Prediction of Alfalfa Forage Yield Loss due to Freezing Injury: II. Model Validation and Example Simulations

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Introduction

A new alfalfa model called ALFACOLD was developed by expanding upon an existing model (ALSIM 1, Level 2) to predict forage yield on a daily basis while accounting for the cumulative effects of freezing injury over multiple years of the same crop. Model description and analysis are presented in a companion paper. Accurate assessment of freezing injury at the start of a growing season can help in managing a shortfall in forage production in the subsequent growing season.

The objective of this study was to test ALFACOLD model's ability to predict field measured forage DM yield and to determine the model's prediction accuracy. Example simulations were presented to show potential applications of the model.

Methods

Model Validation. Validation data consisted of 874 yield observations collected during 1990-93 from variety trials seeded in 1989 and 1990 at Arlington and Lancaster sites in WI. These years were selected because crop reports indicated substantial variation in winter injury during this period. Minimal winter injury occurred following the winter of 1990-91 while moderate to severe injury occurred during 1991-92 and 1992-93. All crops were managed under a 4-cut system, and cutting dates fell around May 26, June 27, July 29 and August 27. Only commercial varieties with at least moderate resistance to different diseases were included. Thirty-nine cultivars with fall growth scores (FGS) ranging between 2.3 and 3.8 were represented. Most cultivars grown in the region fall in the range of 2 to 4 FGS.

Example Simulations

Cold tolerance and freezing injury. Selected simulations were presented to discuss model predictions of cold tolerance and freezing injury in alfalfa. The model was set up to simulate growth and freezing injury during two contrasting years (1990-91 and 1991-92) with respect to snow cover and freezing injury observed in Arlington, WI. Two sets of simulations were run. The first set was started on 1 March 1990 and ended on 31 October 1991, and the second set was started on 1 March 1991 and ended on 31 October 1992. In each set, growth of five alfalfa cultivars with a FGS of 1.5, 2.5, 3.5, 4.5, and 5.5 was simulated. All crops were managed under a 4-cut system in both years.

Risk of yield loss due to freezing injury. The ALFACOLD model has the potential to quantify risk of yield loss due to freezing injury for a specified region. To demonstrate this application, the model was set up to simulate growth during production years 1, 2 and 3 (i.e., crop years 2, 3 and 4) of a 4-year crop, with a new crop seeded each year during 1970 to 1987 in Arlington, WI, for a total of 18 different crops. Simulation was started for each crop on 1 March in the first production year and ended on 31 October in the third production year. Two sets of 18 crops were simulated. In the first set, freezing injury simulation was disabled, so the predicted yield reflected potential yield under conditions of negligible freezing injury. In the second set, freezing injury was simulated.

Results and Discussion

Model Validation. ALFACOLD and ALSIM models were tested against measured yield from 39 cultivars seeded in two years and managed under a 4-cut system for three years after the seeding year at two sites in Wisconsin (Figs. 1, 2). The ALFACOLD model adequately predicted measured yields over multiple production years of a crop. Averaged over the sites, cultivars and years, ALFACOLD model predicted annual forage yield within 12% of the measured yield, compared to an error of 35% with the ALSIM model (Fig. 1). A regression of field measured yield of individual harvests (n=874) on the corresponding ALFACOLD predicted yield indicated that 70% of the measured variability in yield was explained by the model

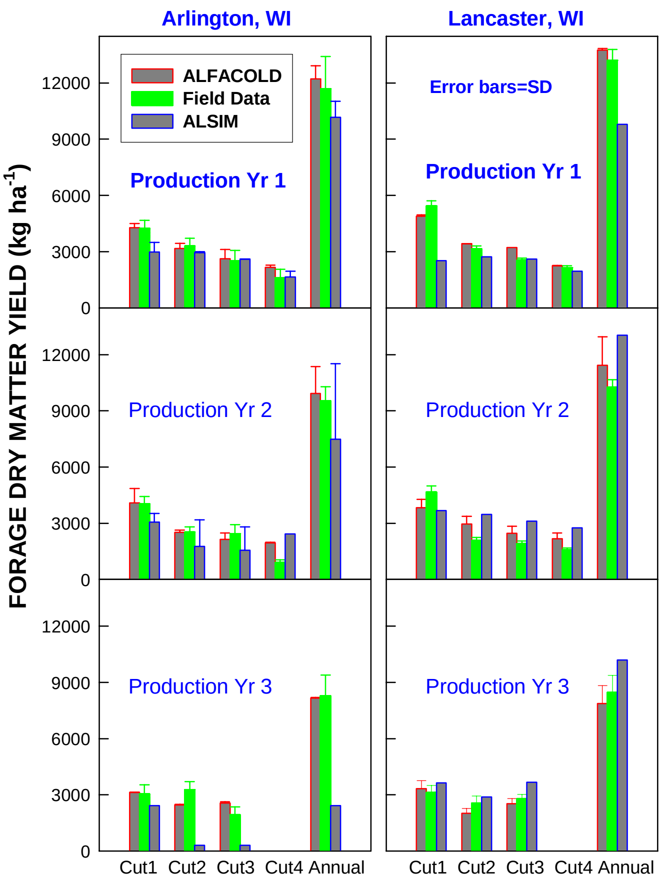

Figure 1. The ALFACOLD and ALSIM 1 (Level 2) model predictions of forage DM yield averaged over 39 cultivars harvested in a four-cut system during three consecutive years after the seeding year compared to the corresponding field measured yield. (Data: 2 sites, 39 varieties, 6 crop years: n=874)

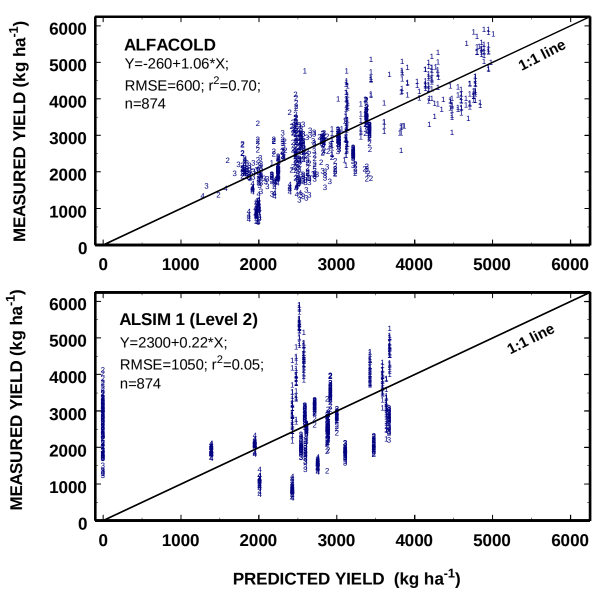

Figure 2. The ALFACOLD and ALSIM 1 (Level 2) model predictions of forage DM yield for 39 cultivars harvested in a four-cut system at two sites during three consecutive years after the seeding year compared to the corresponding field measured yield. (Numbers 1 to 4 represent harvest numbers in a year: 1 for first, 2 for second, 3 for third, and 4 for fourth harvest. Data: 2 sites, 39 varieties, 6 crop years: n=874)

(r^2, Fig. 2). The average difference between measured and predicted yield for harvests 1, 2 and 3 was less than 7%, but ALFACOLD over-predicted fourth cut yield by 38% (Fig. 1). Averaged over the sites, cultivars, years and cuts, ALFACOLD predicted yield with an average standard deviation of 600 kg ha^{-1} cut^{-1} (RMSE, Fig. 2).

Cold tolerance and freezing injury. Cold tolerance was quantified by sub-zero °C temperature that a crop could withstand without being killed. Cold hardening initiated in mid-September (Fig. 3). Cold tolerance increased at a faster rate in hardy cultivars (FGS 1.5) than in cold sensitive cultivars (FGS 5.5), which resulted in greater tolerance of hardy cultivars compared to non-hardy cultivars at any specified time during winter. Plants began to deharden in March and completely lost tolerance to freezing temperature by mid to late April. Non-hardy cultivars completely dehardened about 8-15 days earlier than did the hardy cultivars. Crown temperature represented the predicted soil temperature in the crown region (3 cm), and included the “insulation” effect of snow. Crown temperatures fell below the tolerance temperature of the cold sensitive cultivar resulting in its death (discontinued line, Fig. 3). Even though crown temperatures were much colder in 1990-91 than in 1991-92, the cultivar died early in 1991-92 due to a “cold snap” (rapid fall in temperature for a short duration) in autumn before the crop had a chance to develop adequate tolerance. For the same reason, more plants of medium hardy and cold hardy cultivars were killed in 1991-92 than in 1990-91. Model simulations of hardening, de-hardening, and freezing injury fit reasonably well with qualitative observations reported in the literature.

Yield loss due to freezing injury. Forage yield lost during production year 2 (PY2) and production year 3 (PY3) due to freezing injury in the preceding years was simulated for a 4-year crop of 3.0 FGS, with a new crop seeded each year over a period of 18 years (1970-87). In 3 out of 18 years, predicted yield loss due to freezing injury was 30% or greater during PY2 and 40% or greater during PY3 (Fig. 4). A third of the crops seeded during this period sustained a simulated yield loss of 5% or greater during PY2 and 10% or greater during PY3. The predicted average potential

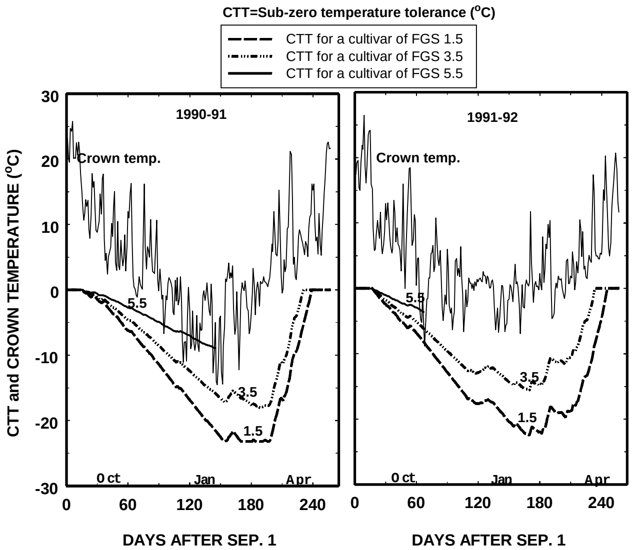

Figure 3. Simulated cold tolerance in cultivars of contrasting fall growth score (FGS) compared to predicted average daily soil temperature in the crown region (3 cm depth) during two winter seasons in Arlington, WI. (Discontinued line for FGS 5.5 indicates total winterkill due to freezing injury.)

annual yield was 11180 kg ha^{-1} (SD 1930 kg ha^{-1}) in 4 harvests, assuming zero freezing injury.

Conclusion

(1) ALFACOLD adequately predicted forage yield measured in the field over multiple production years of the same crop. (2) ALFACOLD predicted yield more accurately than did the ALSIM 1 (Level 2). (3) Breeding alfalfa cultivars for rapid rate of hardening will minimize the lethal effects of "cold snaps" (rapid fall in temperature for short periods) in autumn and winter.

Model Applications

Potential applications of ALFACOLD include: (1) forecasting yield loss due to freezing injury at the start of a growing season; (2) quantifying risk of freezing injury for a specified combination of cultivar and climatic conditions in a region; (3) estimating probability of freezing injury in autumn, winter or spring for a specified cultivar in a region; and (4) serving as a component module in decision support systems.

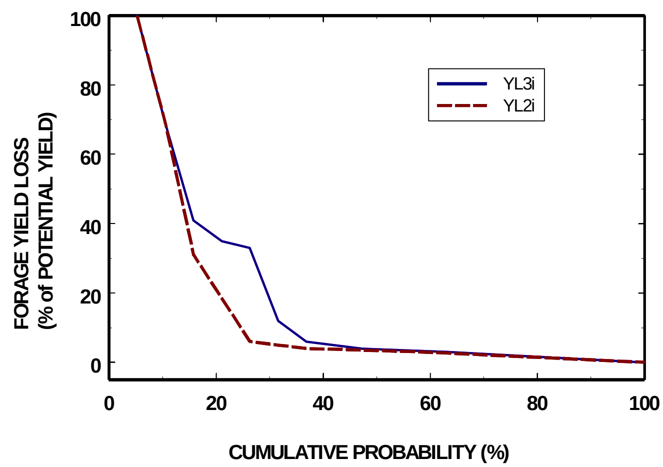

Figure 4. Cumulative probability distribution of simulated forage DM yield lost during production year 2 (YL_{2i}) and production year 3 (YL_{3i}) due to freezing injury in the preceding years in a 4-year alfalfa crop of 3.0 FGS, with a new crop seeded each year for 18 years in Arlington, WI. (Yield loss was expressed as percent of potential annual DM yield predicted with minimal freezing injury).