-inch depth (Bouyoucos, 1916). Other environmental conditions with an observed or suspected effect on first-cut yield (e.g., photoperiod and soil moisture during hardening), have been investigated in the laboratory, greenhouse, and field (McKenzie et al., 1988).

Although the effects of over-winter weather conditions on alfalfa are documented, few studies have attempted to quantify the impact of winter weather on first-cut yield. Sharratt et al. (1986) evaluated the relative importance of fall, winter, and spring weather conditions to first-cut yield in a three-cut harvest system. In their study, over-winter weather variables based on precipitation, daily

minimum and maximum temperature, and solar radiation summarized for discrete periods accounted for 40 to 50% of first-cut yield variability. The relative importance of these over-winter weather variables depended on stand age. Existing models of alfalfa growth do not consider over-winter weather conditions in making growth and development predictions (Fick and Onstad, 1983; Onstad and Shoemaker, 1984; Selirio and Brown, 1979; Smith and Loewer, 1983).

The overall objective of this study was to develop a model for predicting first-cut alfalfa yield based upon over-winter weather in a northcentral location in the USA. Specific objectives were:

1. To determine the relative importance of fall, winter, and spring weather variables to first-cut yield in the second and third years following seeding.
2. To develop a multiple regression model for predicting first-cut yield of moderately winter-hardy cultivars in the second and third years after seeding based upon over-winter weather variables.
3. To validate the predictive model by comparing predicted with 1989 to 1993 measured yields from E. Lansing, MI.



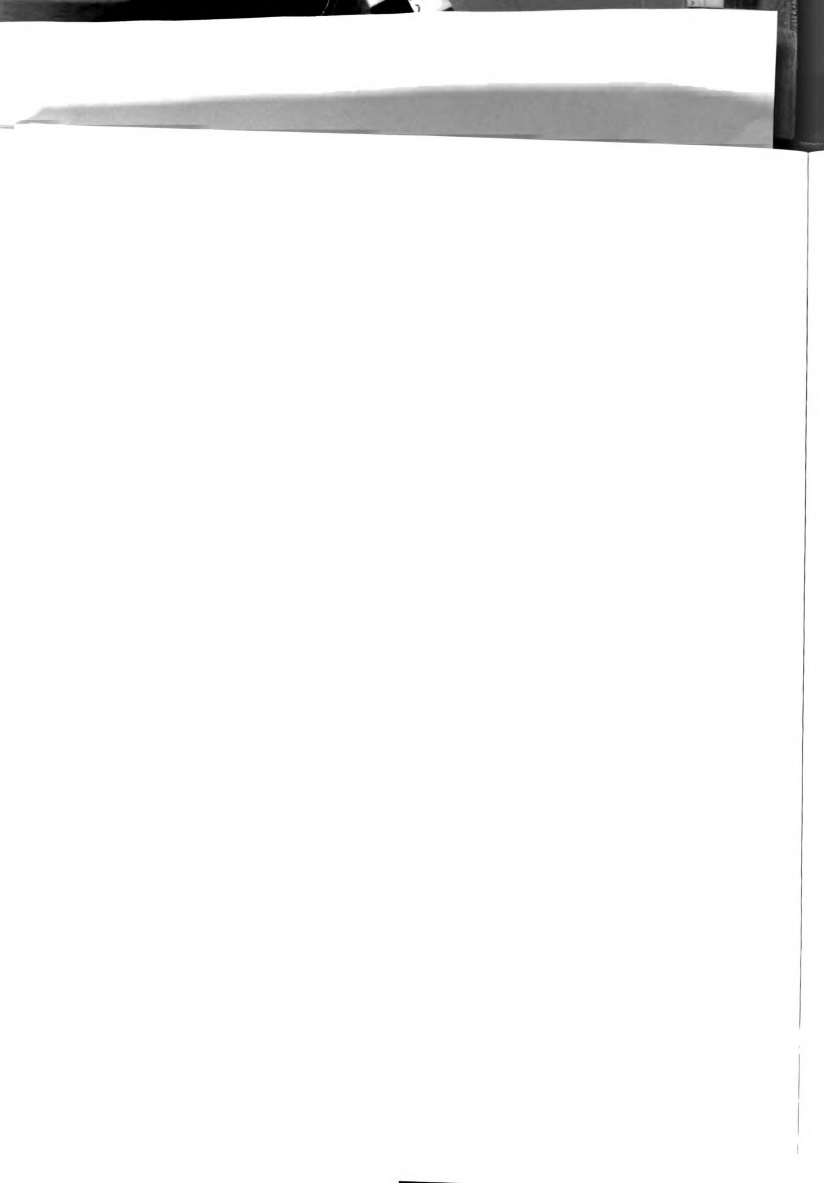
MATERIALS AND METHODS

First-cut yields in the second and third years after seeding of moderately winter-hardy cultivars, i.e., cultivars with Minnesota winterhardiness indices from 4.4 to 4.6 (Univ. of Minnesota, 1989-93), were obtained from Michigan State Univ. alfalfa variety trials (Tesar, 1975-76; Tesar et al., 1972, 1980-86; Hesterman et al., 1988) in E. Lansing, MI for model development. E. Lansing yield data from 1989 to 1993 (Hesterman et al.) was used for model validation. Moderately winterhardy cultivars were included in the study for their assumed similar response to winter weather conditions and for their prevalence on Michigan farms. Second and third year after seeding yields were included for their greater susceptibility to winter injury than in the first year. Mean yields (dry matter t/acre) of four replications in a randomized complete block were used for model development and validation.

Variety trials were conducted on tiled, well drained, neutral pH, Brookston (fine-loamy, mixed, mesic Typic Argiaquolls), Conover (fine-loamy, mixed, mesic Udollic Ochtaqualfs), and Kibbee (fine-loamy, mixed, mesic Aquollic Hapludalfs) loams. Stands were maintained under near optimum conditions with soil test levels above 90 lb/acre for P and above 350 lb/acre for K. After the seeding year, alfalfa was subjected to a four-cut harvest system with cut 1 taken in late May to early June, cut 2 on 5 to 15 July, cut 3 on 15 to 25 August, and cut 4 after 15 October.

Daily weather data (National Oceanic and Atmospheric Administration, 1972-1993) were obtained from the Michigan State Univ. weather station at 42°40' N, 84°29' W, 880 ft ASL, about three miles from the site of the alfalfa variety trials. Weather data included daily maximum and minimum air temperature, precipitation, and snow depth.

Over-winter weather variables were summarized for discrete periods designated as prehardening, hardening, winter, and spring, utilizing an approach similar to Sharratt et al. (1986) but modified for a four-cut system. These periods were delineated by cutting dates, temperature thresholds, and calendar dates. The prehardening period began with the third cut in the fall (mid-August) and lasted until the first occurrence of a maximum daily air temperature of 59°F or less (mid-September). Fifty-nine degrees F is the upper reported threshold for the hardening process in alfalfa (Tysdale, 1933). The hardening period followed the prehardening period and lasted until the first occurrence of an air temperature of 26°F or less (late October). Reported killing frost temperatures for top growth range from 13 (McKenzie and McLean, 1982) to 27°F (Nath and Fisher, 1971). An analysis of E. Lansing data indicated that models using the first occurrence of 26°F or lower to delineate the beginning of winter were more effective in explaining yield variability than models using higher or lower temperatures. Winter was defined as ending on 15 March for purposes of degree day and on 14 April for



temperature cycle accumulations. These cut-off dates were used because: (i) they accounted for more variability (higher r^2) than other dates in a preliminary analysis of the data and (ii) the 15 March cut off isolated the effect of mid-winter warming from the effect of warming in the spring. Spring for purposes of this study began on 15 April and lasted until the first cut (late May or early June).

Weather variables for the prehardening, hardening, winter, and spring periods as defined above were evaluated for their effect on alfalfa yield. Variables in this study included:

1. PHDAYS. Calendar days in prehardening period.
2. HDAYS. Calendar days in hardening period.
3. SDAYS. Calendar days in spring.
4. PHPREC. Avg. daily precipitation in prehardening period (in.).
5. HPREC. Avg. daily precipitation in hardening period (in.).
6. SPREC. Avg. daily precipitation in spring (in.).
7. PHGDD. Accumulated growing degree days in prehardening period.
8. HGDD. Accumulated growing degree days in hardening period.
9. WDD. Accumulated degree days from beginning of winter until 15 March.
10. SGDD. Accumulated growing degree days in spring from 15 April until first cut.

11. WMINT. Minimum daily air temperature during winter period.
12. WTC. Temperature cycles from beginning of winter until April 14.

Thermal time in degree days was calculated as daily mean temperature less a given base temperature summed over the respective period. Degree days were calculated using base temperatures from 32 to 80°F in 0.5°F increments for the prehardening, hardening, and winter periods. No increase in simple r^2 was observed when yields were regressed on accumulated growing degree days based on temperatures outside this range. Spring growing degree days were calculated at 38.5°F, the base suggested by Sharratt et al. (1989).

Winter temperature cycles (WTC) were calculated using a range of base temperatures (27 to 37°F) over all winter days or over days when snow depth was less than 25, 20, 15, 10, 6, 5, 4, 3, 2, and 1 in. Snowdepth was considered in the WTC calculation to take into account its insulation value. One-half WTC was counted for each time the mean daily air temperature either rose above or fell below a given base temperature on a day when snow was less than a given depth. In a similar approach by Portz (1967), the number of times the weekly mean air temperature crossed the freezing mark was used to predict frost heaving. Selected characteristics of the weather variable and yield data sets are shown in Table 1.1.

Table 1.1. Range and mean of first-cut alfalfa yield and selected weather variables used in development of prediction models. Numbers in parentheses represent the means of given variables. N denotes the number of observations. E. Lansing, MI. 1972-88.

Data Set	N	Yield (tons/acre)	HDAYS	SDAYS	PHPREC	PHGDD ₆₉	WDD ₅₁	SGDD _{38.5}	WTC _{31.6}
Second yr after seeding	42	2.01-3.67 (2.91)	10-69 (35)	40-61 (55)	0.02-0.16 (0.11)	3.5-106.5 (41.4)	0-81 (22.4)	600.5-1263.0 (967.7)	8.5-15.0 (11.9)
Third yr after seeding	37	1.92-3.60 (2.50)	10-69 (40)	32-66 (51)	0.03-0.25 (0.15)	11.0-94.5 (33.4)	0-95 (24.6)	630.0-1256.5 (894.0)	8.5-20.0 (13.5)
Combined years	79	1.92-3.67 (2.72)	10-69 (37)	32-66 (53)	0.02-0.25 (0.13)	3.5-106.5 (37.7)	0-95 (23.4)	600.5-1263.0 (933.2)	8.5-20.0 (12.6)

HDAYS = calendar days in hardening period.

SDAYS = calendar days in spring.

PHPREC = avg. daily precipitation (in.) in prehardening period.

PHGDD₆₉ = accumulated growing degree days above 69°F in prehardening period.

WDD₅₁ = accumulated growing degree days above 51°F from beginning of winter until 15 March.

SGDD_{38.5} = accumulated growing degree days above 38.5°F in spring from 15 April until first cut.

WTC_{31.6} = temperature cycles at 31°F on winter days with less than 6 in. snow cover.

Simple linear regression analyses were performed with each of the previously mentioned weather variables as the independent variable and first-cut yield as the dependent variable. The simple regression analysis was important for determining which form of a given independent variable (e.g., growing degree days at various base temperatures) was most suitable for inclusion in the multiple regression equation. Further simple regression analyses were performed using various transformations of weather variables to determine whether responses might be curvilinear. These transformations did not increase coefficients of determination between weather variables and yield; therefore, linear responses were assumed over the range of available data.

Multiple regression analysis was used to develop equations for first-cut yield in the second, third, and combined second and third years after seeding. Variables included in each equation were determined by a forward selection procedure (Glantz and Slinker, 1990). The forward selection algorithm began with no independent variables in the regression equation. Each candidate independent variable was tested to see how it would reduce the residual sum of squares if it were included in the equation, and the one that caused the greatest reduction was added to the regression equation. Next, each remaining independent variable was tested to see if its inclusion in the equation would significantly ($P \leq 0.01$) reduce the residual sum of

squares further, given the other variables already in the equation. At each step, the variable that produced the largest incremental reduction in residual sum of squares was added to the equation, with the steps repeated until none of the remaining candidate independent variables significantly reduced the residual sum of squares. When a variable was significantly related to first-cut yield at more than one base temperature or snow depth, only the form of the variable with the highest r^2 in the combined second and third years after seeding was considered as a candidate independent variable for inclusion in the multiple regression equation.

Data from the second and third years after seeding were analyzed separately to develop a unique multiple regression model for each year. Moreover, a model for the combined second and third years was developed using weather data from both years and year after seeding (YEAR) as independent variables.

Models were validated by comparing predicted and measured yields. Data used in the model validation, i.e., first-cut yields from 1989 to 1993 and antecedent over-winter weather, were not used in the development of these models.

RESULTS AND DISCUSSION

Second Year

Table 1.2 shows the seven weather variables which were associated with first-cut yield in the second year after seeding. Winter degree days above 51°F (WDD_{51}), WMINT, winter temperature cycles at 31°F evaluated on days with <6 in. snow cover ($WTC_{31,6}$), and SPREC were negatively related to first-cut yield. Spring days (SDAYS), $SGDD_{38.5}$, and $PHGDD_{69}$ were positively related to first-cut yield.

The inverse relationship between winter degree days above 51°F and first-cut yield suggests an association between midwinter thaws and plant injury. This association is consistent with the conclusion of Dexter (1941) that alfalfa may deharden during a period of warm winter temperatures and not completely reharden with subsequent cold temperatures. The negative correlation also is consistent with research by Suzuki (1983) who attributed plant stress following a midwinter thaw to the anaerobic environment created by waterlogged soil.

Winter minimum temperature was negatively correlated with first-cut yield. This negative correlation suggests that minimum temperatures during the winter were not harmful. This contrasts with the harsher climate of Minnesota, where Sharratt et al. (1986) observed a positive correlation between first-cut yield and minimum air temperature in the winter and concluded that first-cut yield

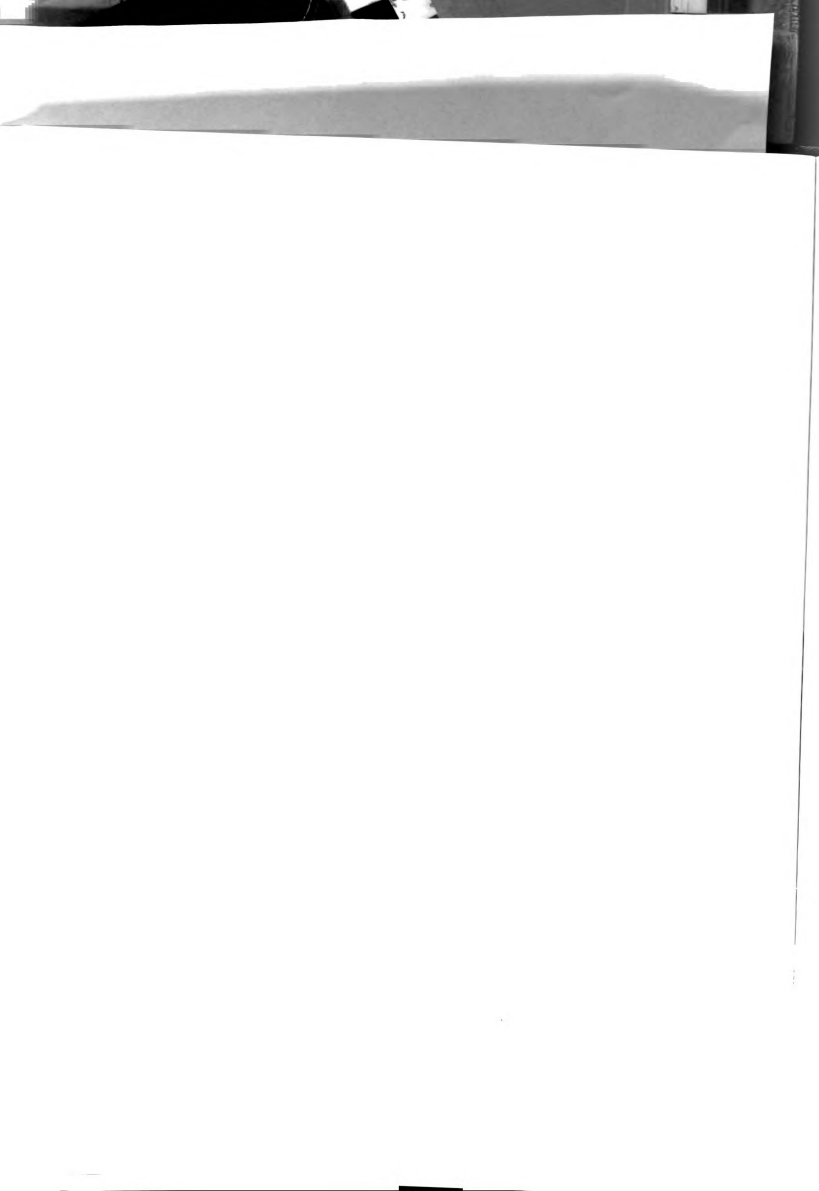
Table 1.2. Simple correlation coefficients of first-cut alfalfa yield and over-winter weather variables in second, third, and combined second and third years after seeding. E. Lansing, MI. 1972-88.

Variable	Second year	Third year	Combined years
PHDAYS	-0.06	-0.31	-0.08
H DAYS	0.26	0.06	0.09
SDAYS	0.65***	0.67***	0.63***
PHPREC	0.30	0.25	0.12
HPREC	0.05	0.07	0.12
SPREC	-0.43**	0.35*	0.01
PHGDD _{69†}	0.52***	0.12	0.40***
HGDD _{32†}	-0.00	0.03	-0.04
WDD _{51†}	-0.65***	0.02	-0.31**
SGDD _{38.5†}	0.60***	0.52***	0.56***
WMINT	-0.60***	0.09	-0.21
WTC _{31,6†‡}	-0.57***	-0.62***	-0.64***
YEAR			-0.44***

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively. N = 42, 37, and 79 in second, third, and combined years, respectively.

† The first subscript following the variable is the base temperature in °F.

‡ The second subscript following WTC indicates that cycles were calculated only on days with less than this snow depth.



was reduced by cold temperature.

Winter temperature cycles at 31°F evaluated on days with less than 6 in. snow cover were negatively correlated with first-cut yield. This correlation is consistent with other observations of the deleterious effects of winter temperature fluctuations on alfalfa persistence. Portz (1967) observed an association between temperature fluctuations around the freezing point and the incidence of frost heaving. Alternating temperatures also may cause persistent ice sheets that can smother and kill alfalfa (Sprague and Graber, 1943). The most negative relationship between WTC and first-cut yield was observed when WTC were accumulated on days with less than 6 in. snow cover. This also agrees with the observations of Bouyoucos (1916) on the insulation value of snow and its contribution to winter survival in alfalfa (Ouellet, 1977).

The negative relationship between first-cut yield and SPREC suggests that wet soil conditions during spring reduced alfalfa yield. Sharratt et al. (1986) also reported the yield reducing effect of wet soil conditions in the spring as determined by the ratio of precipitation to potential evapotranspiration. They attributed these yield reductions to root and leaf diseases.

Observed correlations between SDAYS and first-cut yield and between SGDD_{38.5} and first-cut yield were consistent with other observations of increased photosynthesis and dry matter production with calendar and thermal day

accumulations in the spring (e.g., Sharratt et al., 1986).

Prehardening growing degree days above 69°F were positively correlated with yield. This finding agrees with the documented positive effect of favorable growing conditions during the prehardening period on winter survival (e.g., McKenzie et al., 1988).

Third Year

Four weather variables of the winter and spring periods were significantly related to first-cut yield in the third year after seeding (Table 1.2). The relationships observed between first-cut yield in the third year after seeding and SDAYS, WTC_{31,6}, and SGDD_{38,5} had the same sign and similar r^2 values as in the second year after seeding. However, the relationship between SPREC and first-cut yield was markedly different between the second and third years after seeding. SPREC was negatively correlated with yield in the second year after seeding but positively correlated with yield in the third year after seeding, suggesting that moisture may have become limiting as the stand aged.

Combined Years

Five weather variables of the prehardening, winter, and spring periods and YEAR were significantly related to first-cut yield when data from the second and third years after seeding were combined (Table 1.2). Negative correlations were observed between first-cut yield and WTC_{31,6}, YEAR, and WDD₅₁. Positive correlations were observed between first-cut yield and SDAYS, SGDD_{38,5}, and PHGDD₆₉. Variables



significantly related to first-cut yield in the combined years after seeding were consistent in sign across all years in which they were significant.

The relationship between YEAR and first-cut yield is consistent with the observation of Sheaffer (1989) on the effect of alfalfa stand age on response to over-winter weather conditions. The negative coefficient of YEAR also is consistent with the tendency of yield to decline with stand age.



PREDICTION MODELS

Prediction models for first-cut alfalfa yield in the second, third, and combined second and third years after seeding are shown in Table 1.3.

Second Year

High simple correlations were observed among SDAYS, SGDD, and first-cut yield. Spring days, however, were excluded from the forward selection process in favor of SGDD to ensure the development of a robust model sensitive to the effect of temperature on spring growth in this, the third, and the combined second and third year models. The prediction model developed by forward selection included WDD_{31} and $PHPREC$ with negative coefficients and $SGDD_{38.5}$ and $PHGDD_{69}$ with positive coefficients. This model explained 76% of first-cut yield variability for the second production year. This compares with 50% explained by the equation developed by Sharratt et al. (1986).

Third Year

The third year model (Table 1.3), including $WTC_{31.6}$ and $HDAVS$ with negative coefficients and $SGDD$ with a positive coefficient, explained 69% of yield variability.

Combined Years

The combined second and third year prediction model (Table 1.3) included the same variables as the third year model. This model explained 65% of yield variability over both years.

Table 1.3. Prediction models developed by forward selection for first-cut alfalfa yield with weather variables as independent variables.

Prediction model ¹	R ²	F	degrees of freedom req. res.	
YLD ₂ = 1.58 - 0.00419 WDD ₅₁ + 0.00144 SGDD _{3.5} + 0.00717 PHGDD ₆₈ - 2.39 PHPREC	0.76	29.48 ^{***}	4	37
YLD ₃ = 3.17 - 0.0863 WTC _{31.6} + 0.00119 SGDD _{3.5} - 0.0142 HDAYS	0.69	24.84 ^{***}	3	33
YLD _C = 3.10 - 0.100 WTC _{31.6} + 0.00122 SGDD _{3.5} - 0.00703 HDAYS	0.65	45.74 ^{***}	3	75

¹YLD₂ = dry matter t/acre in first cut of second year after seeding

WDD₅₁ = winter degree days (base 51°F)

SGDD_{3.5} = spring growing degree days (base 38.5°F)

PHGDD₆₈ = prehardening growing degree days (base 69°F)

PHPREC = avg. daily precipitation in prehardening period

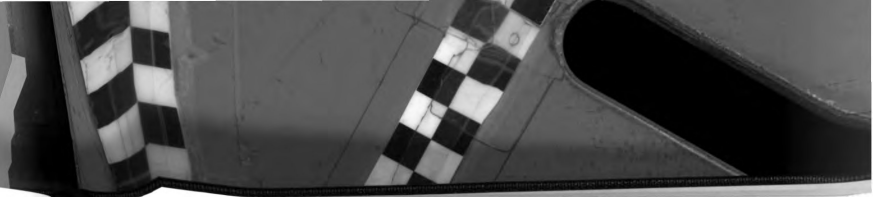
YLD₃ = dry matter t/acre of dry matter in first cut of third year after seeding

WTC_{31.6} = winter temperature cycles (base 31°F evaluated on days with <6 in. snow cover)

HDAYS = days in hardening period

YLD_C = dry matter t/acre of dry matter in first cut in second or third year after seeding

^{***} significant at 0.001 level



Validation

Measured and predicted yields are shown in Table 1.4 for growing years 1989-93. Predictive models performed best when used to predict yields of the same cultivars as used in model development; although, the availability of such data were limited to 1989 and 1990. In 1989 when second year yields of cultivars used in model development were considered, yields predicted by the second year prediction equation averaged 97% of measured yields. Yields predicted by the third year model averaged 92% of measured yields of cultivars used in model development in 1989 and 1990. Yields predicted by the combined second and third year predictive model averaged 90% of 1989 and 1990 measured yields when cultivars used in model development were considered.

The model predictions were least accurate in 1993 when yields were negatively impacted by weather conditions not considered in the model. In 1993, yields predicted by the second year model averaged 124% of measured yields. Those predicted by the third year model averaged 135% and those predicted by the combined second and third year models averaged 144% of measured. These over-predictions likely occurred because the variables included in the models did not take into account the extremely wet soil conditions in fall 1992 and the following spring. These conditions were

Table 1.4. Comparison of measured and model-predicted first-cut alfalfa yields. E. Lansing, MI. 1989-93.

Year	Second year after seeding			Third year after seeding		
	Average measured	Model prediction	2nd yr [†] comb yr [†]	Average measured	Model prediction	3rd yr [†] comb yr [†]
	-----t/acre-----					
1989	2.71	2.59	2.28	2.37	2.05	2.18
1989 [‡]	2.68	2.59	2.28	2.37	2.05	2.18
1990	2.36	1.83	2.18	2.47	2.39	2.28
1990 [§]				2.44	2.39	2.28
1991	2.74	3.30	3.01	2.27	2.81	2.81
1992	2.50	2.52	2.36	1.89	2.48	2.26
1993	1.87	2.32	2.69	1.96	2.64	2.82

[†] Predictive model for second year after seeding.

[‡] Predictive model for combined second and third years after seeding.

[§] Predictive model for third year after seeding.

^{||} 1989 data using only the same cultivars as used in model development.

[¶] 1990 data using only the same cultivars as used in model development.

created in the fall by above normal precipitation (Sept-Nov; +2.27 in) and by below normal temperatures (Sept [-2.9 °F], Oct [-3.4 °F], and [Nov -0.8°F]).

Usefulness and Limitations of Models

Models developed in this study could provide growers with reasonably accurate predictions of first-cut alfalfa yield in years when weather variables considered by the models are the major yield determinants. Predictions could be made from weather data with hand or computer calculations although the availability of weather data may be a problem and the calculations are somewhat tedious. If data were available, such predictions could help forage producers better prepare for forage shortfalls or decide whether to maintain or replace injured stands. Models developed in this study, although having perhaps limited value currently for producers, could contribute to the development of alfalfa growth models that simulate the perennial nature of plant growth in this species.

RESEARCH APPLICATION SUMMARY

Research Question

In areas of the northern USA where alfalfa stands may be injured by severe winters, the ability to estimate future alfalfa yield in the spring would be helpful to farmers for estimating their potential forage shortfalls or to decide whether to maintain or replace an injured stand. Predictive models of first-cut yield based on preceding over-winter weather conditions would be useful to farmers facing these decisions.

In this study, models were developed for predicting first-cut yield of moderately winter-hardy alfalfa in the second and third years after seeding. The relative importance of over-winter weather variables to first-cut yield was evaluated as part of the model development process. Models were validated using an independent data set.

Literature Summary

Identified causes of alfalfa winter injury include temperature fluctuations, lack of snow cover, and persistent ice sheeting. Fluctuating temperatures are detrimental when warm temperatures cause over-wintering alfalfa to initiate growth too early for normal spring development. Heaving injury, caused when plants are lifted from the soil, also is associated with winter temperature fluctuations. Snow cover usually is beneficial, providing insulation from fluctuating and low temperatures. Ice sheeting may cause plants to

smother in metabolic byproducts or to be injured by low temperatures due to the low insulation value of ice. Weather conditions preceding and following winter may condition plants for or promote recovery after severe winter weather. A previously-reported study evaluated the relative importance of over-winter variables to first-cut yield in a three-cut system in Minnesota. In that study, over-winter weather variables relating to solar radiation, temperature, and precipitation summarized for discrete periods accounted for 40 to 50% of yield variability.

Study Description

First-cut yields of moderately winter-hardy alfalfa cultivars in a four-cut system during 1972 to 1988 were obtained from Michigan State University variety trials in E. Lansing, MI for model development. E. Lansing yield data from 1989 to 1993 were used for validation. Weather data were obtained from the Michigan State University weather station. Multiple regression analysis of first-cut yield on weather variables was used to develop predictive equations.

The following prediction model was developed for the second and third years after seeding:

$$YLD = 3.10 - 0.100 WTC_{31,6} + 0.00122 SGDD_{38,5} - 0.00703$$

H DAYS, where

- YLD = dry matter t/acre in first cut of second or third year after seeding.
- $WTC_{31,6}$ = winter temperature cycles, where one-half WTC was counted for each time the mean daily air

temperature rose above or fell below 31°F. Cycles were counted on days when snow depth was less than 6 in., beginning with the first occurrence of a minimum daily air temperature of 26°F or less (late October) through 14 April.

- $SGDD_{38.5}$ = spring growing degree days above 38.5°F accumulated from 15 April to first-cut.
- HDAYS = days in hardening period, i.e., from the first occurrence of maximum daily air temperature of 59°F or less (mid-September) until first occurrence of a mean daily air temperature of 26°F or less (late October).

Applied Questions

Can first-cut alfalfa yield be explained based on over-winter weather conditions?

Yes. In this study, 65% of variability in first-cut yields in the second and third years after seeding was explained by the model.

What over-winter weather variables were most important in explaining first-cut alfalfa yield?

Winter temperature cycles (i.e., number of times the mean daily air temperature rose above and fell below 31°F on days with less than 6 in. snow cover) and spring thermal day accumulation (i.e., growing degree days above a 38.5°F base) were the most important over-winter weather variables affecting variability of first-cut yield of moderately winter-hardy alfalfa cultivars in the second and third years

after seeding. First-cut yield was negatively affected by winter temperature cycles and positively affected by thermal day accumulations in the spring. Minimum daily winter temperature did not reduce first-cut yields.

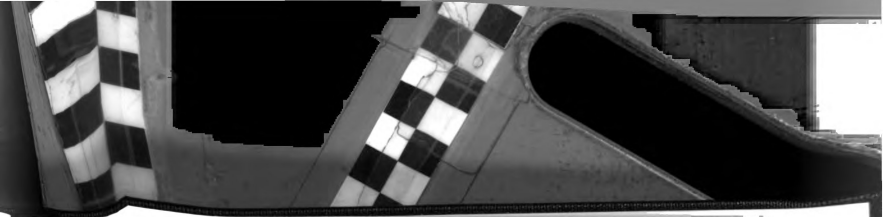
How might this model provide timely, useful information for forage producers?

Based on relationships observed in this study, a producer could predict the effect of winter injury on first-cut yield by 15 April.

For example, let's say that a producer counted 20 winter temperature cycles by 15 April. (The average winter during model development had 12.6 winter temperature cycles. Therefore, in this example winter, there are 7.4 more winter temperature cycles than average.) According to the relationship of -0.1 t/acre per winter temperature cycle shown in the prediction equation, an additional 7.4 winter temperature cycles would be expected to decrease yield by 0.74 tons. With such a prediction, a forage producer would be better able to prepare for forage shortfalls or to decide whether to maintain or replace an injured stand.

What are the model's limitations?

1. Yield may be affected, either negatively or positively, by factors not considered by the model. When this happened with yield-decreasing anaerobic soil conditions in fall 1992, the model over-predicted yields by 44%.
2. Weather data may not be readily assessable.



Recommendations

Known and suspected relationships between over-winter weather variables and first-cut alfalfa yield were confirmed and quantified in this study. A clear negative relationship between fluctuating winter temperature and first-cut yield was established. Based on this study, farmers should be prepared for forage yield decreases following over-winter exposure of alfalfa to greater than normal temperature fluctuations when snow cover is less than 6 inches deep.

REFERENCES

Bouyoucos, G.J. 1916. Soil temperature. Michigan Agric. College Exp. Stn. Tech. Bull. No. 26.

Dexter, S.T. 1941. Effects of periods of warm weather upon the winter hardened condition of a plant. Plant Physiol. 16:181-188.

Fick, G.W., and D. Onstad. 1983. Simple computer simulation models for forage-management applications. p. 483-485. In J.A. Smith and V.W. Hays (ed.) Proc. 14th Int. Grassl. Congr., Lexington, KY. 15-24 June 1981. Westview Press, Boulder, CO.

Glantz, S.A., and B.K. Slinker. 1990. Primer of applied regression and analysis of variance. McGraw-Hill. New York, NY.

Hesterman, O.B., R.H. Leep, and J.J. Paling. 1988. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

_____, _____, and _____. 1989. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

_____, _____, and _____. 1990. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

_____, _____, and _____. 1991. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

_____, _____, and _____. 1992. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

_____, and J.J. Paling. 1993. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

McKenzie, J.S., and G.E. McLean. 1982. The importance of leaf frost resistance to the winter survival of seedling stands of alfalfa. Can. J. Plant Sci. 62:399-405.

_____, R. Paquin, S.H. Duke. 1988. Cold and heat tolerance. In A.A. Hanson (ed.) Alfalfa and alfalfa improvement. Agronomy 29:259-302.

Nath, J., and T. C. Fisher. 1971. Anatomical study of freezing injury in hardy and nonhardy alfalfa varieties treated with cytosine and guanine. Cryobiology. 8:420-430.

National Oceanic and Atmospheric Administration. 1972-1993. Climatological data. National Climatic Data Center. Asheville, NC.

Onstad, D.W., and C.A. Shoemaker. 1984. Management of alfalfa and the alfalfa weevil (*Hypera postica*): an example of systems analysis in forage production. Agric. Systems. 14:1-30.

Ouellet, C.E. 1977. Monthly climatic contribution to the winter injury of alfalfa. Can. J. Plant Sci. 57:419-426.

Portz, H.L. 1967. Frost heaving of soil and plants. I. Incidence of frost heaving of forage plants and meteorological relationships. Agron. J. 59:341-344.

Selirio, I.S., and D.M. Brown. 1979. Soil-moisture based simulation of forage yield. Agric. Meteorol. 20:99-114.

Sharratt, B.S., D.G. Baker, and C.C. Sheaffer. 1986. Climatic effect on alfalfa dry matter production. Part I. Spring Harvest. Agric. For. Meteorol. 37:123-131.

_____, _____, and _____. 1989. Base temperature for application of the growing-degree-day model to field-grown alfalfa. Field Crops Res. 21:95-102.

Sheaffer, C.C. 1989. Fall cutting is a management option in the north. Proc. of the 1989 American Forage and Grassland Conference. p. 23-29. AFGC. Belleville, PA.

Smith, E.M., and O.J. Loewer, Jr. 1983. Mathematical logic to simulate the growth of two perennial grasses. Trans. ASAE. 26:878-883.

Sprague, M.A., and L.F. Graber. 1943. Ice sheet injury to alfalfa. Agron. J. 35:881-894.

Suzuki, M. 1973. Is winter kill predictable? Canada Agriculture. 18(4):10-11.

_____. 1983. Responses of alfalfa to a simulated midwinter thaw. p. 390-393. In J.A. Smith and V.W. Hays

(ed.) Proc. 14th Int. Grassl. Congr., Lexington, KY. 15-24 June 1981. Westview Press, Boulder, CO.

Tesar, M.B. 1975. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Univ. of Neb., Lincoln, NE.

_____. 1976. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Univ. of Neb., Lincoln, NE.

_____, B. Graff, and R.H. Leep. 1986. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

_____, and R.H. Leep. 1980. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Univ. of Neb., Lincoln, NE.

_____, and _____. 1983. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

_____, and _____. 1984. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

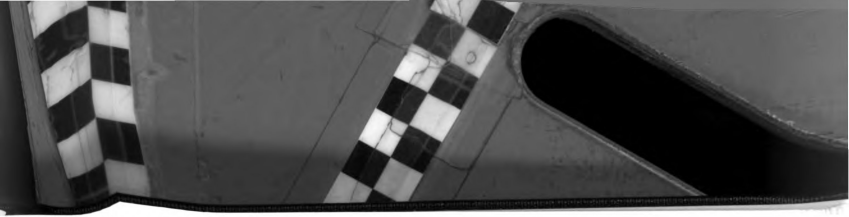
_____, _____, and B. Graff. 1985. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Oklahoma State Univ., Stillwater, OK.

_____, _____, and C. Holland. 1981. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Univ. of Neb., Lincoln, NE.

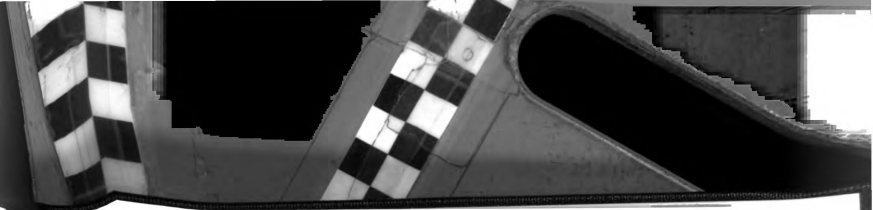
_____, _____, and _____. 1982. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Univ. of Neb., Lincoln, NE.

_____, D.J. Reid, and S.C. Hildebrand. 1972. Alfalfa variety trials. Michigan Agric. Exp. Stn., E. Lansing, MI. In Rep. Central Alfalfa Improve. Conf. Univ. of Neb., Lincoln, NE.

Tysdale, H.M. 1933. Influence of light, temperature, and soil moisture on the hardening process in alfalfa. J. Agric. Res. 46:483-515.



Univ. of Minnesota. 1989-93. Variety trials of farm
crops. Univ. of Minnesota Agric. Exp. Stn. Report 24.

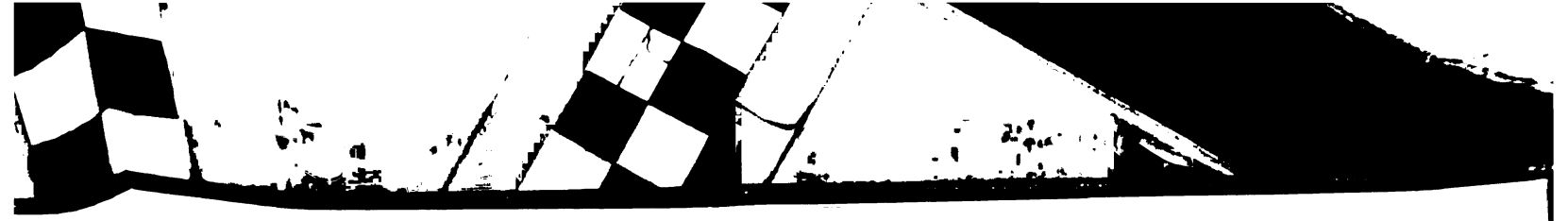


CHAPTER TWO

CORN SILAGE FOLLOWING FIRST-CUT ALFALFA: A FORAGE PRODUCTION ALTERNATIVE?

ABSTRACT

Producer interest in double cropping first-cut alfalfa (*Medicago sativa* L.) and corn (*Zea mays* L.) silage increases in years when forage supplies are limited and where alfalfa stands have been winter injured. Although anecdotal evidence suggests the use of this double-crop forage production alternative, little quantitative information is available on the forage yield and economic return of this system in the north central USA. Simulation was used to evaluate and compare corn silage following first-cut alfalfa with single-crop corn silage and four-cut alfalfa systems over 26 years of south central Michigan weather conditions. Model validation was done using two years of independent E. Lansing, MI field data. The alfalfa/corn silage double-crop system was less profitable than single-crop corn silage and/or 4-cut alfalfa in 22 of the 26 years. In sensitivity analyses using forage prices representing historical extremes, varied first-cut dates, and realistic changes in forage yields, the maximum number of years in which the double-crop system was more profitable than both single-crop corn and four-cut alfalfa was 7 of 26. Although this system has some demonstrated success in other areas of the country, it cannot be generally recommended as an economic alternative for forage production in south central Michigan.



INTRODUCTION

Corn (*Zea mays* L.) silage is occasionally double cropped with first-cut alfalfa (*Medicago sativa* L.) in the north central USA, i.e., corn is planted after first-cut alfalfa is harvested. A recommended forage production alternative in some states (Miller, 1988), this practice is of greater interest to growers when old alfalfa stands are still marginally productive and forage is needed (Smith et al., 1992).

Multiple- and double-crop systems have long been used to maximize production for various crops (Lewis and Phillips, 1976). Although studies in the Southeast have demonstrated the success of multiple- and double-crop systems, including corn silage following first-cut alfalfa, only anecdotal evidence supports the success of this forage production system in Michigan. Reported disadvantages of corn following first-cut alfalfa or similar systems include unpredictable yields and reduced yields due to soil moisture depletion (Widstrom et al., 1984; Ebelhar et al., 1984; Hesterman et al., 1992).

Corn silage following first-cut alfalfa has been recommended in Minnesota for winter-injured stands in years when alfalfa supplies are limited (Fallander, 1989). To decide whether to implement this recommendation, maintain the stand, or replace the stand with corn before first cut, a producer first needs to estimate the potential forage and economic yields for (i) the winter-injured stand,

(ii) corn silage following first-cut alfalfa, and (iii) single-crop corn silage. Models developed to evaluate the effect of winter weather on first-cut alfalfa yield (Durling et al., 1994) could be used to predict forage yield of winter-injured stands. Yield data for commercial corn hybrids and alfalfa varieties is readily available from performance tests conducted in various states (e.g., Dysinger et al., 1994; Hesterman et al., 1994). However, little information is available on forage yield and economic return of corn silage following first-cut alfalfa in the north central USA.

This study was designed to evaluate a corn silage following first-cut alfalfa double-crop system as an alternative for forage production. The specific objectives of this study were: (1) to use field and modelling studies to evaluate the forage yield of double-crop alfalfa/corn silage vs. single-crop corn silage vs. four-cut alfalfa, (2) to compare the economic return from an alfalfa/corn silage double-crop system with returns from single-crop corn silage and four-cut alfalfa systems, and (3) to determine the economic sensitivity of these systems to nutrient prices and to timing of first alfalfa harvest in the double-crop system.

MATERIALS AND METHODS

Field Study

Field studies were conducted at E. Lansing in 1987 and 1988 to evaluate corn silage and alfalfa yields in three forage production systems. The data collected was used to validate the use of the crop models from DAFOSYM (The Dairy Forage System Model; Rotz et al., 1989) in predicting yields for these systems.

Three treatments were evaluated in a randomized complete block experiment with four replications:

- (1) single-crop corn harvested as silage (Treatment C)
- (2) alfalfa harvested four times through the season (Treatment A)
- (3) corn silage following first-cut alfalfa (Treatment AC).

The three cropping treatments were established in plots in existing alfalfa fields. These alfalfa stands were established six or more years earlier. Plot, soil, and site characteristics and cultural practices for each treatment are listed in Table 2.1.

Late spring and early summer drought conditions in 1987 and 1988 (Table 2.2), caused poor germination and emergence of corn in Treatment C so corn was replanted into the existing stand. Irrigation of 1.25 in. was applied to all treatments in May 1987 and 5 in. was applied to all treatments in June and July 1988 (Table 2.1) bringing precipitation totals more near normal.

Table 2.1. Selected plot, soil, and site characteristics and cultural practices for field studies comparing three forage production systems at E. Lansing, MI, 1987-88.

Characteristic or practice	Year	
	1987	1988
Soil		
P test (lb/a)	46	59
K test (lb/a)	200	194
pH	7.5	7.1
Type	Conover loam	Conover loam
Classification	Fine-loamy, mixed, mesic Udollic Ochraqualfs	Fine-loamy, mixed, mesic Udollic Ochraqualfs
Plot size	300 ft ²	450 ft ²
Alfalfa		
Cultivar	Pioneer 531	Pioneer 531
Est. year	1981	1981
Irrigation	0.25" 23 May 1" 25 May	2" 4 June 1" 10 June 2" 4 July
Treatment C (single-crop corn silage)		
Preplant herb.	1.25 qt/a 2,4-D ester	1.25 qt/a 2,4-D ester 2 lb/a atrazine 1 qt/a paraquat
Preem. herb.	2 lb/a atrazine 1.5 qt/a glyphosate	
Postem. herb.		2 lb/a atrazine
Tillage	no-till	no-till
Hybrid (relative maturity)	Great Lakes-579 (105)	Great Lakes-579 (105)
Plant. date	8 May [†]	7 May [†]
Seed. rate	22,100/a	26,200/a
Row spacing (in.)	30	30
Rows/plot	4	6
Fertilizer (lb/a)	80-72-72	121-37-100
Harvest date	1 Oct	25 Oct
Treatment A (alfalfa)		
Cut 1 date	4 June	1 June
Cut 2 date	13 July	4 July
Cut 3 date	20 Aug	12 Aug
Cut 4 date	3 Nov	26 Oct
Fertilizer (lb/a)	0-56-168	0-56-168
Treatment AC (corn silage following first-cut alfalfa)		
Cut 1 date	4 June	1 June
Preplant herb.		
Preem. herb.	2 lb/a atrazine 1 qt/a paraquat 1 pt/a dicamba (split)	1 lb/a atrazine 2 lb/a 1.75 lb/a cyanazine
Tillage	no-till	moldboard plow tandem disk (2x)
Hybrid (relative maturity)	Great Lakes-381 (87)	Great Lakes-365 (85)
Planting date	8 June	3 June
Seed. rate	26,000/a	22,100/a
Row spacing (in.)	30	30
Rows/plot	4	6
Fertilizer (lb/a)	11-37-0	0-0-20
Harvest date	1 Oct	25 Oct

[†] GL-570 planted into existing stand on 22 May @ 17,000 seeds/a following poor emergence due to drought.

[‡] GL-579 planted into existing stand on 4 June following poor emergence due to drought.

Table 2.2. Precipitation norms and deviations at E. Lansing, MI, 1987-88.

Year	<u>May-June</u>		<u>Annual</u>	
	Norm	Deviation	Norm	Deviation
	in.			
1987	6.27	-2.67	28.67	-1.18
1988	6.27	-5.50	28.67	-4.85

Source: National Weather Service Cooperative Station, E. Lansing, MI.

Alfalfa was cut at early to mid-bloom using either a flail-type harvester or sickle-bar mower. Strips measuring 3 or 4 ft wide and 30 ft long were harvested from the center of each plot and weighed. Subsamples (2 lb fresh wt) were dried in a convection oven for 4 days at 140°F to determine moisture content. Alfalfa yields were determined in dry matter (DM) tons/acre. Concentrations of crude protein (CP) and total digestible nutrients (TDN) in the alfalfa were measured by NIRS (near-infrared reflectance spectroscopy) using a Pacific Scientific 6250 scanning monochromator (Pacific Scientific, Silver Springs, MD) and calibration equations developed by Infrasoft International Analytical Services (State College, PA).

For silage yield determination, total above-ground corn plants were hand harvested from 0.002 acre in the middle of the interior two rows of the plots, weighed, subsampled, dried, and adjusted to DM tons/acre. Corn grain and cobs were removed from the stover for nutrient determination. Concentrations of CP and TDN in the stover were determined using the scanning monochromator and software mentioned previously. Nutrient concentrations in corn grain (10% CP and 85% TDN) and cobs (3.2% CP and 50% TDN) were based on published measurements (National Research Council, 1988).

Alfalfa and corn silage yield and quality were used to determine gross income which became the basis for comparing measured with predicted forage production. Market values (\$/ton) of alfalfa and corn silage were determined as the

cost of purchasing the same amount of CP and TDN in the form of soybean meal (SBM) and corn grain (Hesterman et al., 1989). Prices of \$240/ton for SBM and \$2.53/bu for corn grain were used to reflect the long-term SBM DM to corn grain DM price ratio of 2:1 (Borton, 1994). Gross income (\$/acre) was calculated for each treatment as the summation of crop value times yield.

Model Validation

Submodels of the DAFOSYM Program were used to simulate crop growth using 1987 and 1988 temperature, precipitation, and irrigation data from E. Lansing and simulated solar data from about 50 miles northeast of E. Lansing. Yields were simulated for Treatment C with the DAFOSYM corn growth submodel which used the CERES-Maize model, version 2.1 (Jones and Kiniry, 1986). The corn growth submodel simulated grain and biomass yield as a function of soil-water availability, growing degree days, planting date, and other factors. Planting and harvest dates were as shown in Table 2.1. Simulated grain yields were reduced by 33% and biomass yields were reduced by 24% to obtain average grain and silage yields similar to those reported for central lower Michigan (Michigan Department of Agriculture, 1987 and Rossman et al., 1987).

Yield and quality in Treatment A were simulated using the DAFOSYM alfalfa growth submodel which was based on the ALSIM1, level 2 model developed by Fick (1977). Simulated yields were reduced by 10% to improve the applicability of

results to older alfalfa stands. The alfalfa growth submodel simulated dry-matter accumulation and CP and TDN concentration on a daily basis until the harvest date. Daily alfalfa growth was a function of soil-water availability, temperature, solar radiation, and other factors. Quality was predicted from leaf to stem ratios and growing degree days (Rotz et al., 1989; Fick and Onstad, 1988). Alfalfa harvest dates for Treatment A simulations were as shown in Table 2.1.

Alfalfa yield and quality and corn yield in Treatment AC were simulated using the respective alfalfa and corn models. Alfalfa growth was simulated as in Treatment A for the first cut. Corn was planted on the date shown in Table 2.1. Available soil moisture predicted by the alfalfa model following first-cut alfalfa was carried into the corn submodel as the available soil moisture at corn planting.

Crude protein and TDN concentration of alfalfa were output by the submodel. Crude protein and TDN concentration of corn grain, cobs, and stover were based on published measurements (National Research Council, 1988). Adjustments of up to 2.5% CP and 7% TDN were added for the increased nutrient content of Treatment AC corn stover in years when plants were drought stressed (Perry, 1988). Alfalfa and corn silage market values (\$/ton) were determined as the cost of purchasing the same quantities of CP and TDN in the form of SBM at \$240/ton and corn at \$2.53/bu as described for the field study. Gross income (\$/acre) was calculated

for each treatment as the summation of crop value times yield.

Measured and simulated gross incomes are shown in Table 2.3. A correlation (r) of 0.84 was found between the measured and simulated gross incomes and treatment ranking according to gross income was the same for the measured and simulated values in 1987. The ranking of the second and third ranked treatments were reversed between measured and predicted in 1988, although the difference between the second and third highest gross incomes was not significant ($P \leq 0.05$) in the field study. Based on the reasonable level of accuracy of these predictions by the DAFOSYM submodels, a long-term simulation was undertaken to evaluate these three forage production alternatives.

Simulation Study

Model parameters were as described previously for the validation study with these changes: corn was planted on or as soon after May 1 as weather would permit. Alfalfa harvest target dates in simulations were 25 May, cut 1; 1 July, cut 2; and 13 Aug., cut 3. Dates for the first three cuts were delayed up to 10 days to allow CP to approach a 21% target level. The fourth-cut date was fixed on 15 October.

A breakdown of cash variable costs of production (\$/acre) assumed for each treatment is shown in Table 2.4. These values are representative of the costs farmers would incur based upon long-term relative prices in 1994 dollars.

Table 2.3. Measured and simulated gross income for three forage production systems. E. Lansing, MI.

System [†]	-----Gross Income-----			
	1987		1988	
	Measured	Simulated	Measured	Simulated
	-----(\$/acre)-----			
Treatment C	640 [‡]	594 [§]	509 [¶]	503 [#]
Treatment A	449 ^{††}	337 ^{##}	431 ^{¶¶}	428 ^{¶¶}
Treatment AC	251 ^{##}	295 ^{†††}	460 ^{##}	320 ^{¶¶¶}
LSD _{0.05} (within column)	66		65	

[†] Treatment C = single-crop corn silage, A = alfalfa harvested 4 times through season, and AC = corn harvested as silage following first-cut alfalfa.

[‡] 3.4 tons/acre grain DM, 0.2 t/a cob DM, 3.3 t/a stover DM @ 7% CP & 63% TDN.

[§] 3.4 t/a grain DM, 1.0 t/a cob DM, 2.6 t/a stover DM @ 6% CP & 55% TDN.

[¶] 2.6 t/a grain DM, 0.4 t/a cob DM, 2.5 t/a stover DM @ 9% CP & 62% TDN.

[#] 2.8 t/a grain DM, 0.7 t/a cob DM, 2.4 t/a stover DM @ 6% CP & 55% TDN.

^{††} 4.2 t/a alfalfa DM @ 18% CP & 60% TDN.

^{##} 3.1 t/a alfalfa DM @ 19% CP & 59% TDN.

^{¶¶} 4.2 t/a alfalfa DM @ 19% CP & 55% TDN.

^{¶¶} 3.9 t/a alfalfa DM @ 20% CP & 60% TDN.

^{##} 0.1 t/a grain DM, 0.1 t/a cob DM, 0.5 t/a stover DM @ 11% CP & 68% TDN and 2.2 t/a alfalfa DM @ 15% CP & 55% TDN.

^{†††} 0.2 t/a grain DM, 0.0 t/a cob DM, 1.0 t/a stover DM @ 7% CP & 59% TDN and 1.9 t/a alfalfa DM @ 18% CP & 56% TDN.

^{##} 1.4 t/a grain DM, 0.3 t/a cob DM, 1.5 t/a stover DM @ 8% CP & 61% TDN and 2.0 t/a alfalfa DM @ 17% CP & 50% TDN.

^{¶¶¶} 0.5 t/a grain DM, 0.1 t/a cob DM, 0.9 t/a stover DM @ 6% CP & 55% TDN and 1.8 t/a alfalfa DM @ 20% CP & 59% TDN.

Given the short-run planning horizon of one year, the cost of alfalfa establishment was considered sunk and not included as a variable cost. Land costs were not included as production costs because they would not change under alternative forage production scenarios.

Alfalfa and corn silage market values and gross incomes were determined as previously described. Gross margin (\$/acre) was calculated as gross income less the variable costs that varied among these cropping systems as defined in Table 2.4.

Table 2.4. Cash variable costs of production (\$/acre) of three simulated forage production systems at E. Lansing, MI.

Input or field operation	Production System [†]		
	Tmt C	Tmt A	Tmt AC
	—(\$/acre) [‡] —		
Herbicide	14.84 [§]	0.0	17.83 [¶]
Herbicide application @ \$3.90/trip	7.80	0.0	11.70
Tillage	0.0	0.0	0.0
N fertilizer @ 12¢/lb	9.36	0.0	0.0
P ₂ O ₅ fertilizer @ 24¢/lb	16.32	14.88	5.76
K ₂ O fertilizer @ 12¢/lb	13.92	16.44	8.04
B @ \$2.10/lb	0.0	2.10	0.0
Fertilizer application	0.0	1.59	0.0
Seed @ \$.825/1000	19.80	0.0	19.80
Planting	13.79	0.0	13.79
Corn silage harvest @ \$15/acre + 50¢/ton	15.00+	0.0	15.00+
Alfalfa harvest	0.0	84.00	21.00

[†] Tmt C = single-crop corn silage, Tmt A = alfalfa harvested 4 times through the season, and Tmt AC = corn harvested as silage following first-cut alfalfa.

[‡] Values are representative of costs farmers would incur in the trial year based on long-term relative prices in 1994 dollars. Not included are costs for alfalfa establishment, land, and other overhead.

[§] 1.25 qt 2,4-D ester @ \$2.14/qt, 2 lbs atrazine @ \$1.70/lb, and 1 qt paraquat @ \$8.76/qt.

[¶] 2 lb atrazine @ \$1.70/lb, and 1 qt paraquat @ \$8.76/qt, and 1 pt (split) dicamba @ \$5.67/pt.

RESULTS AND DISCUSSION

Simulated forage yield, gross income, and gross margin for the three forage production systems over 26 years are shown in Table 2.5. Treatment C was the forage production system with the highest gross margin in 16 of the 26 years and the highest average gross margin (\$433/acre). Treatment A had the highest gross margin in 6 of the 26 years and Treatment AC had the highest in four of the years. The 26-year average gross margin was \$387/acre for Treatment A and \$320/acre for Treatment AC.

The poor economic performance of Treatment AC was due to the low yield of corn silage following first-cut alfalfa. Treatment AC corn silage yield averaged less than half of Treatment C corn silage yield. The two most favorable years for Treatment AC were 1968 and 1970 (Table 2.5). In these years, July and August precipitation was above normal and the corn growing season (from alfalfa first cut to first frost) was longer than average.

The relatively poor performance of Treatment AC in most years was consistent with other observations of the yield depressing effects of a forage legume preceding corn in a double-crop system. Hesterman et al. (1992) in Michigan attributed reduced yields of corn following perennial legumes in years with early season precipitation deficits to the legumes' use of soil moisture. Ebelhar et al. (1984) in Kentucky reported that high yielding legume cover crops decreased soil moisture content at time of planting corn and

Table 2.5. Simulated forage yield, gross income, and gross margin for three forage production systems and 26 weather years at E. Lansing, Mi. Highest gross margin for each year is underlined.

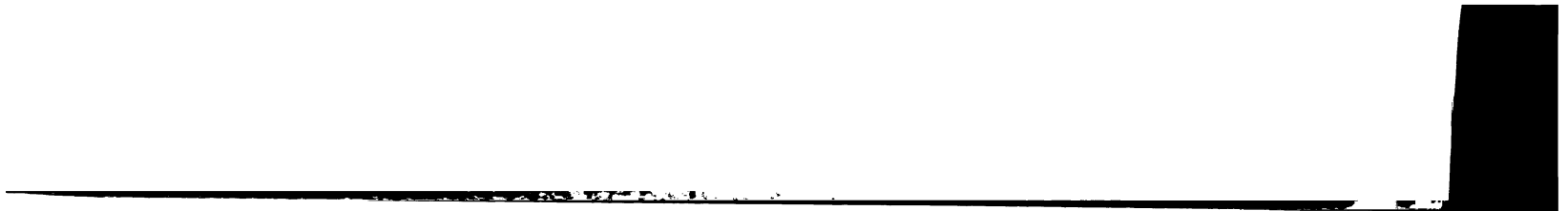
Simulation year	Treatment C ¹				Treatment A ²				Treatment AC ³			
	Corn		Alfalfa		Corn		Alfalfa		Corn		Alfalfa	
	t/a	\$/a	DM	income ⁴	t/a	\$/a	DM	income ⁴	t/a	\$/a	DM	income ⁴
1953	6.9	596	4.6	476	4.6	518	3.9	399	1.9	437	2.8	320
1954	5.4	446	3.7	327	4.5	514	4.5	355	1.9	437	1.4	209
1955	7.3	622	5.0	501	4.9	531	4.9	412	1.9	324	1.4	209
1956	6.8	554	4.3	336	4.7	536	4.7	417	1.6	395	2.3	279
1957	7.1	561	4.3	340	4.4	501	4.4	362	1.9	524	4.1	406
1958	7.1	627	5.0	505	4.4	501	4.4	362	1.9	524	4.1	406
1959	7.4	627	5.0	505	5.0	542	5.0	423	1.8	329	1.7	217
1960	6.1	515	3.96	336	5.1	549	5.1	423	1.8	329	1.7	217
1961	6.8	578	4.57	391	5.1	559	5.1	440	1.8	329	1.7	217
1962	5.2	427	3.09	247	4.9	449	4.9	330	1.8	597	5.0	477
1963	8.0	703	4.9	370	4.1	464	4.1	345	1.6	351	1.7	235
1964	7.1	615	4.3	358	4.9	545	4.9	416	1.6	271	1.1	156
1965	5.3	443	3.25	247	4.77	477	4.77	358	2.0	465	3.0	348
1966	6.4	548	4.3	358	4.31	431	4.3	312	1.8	488	3.6	370
1967	5.8	471	3.52	247	4.98	379	4.98	312	1.7	240	0.5	126
1968	7.4	643	4.4	362	4.3	494	4.3	325	1.8	410	2.4	293
1969	7.1	619	4.3	340	5.4	501	5.4	423	1.9	318	1.3	203
1970	7.1	619	4.3	340	5.4	501	5.4	423	1.9	318	1.3	203
1971	5.5	452	3.14	247	5.71	571	5.71	452	1.9	569	5.7	464
1972	6.8	576	4.5	391	4.13	413	4.13	294	1.8	708	6.2	586
1973	5.6	463	3.44	247	4.2	471	4.2	352	1.9	263	0.5	149
1974	5.4	448	3.29	247	4.6	521	4.6	402	1.8	363	2.48	248
1975	7.3	634	5.13	319	4.1	470	4.1	351	1.9	481	3.2	265
1976	5.4	437	3.19	247	4.88	369	4.88	319	1.7	380	2.1	329
1977	7.2	633	5.12	344	5.35	416	5.35	344	1.9	446	3.2	248
1978	5.9	508	3.88	247	4.63	344	4.63	344	1.8	363	1.8	215
Mean	6.5	553	4.33	337	4.49	330	4.49	330	1.8	292	1.1	177
					506	387	1.8	437	2.8	437	2.8	320

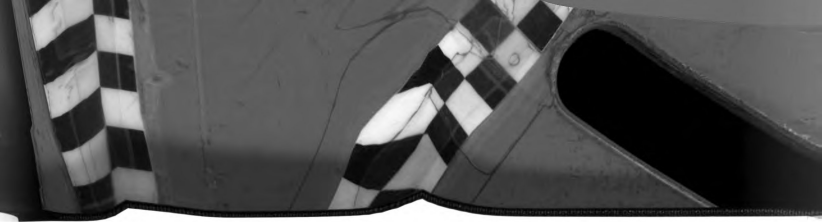
¹ Treatment C = single-crop corn silage, Treatment A = alfalfa harvested 4 times through the season, and Treatment AC = corn in the second year following first-cut alfalfa.

² Corn income is based on a price of \$2.53/ton and alfalfa income is based on a price of \$240/ton.

³ Corn income is based on a price of \$2.53/ton and alfalfa income is based on a price of \$240/ton.

⁴ Gross margin is gross income less select variable costs (Table 2.4).





could be problematic in a dry spring. This problem of soil moisture depletion was corroborated by observations of corn following first-cut alfalfa in Michigan (Lehnert, 1990) and Wisconsin (Smith et al., 1992).



SENSITIVITY ANALYSIS

Further analysis determined the sensitivity of the economics of the forage production systems to changes in nutrient prices, date of first alfalfa harvest in the double-crop system, and forage yield assumptions. This analysis indicates how economic performance (gross margin) is affected by changes in these different scenarios.

Sensitivity to changes in nutrient price was determined under prices representing historical extremes. Crude protein and TDN prices derived from \$271/ton SBM and \$1.92/bu corn grain represented the highest historical SBM:corn grain price ratio (3:1). Nutrient prices derived from \$230/ton SBM and \$3.22/bu corn grain represented the lowest (1.5:1) (Borton, 1994).

Sensitivity analyses are summarized in Table 2.6 which shows the number of years in the simulation in which each system had the highest gross margin and the average gross margin for each treatment. Treatment C and Treatment A were highly sensitive to nutrient price. The low SBM:corn grain ratio favored Treatment C in 22 of the 26 years and the high SBM:corn grain ratio favored Treatment A in 23 of the 26 years. The average gross margin from Treatment C more than doubled with the decrease of the SBM:corn grain price ratio from 3:1 to 1.5:1. Changes in the SBM:corn grain price ratio had little effect on the number of years in which Treatment AC had the highest gross margin.

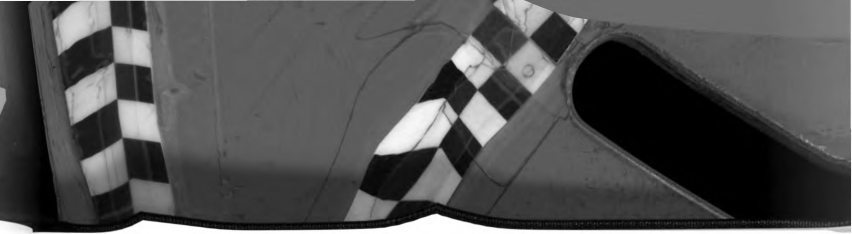
The sensitivity of Treatment AC to timing of first cut

Table 2.6. Sensitivity of forage production systems to variable changes.

<u>Variable changed</u>	<u>Treatment C[†]</u>	<u>Treatment A[†]</u>	<u>Treatment AC[†]</u>
<u>Number of Years in 26 with Highest Gross Margin</u>			
Original simulation	16 (433) [‡]	6 (387)	4 (320)
SBM:corn grain price ratio			
3:1	1 (293)	23 (391)	2 (270)
1.5:1	22 (591)	1 (423)	3 (395)
Treatment AC first-cut date			
25 May	14 (433)	6 (387)	6 (374)
20 May	13 (433)	6 (387)	7 (375)
15 May	14 (433)	6 (387)	6 (359)
10 May	15 (433)	6 (387)	5 (334)
Alfalfa yield			
+10%	11 (433)	11 (438)	4 (340)
+25%	5 (433)	18 (514)	3 (372)
Corn silage yield			
+10%	20 (488)	3 (387)	3 (342)
+25%	23 (569)	0 (387)	3 (376)

[†]Treatment C = single-crop corn silage, A = alfalfa harvested 4 times through season, and AC = corn harvested as silage following first-cut alfalfa.

[‡]Number in parentheses is 26-year average gross margin (\$/acre)

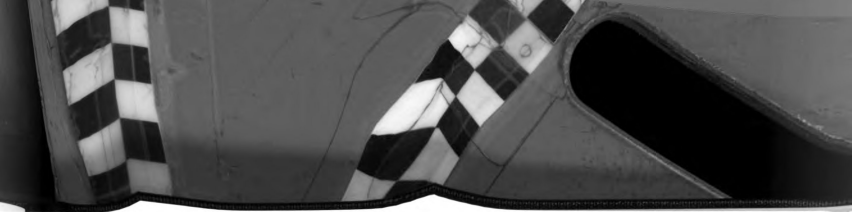


was investigated by changing the first-cut date from a stage-of-growth-based average date of 1 June in the original simulation to fixed dates of 25 May, 20 May, 15 May, and 10 May. As is shown in Table 2.6, the number of years in which Treatment AC had the highest gross margin increased from four in the original simulation to as many as seven with the earlier dates. This increase in Treatment AC gross margin was due to the increased soil moisture and lengthened growing season available for subsequent corn growth allowed by earlier alfalfa harvest.

The third factor investigated in the sensitivity analysis was yield. Table 2.6 shows that the number of years in which Treatment C and Treatment A have the greatest gross margin changes with relative yield of the forage. However, yield changes had little effect on the number of years in which Treatment AC had the highest gross margin.

SUMMARY AND CONCLUSION

Corn is occasionally grown for silage following first-cut alfalfa in the north central USA. In computer simulations based on 26 years of historical weather from south central Michigan, the economic return from corn silage following first-cut alfalfa exceeded the economic return from single-crop corn silage or four-cut alfalfa in only 4 of the 26 years. In sensitivity analyses using realistic changes in model parameters, the number of years in which the double-crop system had the greatest gross margin ranged from only 2 to 7 of 26. In this study, economical yields from the corn silage following first-cut alfalfa system were only attained during long, warm, and wet summers, weather patterns which do not frequently occur in south central Michigan. This study thus supports a conclusion that corn silage following first-cut alfalfa cannot be recommended in south central Michigan.



RESEARCH APPLICATION SUMMARY

Research Question

Producer interest in double cropping first-cut alfalfa and corn silage increases when forage supplies are limited and where alfalfa stands have been injured. Although anecdotal evidence suggests the use of corn silage following first-cut alfalfa as a forage production alternative in the north central USA, little quantitative information is available on the agronomic and economic performance of this system and how it compares with single-crop corn silage and four-cut alfalfa.

Literature Summary

Studies have shown double- and multiple-cropping to maximize production in various crops. Although some of these studies have included corn following first-cut perennial forages, they were conducted in the Southeast where growing seasons are longer than in the north central USA. Reported disadvantages of double-crop alfalfa and corn silage include unpredictable and reduced yields due to soil moisture depletion.

Study Description

Simulation studies were done using 26 years of south central Michigan weather data to evaluate these forage production alternatives: (1) corn silage following first-cut alfalfa, (2) single-crop corn harvested as silage, and (3) alfalfa harvested four times through the growing season. Forage yield and quality and economic profitability were

determined for each system for 26 years. Further analyses evaluated system sensitivity to changes in model parameters including forage price and yield and alfalfa first-cut date.

Applied Questions

How well did double-crop corn silage following first-cut alfalfa perform relative to single-crop corn silage and alfalfa harvested four times?

The double-crop system was the most profitable of the three systems in 4 of the 26 years. Years in which the double-crop system was most profitable were characterized by long growing seasons with above normal precipitation. In 22 of the 26 years, single-crop corn silage and/or four-cut alfalfa were more profitable than the double-crop system.

Is there some forage price level which would favor double-crop corn silage following first-cut alfalfa?

No historical forage price was shown to favor the double-crop system in more than 4 of the 26 years. When further sensitivity analyses were performed using reasonable model parameters varied for yield levels and alfalfa first-cut dates, the maximum number of years when the double-crop system was the most profitable was 7 of 26.

REFERENCES

- Borton, L.R. 1994. A comparison of corn silage and alfalfa for forage on Michigan dairy farms. Ph.D. diss. Michigan State Univ., E. Lansing.
- Durling, J.C., O.B. Hesterman, and C.A. Rotz. 1994. Predicting first-cut alfalfa yields from preceding winter weather conditions. Accepted for publication in J. Prod. Agric.
- Dysinger, K., M. Chamberlain, D.D. Harpstead, J. Lempke, M. Allen, and D. Main. 1994. Hybrids compared 1994. Michigan State University Extension Service Bulletin E-431.
- Ebelhar, S.A., W.W. Frye, and R.L. Blevins. 1984. Nitrogen for legume cover crops for no-tillage corn. Agron. J. 76:51-55.
- Fallander, J. 1989. Check alfalfa stands for winter damage: early detection keeps all options open. p. 18-19. Hay & Forage Grower.
- Fick, G.W. 1977. The mechanisms of alfalfa regrowth: a computer simulation approach. Search: Agriculture 7(3):1-28.
- Fick, G.W., and D.W. Onstad. 1988. Statistical models for predicting alfalfa herbage quality from morphological or weather data. J. Prod. Agric. 1:160-166.
- Hesterman, O.B., R.H. Leep, and J.J. Paling. 1994. Alfalfa varieties for Michigan in 1994. Michigan State University Department of Crop & Soil Sciences File 22.331.
- Hesterman, O.B., T.S. Griffin, P.T. Williams, G.H. Harris, and D.R. Christenson. 1992. Forage legume-small grain intercrops: nitrogen production and response of subsequent corn. J. Prod. Agric. 5:340-348.
- Hesterman, O.B., M. Tesar, J.R. Black, E. DeVuyt, and G. Schwab. 1989. RESEED. Michigan State University Cooperative Extension Service.
- Jones, C.A., and J.R. Kiniry (ed.). 1986. CERES-Maize. A simulation model of maize growth and development. Texas A&M Univ. Press. College Station, TX.
- Lehnert, D. 1990. Sold on no-till. Michigan Farmer. 4:8-10.

Lewis, W.M., and J.A. Phillips. 1976. Double cropping in the Eastern United States. p. 41-50. In Papendick, R.I., P.A. Sanchez, and G.B. Triplett (eds.). Multiple cropping. ASA Spec. Pub. 27. ASA, CSSA, and SSSA, Madison, WI.

Michigan Department of Agriculture. 1987. Michigan agricultural statistics. Lansing, MI.

Miller, F.P. (ed). 1988. Ohio agronomy guide. Ohio Cooperative Extension Service. The Ohio State University.

National Research Council. 1988. Nutrient requirements of dairy cattle, 6th ed. National Academy Press, Washington, DC.

Perry, T.W. 1988. Corn as a livestock feed. In G.F. Sprague and J.W. Dudley (eds.) Corn and corn improvement. 3rd ed. Agronomy 18:941-963.

Rossman, E.C., K. Dysinger, M. Chamberlain, R.H. Leep, O.B. Hesterman, and F.J. Pierce. 1987. Hybrids compared 1987. Michigan State University Cooperative Extension Service Bulletin E-431.

Rotz, C.A, J.R. Black, D.R. Mertens, and D.R. Buckmaster. 1989. DAFOSYM: A model of the dairy forage system. J. Prod. Agric. 2:83-91.

Smith, M.A., P.R. Carter, and A.A. Imholte. 1992. No-till vs. conventional tillage for late-planted corn following hay harvest. J. Prod. Agric. 5:261-264.

Widstrom, N.W., J.R. Young, W.K. Martin, and D.L. Shaver. 1984. Grain and forage yields of irrigated second-crop corn seeded on five planting dates. Agron. J. 76:883-886.

CHAPTER THREE

BREAKEVEN ANALYSIS FOR EVALUATING DOUBLE-CROP ALTERNATIVES

INTRODUCTION

Numerous analytical techniques or decision-making tools may be used in farm management. One such tool is comparative breakeven analysis.

Just as with *mechanical* tools, each *decision-making* tool has a particular application. Comparative breakeven analysis is a decision-making tool that is useful for determining if acreage should be shifted from one crop to another. In this paper we show how breakeven analysis can be used to make an economic comparison of a single crop with a double-crop alternative. Specifically we (i) discuss the concept of double cropping, its applications and limitations, (ii) describe and illustrate the application of comparative breakeven analysis to enterprise selection involving a double-crop alternative, and (iii) discuss additional considerations about using comparative breakeven analysis including differential riskiness among crops.

DOUBLE CROPPING

Double cropping is defined as growing two crops a year in sequence on the same field. Double cropping is one of several multiple-cropping patterns. Another multiple-cropping pattern is intercropping, that is, growing two or more crops simultaneously on the same field (Andrews and



Kassam, 1976). Double cropping and other multiple-cropping patterns may increase economic return without increasing the land base required for crop production. Other benefits of double cropping include economic diversification, increased biodiversity, and reduced soil erosion through more continuous ground cover (Francis, 1986; Papendick, 1976). Reported disadvantages of double cropping include unpredictable yields and lack of adequate information and management practices (Widstrom et al., 1984; Okoli et al., 1984).

Double cropping is widely practiced in the Southern United States but is less common in northern tier North Central States such as Michigan due to the shorter growing season and lack of heat units (Okoli et al., 1984). Examples of sequential double cropping in Michigan include short-season crops such as green beans, edible beans, or soybeans following winter cereals and first-cut hay followed by another crop (e.g., Lehnert, 1990). Intercropping systems in Michigan include forage legumes sown either with or into small grain and harvested as forage after small grain harvest (Hesterman et al., 1992). Intercropping may also involve one crop seeded into another crop to provide ground cover after the first crop is harvested. These cover crops reduce soil erosion through providing continuous ground cover and trap and hold nutrients (Power, 1987).



COMPARATIVE BREAKEVEN ANALYSIS

Comparative breakeven analysis may be used for deciding whether to shift acreage from one crop to another.

Comparative breakeven analysis and its application to single-crop alternatives is described in **Break-Even Analysis for Comparing Alternative Crops**, Michigan State University Extension Bulletin E-2021 (Hilker et al., 1987).

Comparative breakeven analysis as described and illustrated in this paper provides the framework to answer two questions for evaluating double-crop alternatives. First, given the (i) yield, price, and variable costs for a single crop, (ii) yield, price, and variable costs for one crop in a double-crop system, and (iii) yield and variable costs of the other crop in a double-crop system, what would the price of the other crop in the double-crop system have to be to generate the same net return to fixed costs to the double-crop system as generated by the single crop? We call this the breakeven price. Second, given the (i) yield, price, and variable costs for a single crop, (ii) yield, price, and variable costs for one crop in a double-crop system, and (iii) price and variable costs of the other crop in a double-crop system, what would the yield of the other crop in the double-crop system have to be to generate the same net return to fixed costs to the double-crop system as generated by the single crop? We call this the breakeven yield.

In the worksheet and discussion that follow, the original single crop will be referred to as the *defender*. The double-crop alternative will be referred to as the *challenger*. Challenger phase refers to the placing of a challenger in the double-crop sequence.

CASE EXAMPLE

The application of breakeven analysis to a single-crop vs. double-crop decision is illustrated through the following example. Suppose you have an older alfalfa stand that you will be rotating to corn sometime in the coming year. Your objective is to produce as much forage as economically feasible on this acreage. You want to evaluate these alternatives:

- (1) single crop — corn silage
- (2) double crop — first-cut alfalfa hay followed by corn silage.

Field research comparing single-crop corn silage and double-crop alfalfa hay and corn silage was presented in chapter two of this thesis, **Corn Silage Following First-Cut Alfalfa: A Forage Production Alternative?**

Comparisons between single-crop alternatives can be made using comparative breakeven analysis as described in MSU Extension Bulletin E-2021. However, comparing a single crop with a double crop requires a modified procedure.

Let's begin by asking the question, "What combination of double-crop first-cut alfalfa hay (phase I) and corn

silage (phase II) yields and prices would give the same return to fixed costs as single-crop corn silage?"

To calculate the breakeven price and yield combination for one phase of a double-crop challenger, you must first calculate the return for the defender and for the other phase of the challenger. (You can follow these steps on the worksheet.)

A. Calculate the gross revenue per acre for the defender, which is the yield per acre (line 1) multiplied by the price per unit (line 2). In our example, the defender is single-crop corn silage:

$$\text{Gross Revenue} = (18 \text{ ton/acre}) \times (\$28/\text{ton}) = \$504/\text{acre.} \quad (\text{line } 3)$$

B. Sum the defender's variable costs per acre (lines 4, 5, and 6b). In our example, the defender's:

$$\text{Variable Costs} = \$106 + \$24 + \$0 = \$130. \quad (\text{line } 7)$$

C. Subtract the defender's variable costs from the defender's gross revenue to get the defender's net returns to fixed costs per acre (line 3 - line 7). In our example, the defender's:

$$\text{Return to Fixed Cost} = \$504 - \$130 = \$374. \quad (\text{line } 8)$$

This is the return that the challenging crop (corn silage following first-cut alfalfa hay) must meet or exceed to bid land away from the defender (single-crop corn silage).

D. Calculate the gross revenue per acre for phase I of the double-crop challenger, which is the yield per acre (line 9) multiplied by the price per unit (line 10). In our example the phase I challenger is first-cut alfalfa hay and the challenger's:

$$\begin{aligned}\text{Gross Revenue} &= (2.2 \text{ ton/acre}) \times (\$87/\text{ton}) = \\ &\$191.40/\text{acre}.\end{aligned}\quad (\text{line } 11)$$

E. Sum the challenger's phase I variable costs per acre (lines 12, 13, and 14b). In our example, the challenger's:

$$\text{Variable Cost} = \$10 + \$20 + \$0 = \$30. \quad (\text{line } 15)$$

F. Subtract the challenger's phase I variable costs from the challenger's phase I gross revenue to get the challenger's phase I net returns to fixed costs (line 11 - line 15). In our example:

$$\begin{aligned}\text{Challenger's phase I Return to Fixed Cost} &= \$191.40 - \\ &\$30 = \$161.40.\end{aligned}\quad (\text{line } 16)$$

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G. Enter, but do not sum, the variable costs (lines 17, 18, and 19) for phase II of the double-crop challenger (corn silage) in our example.

Preharvest Costs = \$69/acre. (line 17)

Harvest Costs = \$17/acre. (line 18)

Drying and Marketing Costs = \$0/ton. (line 19)

H. Enter yield per acre of challenger phase II. In our example:

Yield of challenger phase II = 12 tons/acre (line 20)

I. Calculate the breakeven price of the challenger phase II. Add challenger's phase II Preharvest Costs, Harvest Costs, and Drying and Marketing Costs ($\text{Costs/Unit} \times \text{Yield}$) (lines 17, 18, and 19×20) to the defender's net return (line 8) and subtract the challenger's phase I net return (line 16). This amount can be thought of as an "imputed" cost. This gives the gross revenue per acre the challenger phase II (corn silage in our example) must generate in order to warrant switching acreage away from the defender (single-crop corn silage in our example). The imputed cost (lines $17 + 18 + (19 \times 20) + 8 - 16$) is divided by the challenger's phase II expected yield per acre (line 20) which gives the

price per unit the challenger phase II must generate to obtain the same returns to fixed costs as would be generated by the defender. In our example:

$$\begin{aligned} \text{Imputed cost} = & (\text{line 21b } (\$69) + \text{line 21c } (\$17) + (\text{line} \\ & 21\text{d } (\$0) \times \text{line 21e } (12)) + \text{line 21f } (\$374) - \text{line 21g} \\ & (\$161.40)) = \$298.60 \end{aligned}$$

and

$$\begin{aligned} \text{Breakeven corn silage price} = & (\$298.60/\text{acre}) \div \text{line 21h} \\ & (12 \text{ ton/acre}) = \$24.88/\text{ton}. \end{aligned} \quad (\text{line 21a})$$

\$24.88/ton answers the question, "What double-crop corn silage price would generate equal net returns to fixed costs for the double- and single-crop alternatives, given the yields, prices, and costs on lines 1 to 20?"

J. Enter price per unit of challenger phase II. In our example:

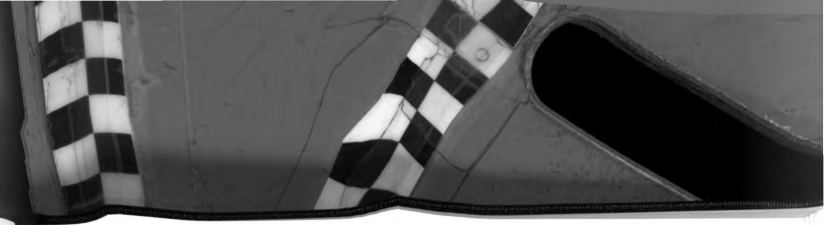
$$\text{Price of Challenger Phase II} = \$28/\text{ton} \quad (\text{line 22})$$

K. The challenger's phase II breakeven yield is calculated in much the same manner. The imputed cost (challenger phase II preharvest and harvest costs, plus return to fixed costs defender, minus return to fixed costs challenger phase I) is

divided by the expected price per unit less drying and marketing costs of the challenger phase II, which gives you the yield needed by the challenger phase II to match the net returns to fixed costs generated by the defender, i.e., breakeven yield. In our example, the:

$$\begin{aligned} \text{Breakeven phase II corn silage yield} &= (\text{line 23b } (\$69) \\ &+ \text{line 23c } (\$17) + \text{line 23d } (\$374) - \text{line 23e } (\$161.40) \\ &\div (\text{line 23f } (\$28/\text{ton}) - \text{line 23g } (\$0)) = 10.66 \\ &\text{tons/acre.} \end{aligned} \quad (\text{line 23a})$$

10.66 tons/acre answers the question, "What double-crop corn silage yield would generate equal net returns to fixed costs for the double- and single-crop alternatives, given the yields, prices, and costs on lines 1 to 19 & 22?"



ADDITIONAL CONSIDERATIONS

As with a mechanical tool, breakeven analysis may be appropriate, inappropriate, or limited by other considerations in a given situation. Appropriate use of breakeven analysis includes comparison including marginal shifts of acreage from one crop to another; however, comparative breakeven analysis is not the most appropriate tool for making whole farm enterprise allocation decisions. Some factors, although not readily quantifiable or explicitly considered by comparative breakeven analysis (e.g., machinery and labor availability, ecological benefits of certain crops or systems, and government program requirements), may be very important in determining crop mix and should not be overlooked.

Another factor that should be considered in determining crop mix is differential yield and price riskiness among crops. Double-crop yields are less predictable than single-crop yields and prices of some commodities are more variable than others.

Michigan State University Extension Bulletin E-2021 suggests two approaches for dealing with differential riskiness in comparative breakeven analysis. One is to add to the variable costs a *risk premium* for dealing with the additional risk. The amount of this risk premium is determined by answering, "What additional net return per acre would I have to earn to compensate for the additional risk of growing the challenger in place of the defender?"

The second approach, *scenario analysis*, is to go through the breakeven analysis using alternative price and yield assumptions. Pessimistic yield and price assumptions show the magnitude of downside risk. In a more sophisticated but tedious procedure, the probability of each assumption could be multiplied by the corresponding return to fixed costs and summed to give the net probability of the downside risk. This procedure is described in Michigan State University Agricultural Economics Staff Paper No. 86-2 (Hesterman et al., 1986).

SUMMARY

In this paper we have discussed the use of comparative breakeven analysis as a farm management tool. Using as an example a double-cropping system that has been tried in Michigan, we showed how comparative breakeven analysis can be used to answer "What double-crop price and yield combinations would give the same return to fixed costs as a single-crop alternative?"

Breakeven Analysis for Evaluating Double-Crop Alternatives

Worksheet

For Comparative Breakeven Analysis
Comparing a Double-Crop Challenger with a Defender

Defender Crop:

Single-crop corn silage

- | | | |
|---|------------------------------------|------------|
| 1. Yield | <u>tons</u> /acre (35% dry matter) | <u>18</u> |
| 2. Price | <u>\$/ton</u> | <u>28</u> |
| 3. Gross Revenue (GR = Yield × Price) (Line 1 × Line 2) | | <u>504</u> |

Variable Costs

- | | |
|--|-------------|
| 4. Preharvest Costs \$/acre | <u>106</u> |
| 5. Harvest Costs \$/acre | <u>24</u> |
| 6. Drying and Marketing Costs a. <u>\$ 0/ton</u> | |
| Line 1 × Line 6a. | b. <u>0</u> |
| 7. Sum of Variable Costs (VC = Line 4 + Line 5 + Line 6b) | <u>130</u> |
| 8. Returns To Fixed Costs (RTFC = GR - VC) (Line 3 - Line 7) | <u>374</u> |

Double-Crop Challenger Phase I:

first-cut alfalfa hay

- | | | |
|---|------------------------------------|---------------|
| 9. Yield | <u>tons</u> /acre (88% dry matter) | <u>2.2</u> |
| 10. Price, \$/ton | <u>87</u> | |
| 11. Gross Revenue (GR = Yield × Price) (Line 9 × Line 10) | | <u>191.40</u> |

Variable Costs

- | | |
|------------------------------|-----------|
| 12. Preharvest Costs \$/acre | <u>10</u> |
| 13. Harvest Costs \$/acre | <u>20</u> |

14. Drying and Marketing Costs a. \$ 0 / tonLine 9 $\times$ Line 14a.b. 015. Sum of Variable Costs (VC = Line 12 + Line 13 + Line 14b) 3016. Returns To Fixed Costs (RTFC = GR - VC)
(Line 11 - Line 15)161.40**Double-Crop Challenger Phase II:**Corn Silage**Variable Costs**

17. Preharvest Costs \$/acre

69

18. Harvest Costs \$/acre

17

19. Drying and Marketing Costs \$/ton

0To bid land away, Return to Fixed Costs Challenger must be greater
than Return to Fixed Costs Defender

To Calculate the Breakeven Price of the Challenger Phase II:

20. Yield of Challenger Phase II 12 tons / acreBreakeven Price = (Preharvest Costs Challenger Phase II + Harvest Costs Challenger Phase II +
(Drying and Marketing Costs/Unit $\times$ Yield of Challenger Phase II) + RTFC Defender - RTFC
Challenger Phase I) / Yield of Challenger Phase II

$$21a. \$ \frac{24.88}{\text{line 8}} / \frac{\text{ton}}{\text{line 16}} = (b. \frac{69}{\text{line 17}} + c. \frac{17}{\text{line 18}} + (d. \frac{0}{\text{line 19}} \times e. \frac{12}{\text{line 20}}) + f. \frac{374}{\text{line 8}} - g. \frac{161.40}{\text{line 16}}) / h. \frac{12}{\text{line 20}}$$

To Calculate the Breakeven Yield of the Challenger Phase II:

22. Price of Challenger Phase II \$ 28 / tonBreakeven Yield = (Preharvest Costs Challenger Phase II + Harvest Costs Challenger Phase II +
RTFC Defender - RTFC Challenger Phase I) / (Price of Challenger Phase II - Drying and Marketing
Costs/Unit)

$$23a. \frac{10.66 \text{ tons}}{\text{acre}} = (b. \frac{69}{\text{line 17}} + c. \frac{17}{\text{line 18}} + d. \frac{374}{\text{line 8}} - e. \frac{101.40}{\text{line 16}})$$

$$/ (f. \frac{28}{\text{line 22}} - g. \frac{0}{\text{line 19}})$$

REFERENCES

- Andrews, D.J., and A.H. Kassam. 1976. The importance of multiple cropping in increasing world food supplies. p. 1-10. In R.I. Papendick (ed). Multiple cropping. ASA Spec. Publ. 27. ASA, Madison, WI.
- Francis, C.A. (ed.). 1986. Multiple cropping systems. Macmillan Publishing Company, New York.
- Hesterman, O.B., T.S. Griffin, P.T. Williams, G.H. Harris, and D.R. Christenson. 1992. Forage legume-small grain intercrops: nitrogen production and response of subsequent corn. J. Prod. Agric. 5:340-348.
- _____, M. Swartz, J. Hilker, and J.R. Black. 1986. A tool for agronomic decision making: the decision tree. Michigan State University Agricultural Economics Staff Paper No. 86-2.
- Hilker, J.H., J.R. Black, and O.B. Hesterman. 1987. Break-even analysis for comparing alternative crops. Michigan State University Cooperative Extension Service Bulletin E-2021.
- Lehnert, Dick. 1990. Sold on no-till. Michigan Farmer. 4:8-10.
- Okoli, P.S.O., P.N. Drolsom, and J.M. Scholl. 1984. Forage production and weed control in a double-cropping program. Agron. J. 76:363-366.
- Papendick, R.I. (ed). 1976. Multiple cropping. ASA Spec. Publ. 27. ASA, Madison, WI.
- Power, J.F. (ed.). 1987. The role of legumes in conservation tillage systems. Soil Conserv. Soc. Am., Ankeny, IA.
- Widstrom, N.W., J.R. Young, W.K. Martin, and D.L. Shaver. 1984. Grain and forage yields of irrigated second-crop corn seeded on five planting dates. Agron. J. 76:883-886.



Breakeven Analysis for Evaluating Double-Crop Alternatives

Worksheet

For Comparative Breakeven Analysis
Comparing a Double-Crop Challenger with a Defender

Defender Crop:

-
1. Yield _____/acre _____
 2. Price \$/_____ _____
 3. Gross Revenue (GR = Yield $\times$ Price) (Line 1 $\times$ Line 2) _____

Variable Costs

4. Preharvest Costs \$/acre _____
5. Harvest Costs \$/acre _____
6. Drying and Marketing Costs a. \$ _____/_____
- Line 1 $\times$ Line 6a. b. _____
7. Sum of Variable Costs (VC = Line 4 + Line 5 + Line 6b) _____
8. Returns To Fixed Costs (RTFC = GR - VC) (Line 3 - Line 7) _____

Double-Crop Challenger Phase I:

-
9. Yield _____/acre _____
 10. Price, \$/_____ _____
 11. Gross Revenue (GR = Yield $\times$ Price) (Line 9 $\times$ Line 10) _____

Variable Costs

12. Preharvest Costs \$/acre _____
13. Harvest Costs \$/acre _____

14. Drying and Marketing Costs a. \$ ____ / ____

Line 9 × Line 14a.

b. ____

15. Sum of Variable Costs (VC = Line 12 + Line 13 + Line 14b) ____

16. Returns To Fixed Costs (RTFC = GR - VC)
(Line 11 - Line 15) ____

Double-Crop Challenger Phase II:

Variable Costs

17. Preharvest Costs \$/acre ____

18. Harvest Costs \$/acre ____

19. Drying and Marketing Costs \$/ ____

To bid land away, Return to Fixed Costs Challenger must be greater
than Return to Fixed Costs Defender

To Calculate the Breakeven Price of the Challenger Phase II:

20. Yield of Challenger Phase II ____ / acre

Breakeven Price = (Preharvest Costs Challenger Phase II + Harvest Costs Challenger Phase II +
(Drying and Marketing Costs/Unit × Yield of Challenger Phase II) + RTFC Defender - RTFC
Challenger Phase I) / Yield of Challenger Phase II

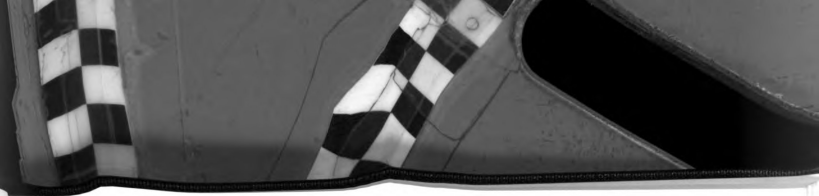
21a. \$ ____ / ____ = (b. $\frac{\text{line 17}}{\text{line 17}}$ + c. $\frac{\text{line 18}}{\text{line 18}}$ + (d. $\frac{\text{line 19}}{\text{line 19}}$ × e. $\frac{\text{line 20}}{\text{line 20}}$)
+ f. $\frac{\text{line 8}}{\text{line 8}}$ - g. $\frac{\text{line 16}}{\text{line 16}}$) / h. $\frac{\text{line 20}}{\text{line 20}}$

To Calculate the Breakeven Yield of the Challenger Phase II:

22. Price of Challenger Phase II \$ ____ / ____

Breakeven Yield = (Preharvest Costs Challenger Phase II + Harvest Costs Challenger Phase II +
RTFC Defender - RTFC Challenger Phase I) / (Price of Challenger Phase II - Drying and Marketing
Costs/Unit)

$$23a. \frac{\text{_____}}{\text{_____}} / \text{acre} = (b. \frac{\text{_____}}{\text{line 17}} + c. \frac{\text{_____}}{\text{line 18}} + d. \frac{\text{_____}}{\text{line 8}} - e. \frac{\text{_____}}{\text{line 16}}) \\ / (f. \frac{\text{_____}}{\text{line 22}} - g. \frac{\text{_____}}{\text{line 19}})$$



CHAPTER FOUR

AVOIDING WINTER INJURY TO ALFALFA

Alfalfa stands in Michigan are sometimes injured during the winter. The most common weather-related causes of winter injury are extremely low or fluctuating temperatures, persistent ice sheeting, and lack of snow cover. This bulletin describes how alfalfa plants are injured or killed during the winter and recommends practices to reduce the risk of winter injury. Also presented is a method to estimate yield losses for alfalfa stands that have sustained winter injury.

CAUSES OF WINTER INJURY

Extremely Low and Fluctuating Temperatures

The capacity of plants to survive the effects of low temperatures is called cold hardiness. Cold hardiness is redeveloped each fall in response to decreasing day length and temperature. The extent to which cold hardiness develops depends upon the alfalfa variety. Cold hardiness is not developed to the same extent in all parts of the plant. Alfalfa herbage can be injured or killed when temperatures drop below 28°F in the fall. Cold hardened crowns and roots are not injured until temperatures drop below 0°F. Snow, soil, and/or stubble usually protect alfalfa from lethal effects of fluctuating or cold temperatures in Michigan.

Fluctuating temperatures are detrimental when warm temperatures cause over-wintering alfalfa to initiate growth

too early for normal spring development. When temperatures rise to 50 to 60°F for several days during mid-winter, overwintering alfalfa can break dormancy. When this happens, crown buds elongate and grow, depleting stored root reserves. Then, when normal cold temperatures resume, crown buds can be killed. When conditions suitable for regrowth occur in the spring, regrowth is delayed. The most cold hardy alfalfa varieties are the least apt to break dormancy in the winter.

Frost heaving is another type of injury caused by temperature fluctuations. Heaving occurs when alfalfa crowns and roots are forced above the soil surface by the action of freezing and thawing. This occurs in the late winter and early spring on heavy and/or poorly drained soils. Frost-heaved plants can be injured in four ways:

- (1) Roots can be mechanically damaged by the lifting itself;
- (2) Roots and crowns can be dried out when exposed to the air;
- (3) Exposed crowns and roots can be injured by cold air temperatures; and
- (4) Lifted plants can be cut off below the crown when harvested.

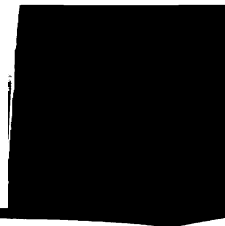
Persistent Ice Sheeting

Persistent ice sheeting is another environmental condition that can injure or kill alfalfa during winter. Plants can be covered with ice by a sleet or ice storm or when a mid-winter thaw is followed by freezing temperatures. Injury or death can occur in two ways under these conditions. First, plants encased in ice for a week or more

can be smothered by metabolic byproducts (e.g., CO_2 , ethanol, and methanol) that cannot escape through the ice. Second, ice covered plants are injured when exposed to cold air temperatures due to the low insulation value of ice.

Lack of Snow Cover

Although ice can injure alfalfa, snow is usually beneficial. Snow is a good insulator, offering protection from extremely cold temperatures and fluctuating temperatures. A cover of 6 inches of uncompacted snow will protect alfalfa plants from injury down to an air temperature of -20°F . Therefore, winters without much snow cover generally cause the most damage to alfalfa stands.



REDUCING THE RISK OF WINTER INJURY

You cannot control the weather. However, you can reduce the risk of winter injury through variety selection, maintaining young stands, potassium fertilization, soil drainage, snow retention, and timely cutting management.

Variety Selection

The risk of winter injury is reduced when winter-hardy varieties are grown. Winterhardiness is the capacity of a plant to survive adverse conditions during the winter. Alfalfa varieties are rated for winterhardiness based upon an observed relationship between fall dormancy and winterhardiness. Varieties that produce the least top growth following a mid-September cutting are termed very fall dormant and tend to be more winterhardy. A fall dormancy rating system used in Minnesota, Michigan, and elsewhere, identifies nine levels of dormancy:

very dormant [index 1]

dormant [2]

moderately dormant [3]

semidormant [4,5,6]

moderately nondormant [7]

nondormant [8]

very nondormant [9]

Varieties with fall dormancy ratings of 1 and 2 are recommended for long-term stands of 5 or more years or for pasture in Michigan. Additionally, varieties with fall dormancies of 3 and 4 can be recommended for long-term

stands if they have been tested in northern Michigan and show adequate productivity and survival. Varieties with fall dormancy ratings from 1 to 5 can be planted for short-term stands of 2 to 4 years. Fall dormancy ratings and recommendations for alfalfa varieties tested in Michigan are reported in an annual report of alfalfa variety trials (e.g., MSU Dept. of Crop & Soil Sciences File 22.331).

The use of fall dormancy ratings to indicate winterhardiness is based on the assumption of a strong relationship between these two characteristics. However, recent evidence indicates a weaker relationship between fall dormancy and winterhardiness in many newer semidormant varieties. These varieties are characterized by rapid regrowth after cutting and multiple disease resistance. Therefore, an accurate characterization of the winterhardiness of these varieties cannot be based solely on fall regrowth but also must include evaluating plant survival through the winter.

The risk of winter injury is also reduced when disease resistant varieties are grown. An alfalfa variety is made up of plants that are not genetically uniform. Therefore, the disease resistance rating of a variety is based upon the percentage of individual plants showing resistance to a disease. Five categories are used to rate disease resistance:

Susceptible, 0 to 5% resistant plants

Low Resistance, 6 to 14% resistant plants

Moderate Resistance, 15 to 30% resistant plants

Resistant, 31 to 50% resistant plants

High Resistance, >50% resistant plants

Disease resistance helps alfalfa plants survive the winter. The risks associated with low or fluctuating temperature, persistent ice sheeting, and lack of snow cover are increased in diseased plants. Diseased plants are less vigorous, develop less cold hardiness, and can be easily injured during the winter. Wounds resulting from winter injury provide a point of entry for disease organisms. This cycle intensifies as plants grow older. Resistance to bacterial wilt is recommended for varieties grown anyplace in Michigan and resistance to anthracnose is recommended for varieties grown in the Lower Peninsula. In addition, phytophthora root rot resistance is recommended when alfalfa is grown on poorly or somewhat poorly drained soils.

Recommendation: Choose alfalfa varieties that are moderately winterhardy, winterhardy, or very winterhardy and resistant to bacterial wilt and anthracnose. Yield, winterhardiness, and disease resistance ratings of individual varieties are published in MSU Extension Bulletin E-1098 (Hesterman et al., 1991) and MSU Dept. of Crop & Soil Sciences File 22.331 (Hesterman et al., published yearly in January).

Stand Age

Another way to reduce the risk of winter injury is to maintain young stands. Young alfalfa stands are less

susceptible than older stands to winter injury for two reasons. First, young plants are less likely to be affected by disease and less predisposed to winter injury. Second, young stands generally have higher plant populations than older stands, so some plants can be winterkilled with little effect on total yield. Table 4.1 shows that 4-year-old stands of alfalfa cut three or four times suffered greater winter injury due to cutting in mid-September and mid-October than 2-year-old stands subject to the same cutting schedules.

The risk of winter injury to seedling alfalfa increases if alfalfa is planted too late in the summer. For the hardening processes to be effective, plants need to develop several trifoliolate leaves before winter. Therefore, the last recommended dates for summer seedings are August 15 in southern Michigan and August 1 in northern Michigan.

Recommendation: Plant new stands each year, but do not plant after recommended dates. If you harvest some of your alfalfa in the fall, harvest the young stands and let the older stands remain unharvested going into the winter.

Table 4.1. Effects of alfalfa stand age and harvest schedules with variable date of fall cutting on first-cut yield and stand density following a severe Minnesota winter.

Cuts/yr	Final cut date	<u>2-yr-old stand</u>		<u>4-yr-old stand</u>	
		Stands	Yield	Stands	Yield
		%	Ton/acre	%	Ton/acre
3	15 Sept.	75	1.7	18	0.9
	15 Oct.	78	1.9	12	0.7
4	15 Sept.	55	1.0	12	0.5
	15 Oct.	70	1.3	16	1.2
LSD _{0.05}		11	0.2	8	0.4

Source: Adapted from Sheaffer, 1989.

Potassium

The risk of winter injury is reduced when soil levels of potassium (K) are adequate. Adequate levels of K promote vigorous and healthy alfalfa and help protect against winter injury. Figure 4.1 shows how K fertilization benefits stand density. Higher K fertilizer rates resulted in higher alfalfa plant populations in the spring of the fourth year. The beneficial effect of K fertilization was especially evident with the more intense cutting schedule.

Recommendation: Test soil and apply fertilizer according to Table 4.2 to achieve a realistic yield goal. If the recommended amount is less than 400 lbs K_2O /acre, broadcast all the fertilizer for one year in a single application. Broadcast in the spring, summer, or fall when the soil is firm enough to support the spreading equipment and when the foliage is dry enough to prevent sticking and burning.

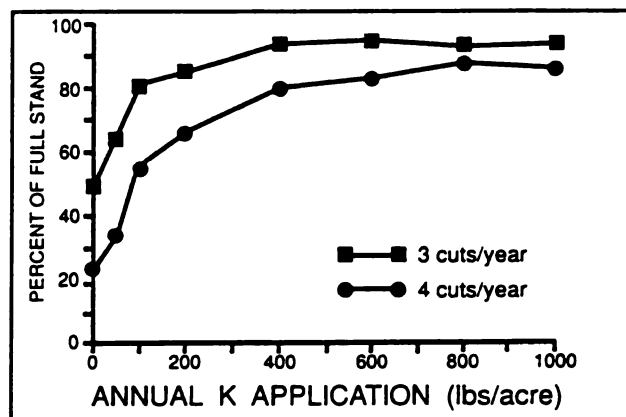


Figure 4.1. How K fertilizer and the number of cuts affect an alfalfa stand in the spring of the fourth year. Source: Smith et al., 1986.

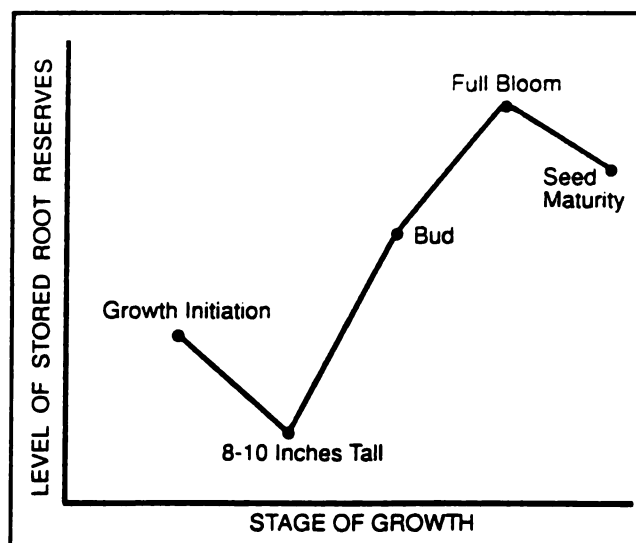
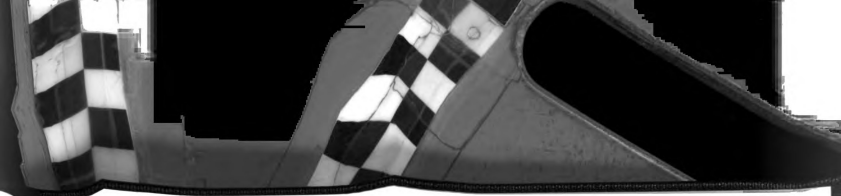


Figure 4.2. Alfalfa growth stages and level of stored root reserves.

Table 4.2. Annual potassium (K_2O) recommendations for alfalfa grown on mineral soils.

	-----yield goal (tons/acre)-----						8
	3	4	5	6	7		
Soil test (lbs K/a)	Potassium recommendation, lb K_2O /acre on sandy loams and loamy sands						
25	290	310	340	360	390	410	
50	260	290	310	340	360	390	
75	240	260	290	310	340	360	
100	210	240	260	290	310	340	
125	190	210	240	260	290	310	
150	160	190	210	240	260	290	
175	140	160	190	210	240	260	
200	110	140	160	190	210	240	
225	90	110	140	160	190	210	
250	60	90	110	140	160	190	
275	40	60	90	110	140	160	
300	0	40	60	90	110	140	
325	0	0	40	60	90	110	
350	0	0	0	40	60	90	
375	0	0	0	0	40	60	
400	0	0	0	0	0	40	
Soil test (lbs K/a)	Potassium recommendation, lb K_2O /acre on loams, clay loams, and clays						
25	270	320	370	420	470	520	
50	240	290	340	390	440	490	
75	200	250	300	350	400	450	
100	160	210	260	310	360	410	
125	120	170	220	270	320	370	
150	90	140	190	240	290	340	
175	50	100	150	200	250	300	
200	0	60	110	160	210	260	
225	0	20	70	120	170	220	
250	0	0	40	90	140	190	
275	0	0	0	50	100	150	
300	0	0	0	0	60	110	
325	0	0	0	0	20	70	
350	0	0	0	0	0	40	
375	0	0	0	0	0	0	

Source: Michigan State University Cooperative Extension
Bulletin E-550



Soil Drainage

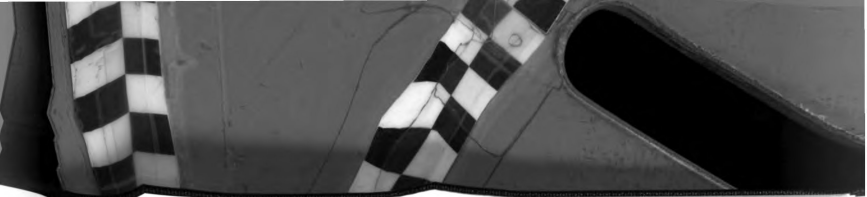
The risk of winter injury is increased when alfalfa is grown on poorly or somewhat poorly drained soils. Injury from frost heaving and persistent ice sheeting is more apt to be a problem in low, wet areas or on poorly drained soils. Moreover, saturated and wet soil conditions promote diseases such as phytophthora root rot during the growing season and can limit hardening in the fall.

Recommendation: Grow alfalfa on well drained soils, and do not irrigate alfalfa in the fall. Other forage legumes (e.g., birdsfoot trefoil or clover) are better choices for wet areas. If you must grow alfalfa in wet areas, select a variety resistant to phytophthora root rot.

Snow Retention

The risk of winter injury is reduced when alfalfa is insulated from lethal cold temperatures and wide temperature fluctuations by a covering of snow. Although there is no practical way to control amount of snowfall, there are ways to retain the snow once it has fallen. Snow can be trapped by unmowed strips in the field, high stubble (6 inches), and fall regrowth. Conversely, manure spread on snow can cause the snow to melt.

Recommendation: Raise mowing height at the final harvest to 6 inches to retain snow. Avoid spreading manure on snow-covered alfalfa.



Seasonal Cutting Strategy

When and how often alfalfa is cut probably has a greater impact on winter injury than any other management practice. As you develop a seasonal cutting strategy for a field of alfalfa, consider both the impact of the strategy on the stored root reserves of the alfalfa plants and your goals for alfalfa production.

Stored root reserves are important. They provide energy for regrowth in the spring and after each cutting. Stored root reserves are also the main energy source for alfalfa during the winter. The storage and depletion of root reserves follows a cyclic pattern. Figure 4.2 graphically represents the relationship between alfalfa growth stage and level of stored root reserves for one regrowth cycle. Stored root reserves decline from initial regrowth (in the spring or after the alfalfa is cut) until plants have produced 8 to 10 inches of top growth. Plants with 8 to 10 inches of top growth can synthesize enough carbohydrates by photosynthesis to begin to replenish the root reserves. The maximum level of stored root reserves is usually achieved at full bloom. Between full bloom and seed maturity, the level of stored root reserves declines slightly. This decline is due to the decreased photosynthetic efficiency of the older leaves and the concentration of carbohydrates in developing seeds and new shoots.

Cutting or grazing alfalfa frequently and/or at early stages of growth throughout the season can deplete stored root reserves. Root reserves can also be depleted when frost kills fall regrowth in early growth stages. Alfalfa plants that go into the winter with depleted root reserves are more susceptible to winter injury.

Your production goals for alfalfa are the second major factor to consider as you develop a seasonal cutting strategy. Goals for alfalfa production usually relate to forage yield, forage quality, and/or stand persistence. It is impossible to simultaneously maximize forage yield, forage quality, and stand persistence. As alfalfa plants mature and increase in biomass per acre (forage yield) they decrease in concentration of nutrients per ton of biomass (forage quality). The number of years that any alfalfa stand will be productive is affected by many factors, both controllable and uncontrollable. The seasonal cutting strategy that you develop involves a trade-off among your needs for high forage yield, high forage quality, and stand persistence.

Recommendations:

(1) Schedule your cuttings based upon alfalfa stage of growth and your goals for forage production. Harvest at the early bloom stage of growth to maximize nutrient yield per acre and ensure that root reserves have been restored to a reasonably high level. Harvesting earlier maximizes forage quality but does not ensure adequate levels of stored root

reserves. Harvesting later maximizes yield and stored root reserve levels but forage quality is lowered.

(2) Offset the risk of winter injury by selecting multiple disease resistant, winter hardy varieties, maintaining young stands, keeping soil fertility levels high, growing alfalfa on well drained soils, and retaining snow in the winter if possible.

(3) Delay the first cutting of winter-injured stands until full bloom. If alfalfa plants were frost heaved, cut above the normal height to avoid crown injury.

(4) Reduce the risk of winter injury by allowing time for replenishing root reserves (indicated by early bloom growth stage or later) at least once annually if you are going to take three or four cuts in Michigan.

(5) Reduce the risk of winter injury by taking the fourth cut after the last killing frost (mid-October in southern-lower Michigan).

(6) Cut four times per year after the establishment year for high yields of quality forage with good persistence (late May through June 5 at late bud; July 5 through 10 at early bloom; August 15 through 25 at early bloom; and October 15 through 31 in southern-lower Michigan).

HOW TO ESTIMATE YIELD LOSS DUE TO WINTER KILL

The risk of winter injury and winter kill can be reduced but not eliminated. Following a severe winter, some yield loss is inevitable. An early and reliable estimate of this yield loss may help you plan to meet forage needs. Estimates of yield losses are also important when you are trying to decide whether to maintain, reseed, or plant your alfalfa field to another crop. To estimate yield losses you need to know: (1) typical or long term average yield for that field, (2) stand age, (3) viable plant population.

Information on typical or long term average yield and stand age should be in your farm records. Viable plant population, however, can only be determined by a hands-on inspection and count. Do an initial inspection in early April when spring regrowth normally begins. If the results of this inspection are inconclusive, you need to inspect again in a couple of weeks. Although the inspection procedure may seem tedious, the only difficult part is determining whether plants are viable.

Viable plants are plants that are alive and healthy enough to produce forage throughout the season. To determine viability, split open a few crowns and roots. Viable plants have firm white roots while non-viable plants have decaying yellowish-brown to black roots. Some plants may have enough carbohydrate reserves in the crown to begin spring regrowth, but their roots are dead or will die before the end of the season. These plants are not viable.

Figures 4.3 to 4.6 will help you to distinguish between viable and nonviable plants.

Viable plant populations are expressed as viable plants per square foot. Counting is easier if you make a 1 foot by 1 foot square frame. Throw this frame randomly in the field and count the viable plants within. Repeat this procedure at least 20 times. For areas larger than 20 acres, take a minimum of one count per acre (e.g., at least 30 counts for 30 acres). Calculate the average number of viable plants per square foot over the area for which the estimate is being made. If the winter injured plants are not uniformly distributed throughout the field, subdivide the field for sampling. For example, a field might have a low spot where plants were killed by ice and an upland area where there was little injury. In this case take separate counts and calculate separate averages for the low and upland areas.

Table 4.3 shows the effect of stand age and viable plant population on potential yield. You can use estimates directly from this table if the field that you are evaluating had a full stand last fall. A full stand is the number of plants per square foot that corresponds to the 100% potential yield level for the age of stand in question (e.g., for a stand seeded three years ago, a full stand is one with at least 5 to 6 viable plants per square foot). If the field that you evaluate had a full stand last fall, yield loss this year is estimated by the difference between 100% and the percent of potential yield as read from the



Figure 4.3. No injury. Roots are solid white internally. Tillers are beginning to green and are solidly attached to the root.



Figure 4.4. Moderate injury. Roots are solid and white but brown damaged areas occur in old tissue of the crown down 1 to 2 inches. Growth beginning. With favorable growing conditions and a delayed first cutting, many of these plants will survive.

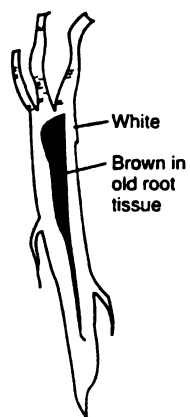


Figure 4.5. Severe injury. Roots white on outside. Brown discoloration carries down in center of the root. The chances are not very good that these plants will survive.



Figure 4.6. Dead plants. Roots are discolored, mushy, and partly rotted. Top growth can be readily pulled from the crown. (Source of Figures 4.3-4.6: Rohweder and Smith, 1978.)

**Table 4.3. How stand age and viable plant population
affect the percent of potential alfalfa yield.**

-----Viable Plants Per Square Foot-----								
Year Seeded	1	2	3	4	5-6	7-9	10-15	>15
-----percent of potential yield-----								
Last year	15	25	30	40	50	65	80	100
2 years ago	30	50	60	70	85	100	100	100
3 years ago	30	65	70	85	100	100	100	100
4 years ago	50	70	85	100	100	100	100	100
>4 years ago	75	90	100	100	100	100	100	100

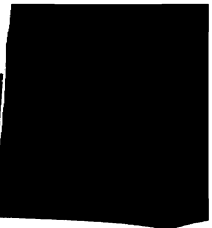


table. If the field that you evaluate had less than a full stand last fall, then yield loss this year is estimated by the difference between percent of potential yield at the viable plant population last fall and the percent of potential yield at the plant population measured this spring.

Example 1. A 15 acre alfalfa field was covered by ice for two weeks last winter. According to farm records the long term average yield is 6 tons/acre. The field was seeded 3 years ago. Last fall the plant population was 7 plants per square foot (more than a full stand). This spring the farmer found a thin stand throughout the 15 acres. The farmer randomly sampled 20-one square foot areas, finding an average of 3 viable plants per square foot.

From Table 4.3, the farmer finds the percent of potential yield with 3 viable plants per square foot on a three year old seeding is 70%. The estimated yield loss is 30% ($100-70\%$) or 1.8 tons/acre ($30\% \times 6$ tons/acre).

Example 2. A 40 acre alfalfa field was seeded two years ago. The long term average yield is 5 tons/acre. There were 5 plants per square foot last fall. This field was winter killed and is now very thin. The farmer randomly sampled 40-one square foot areas and calculated the average viable plant population to be only 3 plants per square foot this spring. What is the farmer's estimated yield loss? It is calculated in three steps:

Step 1: Percent of potential yield last fall was 85%
(5 plants per square foot on a two year old seeding).

Step 2: Percent of potential yield this spring was 60%
(3 plants per square foot on a two year old seeding).

Step 3: Estimated yield loss this year 25% (85-60%) or
1.25 tons/acre (25% x 5 tons/acre).



SUMMARY

In this bulletin we have discussed how alfalfa plants are injured or killed in the winter, management practices to reduce the risk of winter injury, and how to estimate yield loss due to winterkill. We have provided this information to help you reduce the risk of winter injury in your fields and anticipate and plan for yield reductions due to winterkill.

REFERENCES

- Hanson, A.A., D.K. Barnes, and R.R. Hill, Jr. (ed.). 1988. Alfalfa and alfalfa improvement. ASA, CSSA, SSSA, Madison, WI.
- Hart, L.P., and J.L. Clayton. 1986. Alfalfa diseases. MSU Cooperative Extension Service Bulletin E-1976.
- Hesterman, O.B., R.H. Leep, and J.J. Paling. 1991. Alfalfa variety recommendations for Michigan. MSU Cooperative Extension Service Bulletin E-1098.
- Hesterman, O.B., R.H. Leep, and J.J. Paling. 1991 (updated yearly as a supplement to E-1098). Alfalfa varieties for Michigan in 1991. MSU Dept. of Crop & Soil Sciences File 22.331.
- Rohweder, D.A., and D. Smith. 1978. Winter injury to forages. University of Wisconsin Extension Service Bulletin A2905.
- Sheaffer, C.C. 1989. Fall cutting is a management option in the North. Proceedings of the 1989 American Forage and Grassland Conference. p. 23-29. AFGC. Belleville, PA.
- Smith, D., R.J. Bula, and R.P. Walgenbach. 1986. Forage management 5th ed. Kendall/Hunt Publishing Company, Dubuque, IA.
- Warncke, D.D., D.R. Christenson, and M.L. Vitosh. 1985. Fertilizer recommendations: vegetable and field crops in Michigan. MSU Cooperative Extension Service Bulletin E-550.

APPENDIX

Appendix Table A.1. First-cut alfalfa yields in second and third harvest years after seeding. Four-cut system after seeding year. E. Lansing, MI.

cultivar	Minnesota winterhard. index	Estab. year	Dry Matter Yield	
			2 nd year after seed.	3 rd year after seed.
---t/acre---				
Thor	4.5	1969	†	2.56
Saranac	4.5	1969	†	2.46
Apex	4.6	1969	†	2.04
Honeoye	4.6	1973	2.45	2.51
SaranacAR	4.6	1973	2.51	2.42
Saranac	4.5	1973	2.48	2.51
FunkG-777	4.5	1973	2.09	2.49
Saranac	4.5	1978	3.17	2.36
Honeoye	4.6	1978	3.17	2.44
SaranacAR	4.6	1978	3.04	2.07
Trident	4.5	1978	2.99	2.39
Answer	4.6	1978	2.01	2.67
Duke	4.5	1980	3.43	2.94
FunkG-2815	4.4	1980	3.06	2.96
Saranac	4.5	1980	2.95	2.52
SaranacAR	4.6	1980	2.73	2.33
Honeoye	4.6	1981	2.55	3.60
Saranac	4.5	1981	2.68	3.41
Duke	4.5	1981	2.33	3.36
ApolloII	4.5	1981	2.47	3.23
DK135	4.5	1982	3.67	2.19
Endure	4.6	1982	3.61	2.35
Advantage	4.6	1982	3.51	2.31
Drummor	4.4	1982	3.52	2.14
ApolloII	4.5	1982	3.31	2.01
Preserve	4.5	1982	3.64	2.29
Saranac	4.5	1982	3.48	1.95
Trident	4.5	1982	3.37	1.92
Trumpetor	4.4	1982	3.44	2.05
Advantage	4.6	1983	3.21	2.78
ApolloII	4.5	1983	3.30	2.55
Drummor	4.4	1983	3.10	2.56
SaranacAR	4.6	1983	2.98	2.30
Saranac	4.5	1983	2.75	2.38
Trumpetor	4.4	1983	3.02	2.75
DK135	4.4	1984	2.98	‡
Preserve	4.5	1984	2.93	‡
Advantage	4.6	1984	2.79	‡
Drummor	4.4	1984	2.70	‡
Trumpetor	4.4	1984	3.12	‡
ApolloII	4.5	1984	2.54	‡
Endure	4.6	1985	‡	2.34
Drummor	4.4	1985	‡	2.34
FunkG-2815	4.4	1986	2.21	2.42 [‡]

Appendix Table A.1 (cont'd)

Endure	4.6	1986	2.39	2.50 [‡]
Preserve	4.5	1986	2.47	2.39 [‡]
Drummor	4.4	1986	2.23	2.15 [‡]
DK135	4.4	1987	2.87 [‡]	2.25 [‡]
Endure	4.6	1987	2.65 [‡]	2.64 [‡]
FunkG-2815	4.4	1987	2.53 [‡]	2.43 [‡]
FunkG-2841	4.5	1987	2.61 [‡]	2.24 [‡]
DK125	4.5	1987	2.65 [‡]	2.39 [‡]
Target II	4.5	1987	2.84 [‡]	2.68 [‡]
Dynasty	4.5	1987	2.79 [‡]	2.64 [‡]
Bronco	4.4	1988	2.30 [‡]	2.12 [‡]
DK125	4.5	1988	2.36 [‡]	2.16 [‡]
Garst 630	4.5	1988	2.48 [‡]	2.40 [‡]
Chief	4.5	1988	2.33 [‡]	2.06 [‡]
FunkG-2841	4.5	1988	2.33 [‡]	2.06 [‡]
2833	4.6	1988	2.42 [‡]	2.51 [‡]
Quest	4.6	1988	2.34 [‡]	2.30 [‡]
Pioneer 5432	4.6	1988	2.34 [‡]	2.54 [‡]
FunkG-2841	4.5	1989	2.90 [‡]	1.90 [‡]
Garst 630	4.5	1989	2.87 [‡]	2.35 [‡]
Allegiance	4.4	1989	2.82 [‡]	1.95 [‡]
Chief	4.5	1989	2.45 [‡]	1.65 [‡]
Vector	4.4	1989	2.74 [‡]	1.70 [‡]
Multi-plier	4.5	1989	2.90 [‡]	1.93 [‡]
Flint	4.6	1989	2.48 [‡]	1.73 [‡]
Multi-plier	4.5	1990	2.59 [‡]	1.96 [‡]
Chief	4.5	1990	2.48 [‡]	1.79 [‡]
Garst 630	4.5	1990	2.78 [‡]	2.30 [‡]
Flint	4.6	1990	2.49 [‡]	2.04 [‡]
DK 125	4.5	1990	2.41 [‡]	1.78 [‡]
Pioneer 5432	4.6	1990	2.48 [‡]	2.01 [‡]
Allegiance	4.4	1990	2.46 [‡]	1.98 [‡]
G-2833	4.6	1990	2.53 [‡]	1.89 [‡]
G-2841	4.5	1990	2.30 [‡]	1.91 [‡]
Target II	4.5	1991	2.08 [‡]	
Garst 630	4.5	1991	2.05 [‡]	
DK 125	4.5	1991	1.83 [‡]	
Multi-plier	4.5	1991	1.87 [‡]	
DK 133	4.5	1991	1.79 [‡]	
G-2833	4.6	1991	1.73 [‡]	
RamRod	4.5	1991	1.88 [‡]	
G-2841	4.5	1991	1.69 [‡]	

[†] Excluded from model development because fourth cut was not taken in previous fall.

^{*} Excluded from model development because flooding during previous fall precluded fourth cut.

[‡] Excluded from model development but used in model validation.

Appendix Table A.2. Forward selection steps generated by PlotIT (Scientific Programming Enterprises, Haslett, MI) in development of multiple regression equation for first-cut yield in second year after seeding.

Step 1 Variable Entered WDD₅₁

M u l t i p l e R e g r e s s i o n A n a l y s i s

Multiple R	.647	F Change	28.8
R ²	.418	R ² Change	.418
Adjusted R ²	.404	SS Change	3.57
Std. Err. of Est.	.352	% of SS Change	41.8

	Reg. Coeff.	Std. Err. Reg. Coeff.	β Wt.	Std. Err. β Wt.	Student T value	Sig.
WDD ₅₁	-.00987	.00184	-.647	.121	-5.36	.00
B(0)	3.14					

A n a l y s i s O f V a r i a n c e

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	3.57	1	3.57		
Res.	4.96	40	.124	28.7	.000
Total	8.53	42	cases		

A N A L Y S I S O F R E S I D U A L S

Number of positive residuals:	23
Largest positive residual:	.535
Number of negative residuals:	19
Largest negative residual:	-1.01
Number of sign runs:	10
Significance of sign runs test:	.0002
Average absolute residual:	.273
Residual sum of squares:	4.96
Residual mean square:	.124
Residual standard deviation:	.352

Appendix Table A.2 (cont'd)

Durbin-Watson statistic: 1.06
 Auto-correlation coefficient: .450

Step 2 Variable Entered SGDD_{38.5}

M u l t i p l e R e g r e s s i o n A n a l y s i s

Multiple R	.729	F Change	-6.65
R ²	.531	R ² Change	.113
Adjusted R ²	.507	SS Change	.964
Std. Err. of Est.	.320	% of SS Change	11.3

	Reg. Coeff.	Std. Err. Reg. Coeff.	β Wt.	Std. Err. β Wt.	Student T value	Sig.
WDD ₅₁	-.00715	.00189	-.469	.124	-3.78	.00
SGDD _{38.5}	.000930	.000303	.380	.124	3.07	.00
B(0)	2.17					

A n a l y s i s O f V a r i a n c e

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	4.53	2	2.26		
Res.	4.00	39	.103	22.1	.000
Total	8.53	42	cases		

A N A L Y S I S O F R E S I D U A L S

Number of positive residuals:	22
Largest positive residual:	.539
Number of negative residuals:	20
Largest negative residual:	-.940
Number of sign runs:	14
Significance of sign runs test:	.0098
Average absolute residual:	.249
Residual sum of squares:	4.00
Residual mean square:	.103

Appendix Table A.2 (cont'd)

Residual standard deviation: .320
 Durbin-Watson statistic: 1.27
 Auto-correlation coefficient: .360

Step 3 Variable Entered PHGDD₆₉

M u l t i p l e R e g r e s s i o n A n a l y s i s

Multiple R	.844	F Change	9.20
R ²	.712	R ² Change	.181
Adjusted R ²	.689	SS Change	1.54
Std. Err. of Est.	.254	% of SS Change	18.1

	Reg. Coeff.	Std. Err. Reg. Coeff.	β Wt.	Std. Err. β Wt.	Student T value	Sig.
WDD ₅₁	-.00229	.00180	-.150	.118	-1.27	.21
SGDD _{38.5}	.00142	.000261	.580	.107	5.44	.00
PHGDD ₆₉	.00601	.00123	.512	.105	4.88	.00
B(0)	1.34					

A n a l y s i s O f V a r i a n c e

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	6.07	3	2.02		
Res.	2.46	38	.0647	31.3	.000
Total	8.53	42	cases		

A N A L Y S I S O F R E S I D U A L S

Number of positive residuals: 22
 Largest positive residual: .522
 Number of negative residuals: 20
 Largest negative residual: -.638
 Number of sign runs: 20
 Significance of sign runs test: .325
 Average absolute residual: .185

Appendix Table A.2 (cont'd)

Residual sum of squares:	2.46
Residual mean square:	.0647
Residual standard deviation:	.254
Durbin-Watson statistic:	1.83
Auto-correlation coefficient:	.074

Step 4 Variable Entered PHPREC

Multiple Regression Analysis

Multiple R	.872	F Change	-1.81
R ²	.761	R ² Change	.049
Adjusted R ²	.735	SS Change	.421
Std. Err. of Est.	.235	% of SS Change	4.93

	Reg. Coeff.	Std. Err. Reg. Coeff.	β Wt.	Std. Err. β Wt.	Student T value	Sig.
WDD ₅₁	-.00419	.00180	-.274	.118	-2.33	.03
SGDD _{38.5}	.00144	.000241	.590	.099	5.99	.00
PHGDD ₆₉	.00717	.00121	.611	.103	5.92	.00
PHPREC	-2.39	.863	-.294	.106	-2.76	.01
B(0)	1.58					

Analysis of Variance

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	6.49	4	1.62		
Res.	2.04	37	.0551	29.5	.000
Total	8.53	42	cases		

ANALYSIS OF RESIDUALS

Number of positive residuals:	24
Largest positive residual:	.484
Number of negative residuals:	18
Largest negative residual:	-.841

Appendix Table A.2 (cont'd)

Number of sign runs:	20
Significance of sign runs test:	.366
Average absolute residual:	.161
Residual sum of squares:	2.04
Residual mean square:	.0551
Residual standard deviation:	.235
Durbin-Watson statistic:	2.40
Auto-correlation coefficient:	.000

Appendix Table A.3. Forward selection steps generated by PlotIT (Scientific Programming Enterprises, Haslett, MI) in development of multiple regression equation for first-cut yield in third year after seeding.

Step 1 Variable Entered WTC_{31,6}

M u l t i p l e R e g r e s s i o n A n a l y s i s

Multiple R	.620	F Change	21.8
R ²	.384	R ² Change	.384
Adjusted R ²	.367	SS Change	2.26
Std. Err. of Est.	.322	% of SS Change	38.4

	Reg. Coeff.	Std. Err. Reg. Coeff.	β Wt.	Std. Err. β Wt.	Student T value	Sig.
WTC _{31,6}	-.0897	.0192	-.620	.133	-4.67	.00
B(0)	3.71					

A n a l y s i s O f V a r i a n c e

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	2.26	1	2.26		
Res.	3.62	35	.103	21.8	.000
Total	5.88	37	cases		

A N A L Y S I S O F R E S I D U A L S

Number of positive residuals:	13
Largest positive residual:	.652
Number of negative residuals:	24
Largest negative residual:	-.445
Number of sign runs:	10
Significance of sign runs test:	.0035
Average absolute residual:	.251
Residual sum of squares:	3.62
Residual mean square:	.103
Residual standard deviation:	.322
Durbin-Watson statistic:	.711

Appendix Table A.3 (cont'd)

Auto-correlation coefficient: .622

Step 2 Variable Entered SGDD_{38.5}

Multiple Regression Analysis

Multiple R	.723	F Change	-3.17
R ²	.523	R ² Change	.139
Adjusted R ²	.495	SS Change	.818
Std. Err. of Est.	.287	% of SS Change	13.9

	Reg. Coeff.	Std. Err. Reg. Coeff.	β Wt.	Std. Err. β Wt.	Student T value	Sig.
WTC _{31.6}	-.0758	.0177	-.524	.122	-4.28	.00
SGDD _{38.5}	.000663	.000211	.385	.122	3.15	.00
B(0)	2.93					

Analysis of Variance

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	3.08	2	1.54		
Res.	2.80	34	.0825	18.66	.000
Total	5.88	37	cases		

ANALYSIS OF RESIDUALS

Number of positive residuals:	19
Largest positive residual:	.584
Number of negative residuals:	18
Largest negative residual:	-.591
Number of sign runs:	14
Significance of sign runs test:	.0481
Average absolute residual:	.218
Residual sum of squares:	2.80
Residual mean square:	.0825
Residual standard deviation:	.287

Appendix Table A.3 (cont'd)

Durbin-Watson statistic: .727
 Auto-correlation coefficient: .626

Step 3 Variable Entered HDAYS

M u l t i p l e R e g r e s s i o n A n a l y s i s

-----	-----	-----	-----
Multiple R	.833	F Change	6.19
R ²	.693	R ² Change	.170
Adjusted R ²	.665	SS Change	.999
Std. Err. of Est.	.234	% of SS Change	17.0
-----	-----	-----	-----

	Reg.	Std. Err.	β	Std. Err.	Student	
	Coeff.	Reg. Coeff.	Wt.	β Wt.	T value	Sig.
BWTC _{31.6}	-.0863	.0146	-.596	.101	-5.90	.00
SGDD _{38.5}	.00119	.000211	.689	.122	5.63	.00
HDAYS	-.0142	.00333	-.527	.123	-4.27	.00
B(0)	3.17					
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A n a l y s i s O f V a r i a n c e

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	4.08	3	1.36		
Res.	1.80	33	.0547	24.8	.000
Total	5.88	37	cases		
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A N A L Y S I S O F R E S I D U A L S

Number of positive residuals:	21
Largest positive residual:	.364
Number of negative residuals:	16
Largest negative residual:	-.400
Number of sign runs:	16
Significance of sign runs test:	.183
Average absolute residual:	.193
Residual sum of squares:	1.80

Appendix Table A.3 (cont'd)

Residual mean square:	.0547
Residual standard deviation:	.234
Durbin-Watson statistic:	1.30
Auto-correlation coefficient:	.306

Appendix Table A.4. Forward selection steps generated by PlotIT (Scientific Programming Enterprises, Haslett, MI) in development of multiple regression equation for first-cut yield in combined second and third years after seeding.

Step 1 Variable Entered WTC_{31,6}

M u l t i p l e R e g r e s s i o n A n a l y s i s

Multiple R	.639	F Change	53.0
R ²	.408	R ² Change	.408
Adjusted R ²	.400	SS Change	7.25
Std. Err. of Est.	.370	% of SS Change	40.8

	Reg. Coeff.	Std. Err. Reg. Coeff.	β Wt.	Std. Err. β Wt.	Student T value	Sig.
WTC _{31,6}	-.113	.0156	-.639	.0877	-7.28	.00
B(0)	4.15					

A n a l y s i s O f V a r i a n c e

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	7.25	1	7.25		
Res.	10.5	77	.137	53.0	.000
Total	17.8	79 cases			

A N A L Y S I S O F R E S I D U A L S

Number of positive residuals:	36
Largest positive residual:	.849
Number of negative residuals:	43
Largest negative residual:	-.724
Number of sign runs:	17
Significance of sign runs test:	.000
Average absolute residual:	.309
Residual sum of squares:	10.5
Residual mean square:	.137
Residual standard deviation:	.370
Durbin-Watson statistic:	.882



Appendix Table A.4 (cont'd)

Auto-correlation coefficient: .555

Step 2 Variable Entered SGDD_{38.5}

Multiple Regression Analysis

Multiple R	.776	F Change	4.61
R ²	.603	R ² Change	.195
Adjusted R ²	.592	SS Change	3.47
Std. Err. of Est.	.305	% of SS Change	19.5

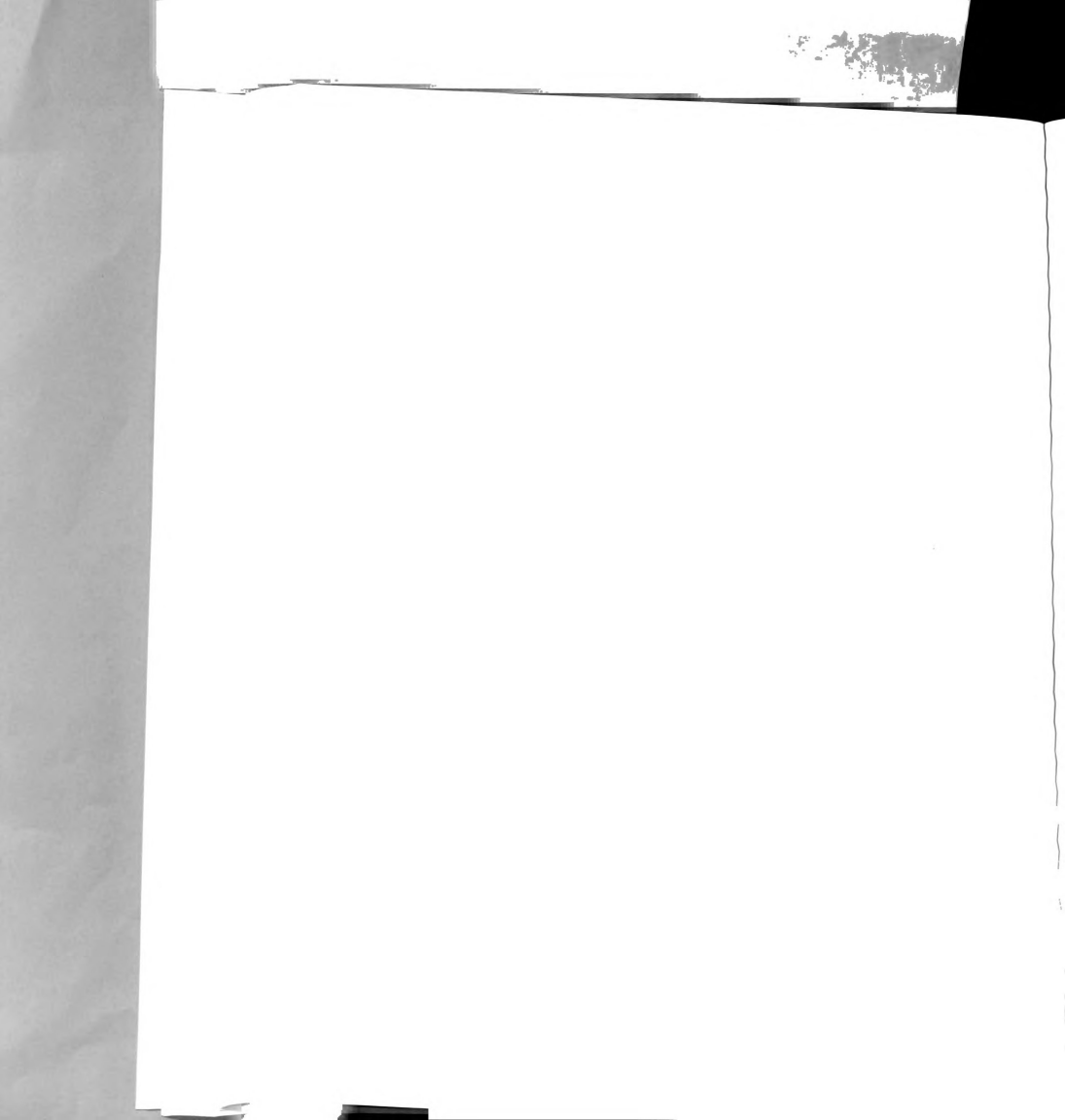
	Reg. Coeff.	Std. Err. Reg. Coeff.	β Wt.	Std. Err. β Wt.	Student T value	Sig.
WTC _{31.6}	-.0968	.0131	-.546	.0739	-7.39	.00
SGDD _{38.5}	.00101	.000166	.4510	.0739	6.10	.00
B(0)	3.00					

Analysis Of Variance

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	10.7	2	5.36		
Res.	7.07	76	.0930	57.6	.000
Total	17.8	79	cases		

ANALYSIS OF RESIDUALS

Number of positive residuals:	42
Largest positive residual:	.476
Number of negative residuals:	37
Largest negative residual:	-.857
Number of sign runs:	29
Significance of sign runs test:	.0068
Average absolute residual:	.236
Residual sum of squares:	7.07
Residual mean square:	.0930
Residual standard deviation:	.305



Appendix Table A.4 (cont'd)

Durbin-Watson statistic: .961
 Auto-correlation coefficient: .519

Step 3 Variable Entered HDAYS

M u l t i p l e R e g r e s s i o n A n a l y s i s

Multiple R	.804	F Change	-11.9
R ²	.647	R ² Change	.044
Adjusted R ²	.632	SS Change	.782
Std. Err. of Est.	.289	% of SS Change	4.40

	Reg. Coeff.	Std. Err. Reg. Coeff.	β Wt.	Std. Err. β Wt.	Student T value	Sig.
WTC _{31,6}	-.0100	.0125	-.564	.0704	-8.01	.00
SGDD _{38,5}	.00122	.000172	.545	.0765	7.12	.00
HDAYS	-.00703	.00230	-.232	.0759	-3.06	.00
B(0)	3.10					

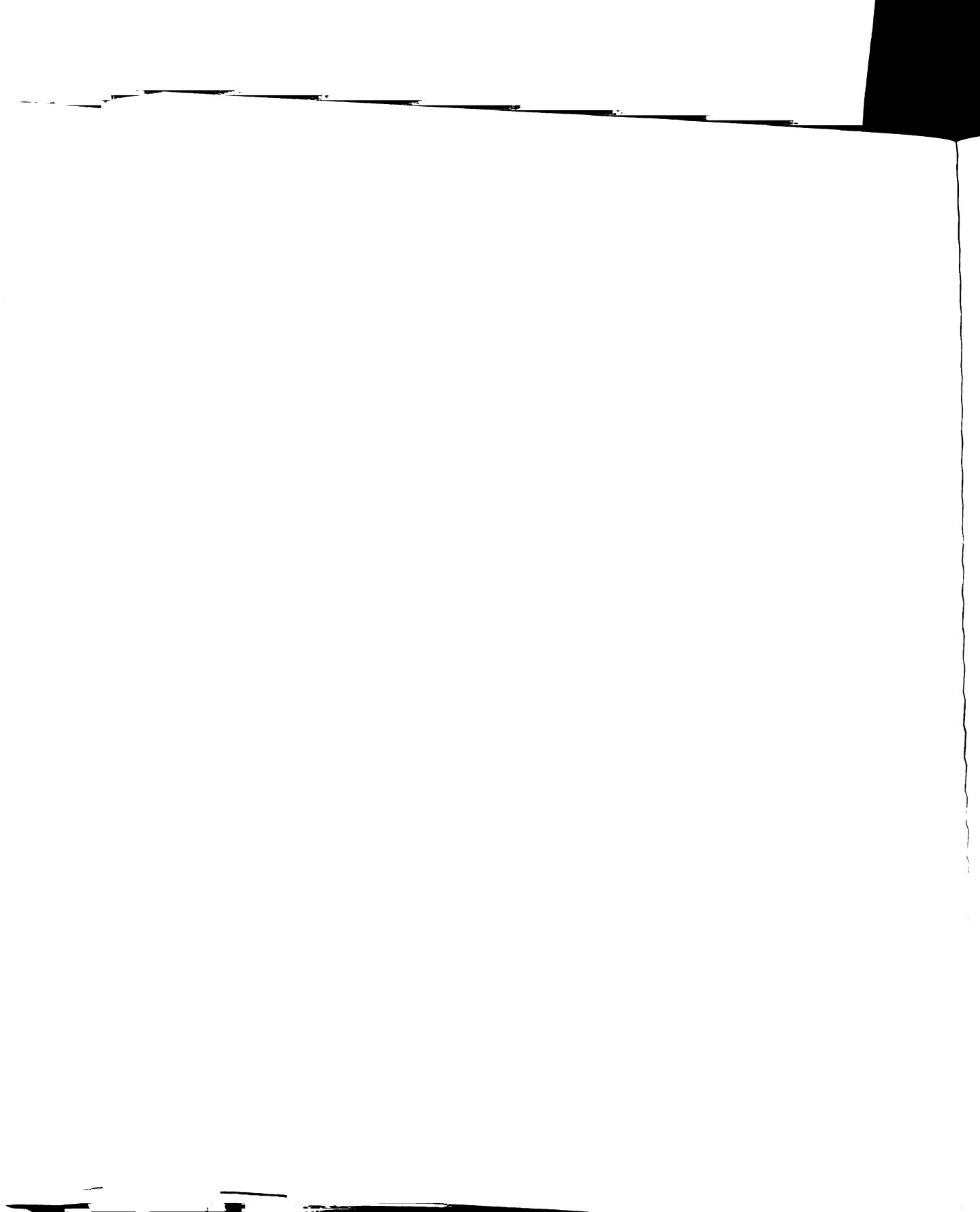
A n a l y s i s O f V a r i a n c e

	SS	Deg. of Freedom	Error Mean Sq.	F-test	Sig.
Reg.	11.5	3	3.83		
Res.	6.29	75	.083	45.7	.000
Total	17.8	79	cases		

A N A L Y S I S O F R E S I D U A L S

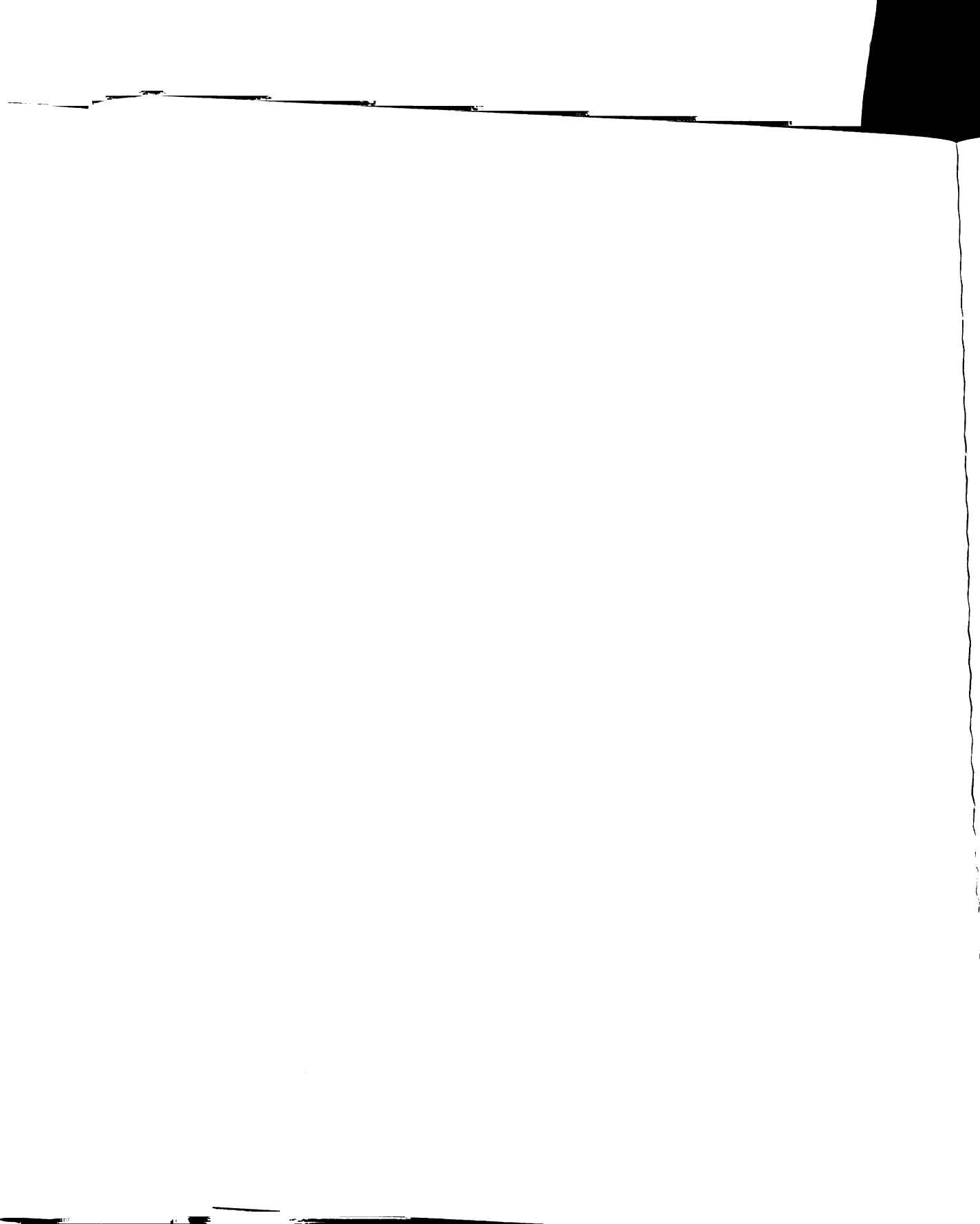
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Number of positive residuals:	44
Largest positive residual:	.541
Number of negative residuals:	35
Largest negative residual:	-.816
Number of sign runs:	25
Significance of sign runs test:	.0004
Average absolute residual:	.229
Residual sum of squares:	6.29



Appendix Table A.4 (cont'd)

Residual mean square:	.0838
Residual standard deviation:	.289
Durbin-Watson statistic:	1.12
Auto-correlation coefficient:	.436



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