SIMULATING THE EFFECT OF CONDITIONING ON THE DRYING OF CUT GRASS

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Abstract

Field wilting and drying of hay is an important agricultural process upon which the quality of material subsequently conserved is dependent. The research described here aims at translating the biophysical processes that affect field drying of grass into parameters sets to be used for decision support systems that would aid effective management of field wilting for silage making. A mechanistic model of field drying of grass was implemented, largely based on Thompson's (1981) multi-layer canopy representation. Given the meteorological conditions at a 10 minutes interval, an iterative algorithm calculates the profile of evaporation within a drying swath. The time course of moisture content is calculated by integration. The model is shown to reproduce in detail changes of swath moisture content, including dew interception at night time.
Three input parameters (i.e. swath resistance per unit tissue moisture content, minimum initial resistance and water content at stomatal closure) were adapted in order to simulate different conditioning treatments. Model predictions and measurements on reference plots were compared with experimental drying rates of perennial rye-grass *(Lolium perenne)*, either lightly or heavily conditioned. The results make clear that coupling grass handling procedures to parameters of a mechanistic model of the drying process can provide tools for use in optimising such procedures.

1. Introduction

Grass and grass products are very important for feeding ruminants. Conservation is necessary both for that part of the year that forage production is below the amount required to feed livestock and to level off the peak rate of production during the growing season. Silage and hay making are the most common ways of conservation. Beside quantity, forage quality is getting increasing attention, as a primary factor in determining quality of product (either milk of meat). This means that techniques to improve field drying for the production of both hay and (wilted) silage are being investigated (Bosma, 1991). Grass drying implies removal of water that is variously bound to the material. Reduction of moisture content to 50% of its value at mowing is often taken as the standard by which drying systems are evaluated. As field drying is the cheapest way to remove water, a lot of new techniques and systems are aimed at enhancing it.

Field drying is a complex biophysical process involving water retaining properties of the grass, energy absorption and utilization, and removal of vapour from the swath (Bosma and

Gabriëls, 1992). A mechanistic description of the drying process, giving insight into the interactions among weather conditions, grass yield and the effect of treatments, may satisfy the need for prediction of the field drying duration under given climatic conditions and different grass handling procedures (Thompson et al., 1985). The research described here is aimed at translating the biophysical processes that affect the removal of moisture from grass crops into parameter sets that would aid effective management of field wilting for silage making. Such parameters could be useful also for designers and manufacturers of agricultural machinery for forage harvesting (Bosma and Knight, 1992).

2. Short description of the model

The model described here is a modification of Thompson's (1981) multi-layer model that represents a cut and drying swath like a multi-layered canopy, distributed uniformly in both the horizontal and vertical directions. The thickness of each layer depends obviously on their number and swath height. Given the meteorological conditions at a time interval (10 minutes, in the present work), the evaporation and temperature profiles within the swath are calculated by means of an iterative algorithm, starting from the energy balance of each layer. The time course of moisture content is calculated by integration.

2.1 General

The energy balance of each layer *(i)* can be written as:

$$R_n(i) = H(i) + \lambda E(i) + C(i) + R_l(i) \qquad \text{W m}^{-2} \quad (1)$$

where the net radiation available to the *i*th layer, R_n, is balanced by the fluxes of sensible heat, H and C (respectively for convection and conduction); latent heat, λE, to and from the layer; and net exchange of thermal radiation, R_l, between adjoining layers. Net radiation within the canopy is assumed to decrease exponentially with increasing leaf area index, *LAI*, in accordance with an empirical extinction coefficient that is a function of sun elevation. Thermal radiation exchange between adjoining layers depends on their temperature, the interception being calculated by presuming that cut leaves lay in a mainly horizontal fashion. As all the fluxes on the right hand side are dependent on layer temperature, which, in turn, depends on the temperature of all the other layers, Eq(1) has to be solved simultaneously for all layers. Hence a matrix inversion routine was embedded into an iterative algorithm, that ended when the temperature of all layers was suffciently steady.

The flux densities of sensible and latent heat are calculated through a sub-model that requires the specification of resistances to transfer of heat and water vapour. Within the swath, heat and vapour movement occur across both turbulent and laminar boundary layers; in addition, the pathway of water vapour includes the diffusion from within the plant tissue to its surface. The turbulent diffusion coefficient K at the top of the swath is calculated in order to derive the resistance to turbulent transfer between adjacent layers and between the soil surface and the bottom layer. K is calculated using flux-profile relations for non-neutral conditions (Dyer et al., 1970; Webb, 1970). In addition, vapour released into the bottom of the swath by the stubble and by the soil surface (that can either be wet or dry) is accounted for.

Water vapour release from plant tissue during drying is assumed to follow different patterns. In the earlier stages of the drying process stomata are open and constitute the easiest pathway for vapour loss, so that leaf tissue resistance r_l *(i)* is equal to stomatal resistance. The

latter is assumed to vary with shortwave irradiation, R_g,—attenuated upon passage through the canopy in the same fashion as net radiation. Accordingly:

$$r_l(i) = \frac{r_{min}}{2\,LAI(i)}\left(1 + \frac{40}{1+R_g(i)}\right) \qquad \text{s m}^{-1} \quad (2)$$

where r_{min} is the minimum possible stomatal resistance in full sunshine (e.g. Jarvis, 1976; Stanghellini, 1987) and $2LAI$ is a conversion factor from unit leaf surface area to unit ground area.

Stomatal closure is assumed to happen when tissue moisture content falls below a threshold value, T, expressed as a fraction of initial water content. After stomatal closure, the resistance to vapour loss rises to a much higher value, and leaf resistance, r_l, is allowed to be inversely proportional to residual tissue water content:

$$r_l(i) = \frac{1}{W(i)}\frac{r_{sw}}{2\,LAI(i)} \qquad \text{s m}^{-1} \quad (3)$$

where r_{sw} is the resistance of unit leaf surface area, per fractional water content of swath and W is the fractional water content of tissue (dry-weight basis).

When conditions are such that either condensation or evaporation of dew (or rain water) would take place rather than tissue drying, then leaf tissue resistance is set to zero. It was found, however, that in this case the algorithm may not converge, as estimated conditions during iterations could switch from one case to the other. This problem was solved by defining a new leaf resistance r'_l smoothed by means of a S-function:

$$r'_l(i) = \frac{r_l(i)}{1+e^{k(F_i-E_i)}} \qquad \text{s m}^{-1} \quad (4)$$

where F_i is the dew or rain water present in layer i at the beginning of the time interval, E_i is the current estimate of either evaporation ($E_i > 0$) or condensation ($E_i \leq 0$) from the layer, cumulated for the time interval. Whenever $F_i - E_i\_0$ (either condensation or non sufficient evaporation for drying), then r'_l is zero, whereas for $F_i - E_i\_0$ r'_l is equal to r'_l, calculated either by means of Eq(2) or (3), whichever is appropriate. The steepness of the transition is determined by k, an arbitrary coefficient, that was fixed after some trials and errors.

Model predictions were successfully compared with experimental drying rates of perennial rye-grass *(Lolium perenne)*. As an example, Fig. 1 shows measured and simulated drying progression during 3 sunny days in October. It may be concluded that the model reproduces in detail changes of swath moisture content, including dew interception at night.

Figure 1. Measured and simulated swath drying dynamics, on 8, 9 and 10 October 1993. Points are means of five measurements, with standard deviation bars.
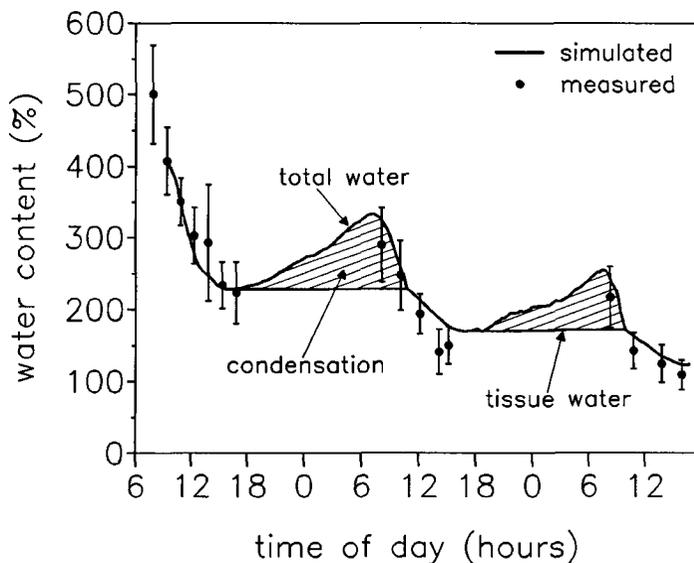
2.2 Simulation of maceration

A model fit for decision supporting about field operations has to account for the environmental effect on the drying rate, in such a way that the impact of variables that can be modified by such operations (like swath thickness and degree of maceration) can be split from the effect of weather. Since the simulation of drying after various mechanical conditioning treatments was required, the drying rates of unconditioned grass; lightly; and intensively conditioned were described modifying the patterns of tissue resistances to moisture loss. Both minimum resistance value (r_{min}) and swath resistance after stomatal closure (r_{sw}) were assumed to be modified by conditioning, since cuts and abrasions on treated leaves imply easier pathways for moisture loss. In our simulation, it is suggested that light conditioning (crimping) and heavy treatment (macerating) reduce both r_s and r_{sw} by 50% and 75%, respectively. The threshold value, T, of tissue moisture content at which stomata close is reported to vary, for different species, between 0.80 and 0.70 of water content at cutting (Harris et al., 1980). Due to the lack of a precise general relationship between water concentration and stomatal closure, given the relevance of this threshold value in the model performance, T was determined by scanning electron microscope observations. The fraction of initial water content was adapted to 0.90 for heavy conditioning and to 0.80 for light conditioned and untreated grass. As an example of the model performance, experimental drying rates of perennial rye-grass exposed to two degrees of maceration ("light" and "heavy") and untreated, are compared with model predictions in Fig. 2, for one day of field exposure.
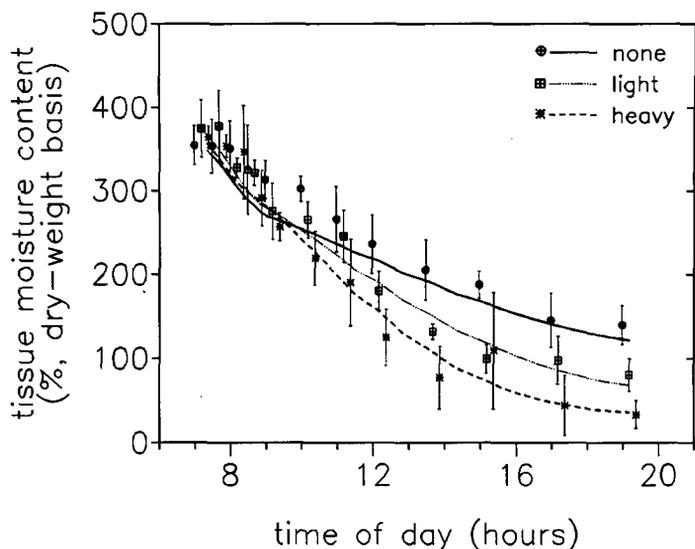
Figure 2. Swath water content on the 24th of June 1994, for three different treatments. Points are means of five measurements with standard deviation bars. Lines are simulation results, as indicated.

3. Discussion

As the results of simulation agree fairly well with field trial measurements, the model can be used to predict the effect of either yield or treatments on field drying, under various weather conditions. The effect of conditioning was simulated, for instance, with data of both a typical summer day (Fig. 3) and of the less favourable case of a cloudy day in May (Fig. 4). The simulation results show that conditioning has the largest impact under good drying weather, when evaporation is limited by leaf resistance. On the other hand, when the weather is limiting evaporation, intensive conditioning has a quite small effect on final water content. Experimentally it was proven (Fig. 5) that short exposures in unfit weather can be best achieved by a thin layer (lower yield and/or wider spreading).

A true optimization of grassland management, however, requires the costs of the various options to be quantified. Conditioning is expensive not only with respect to labour and machinery, but also in terms of lost material and poorer quality. On the other hand, a thin layer means a wider spreading, and thus lost production from the area covered. Short of sufficient knowledge about costs and benefits, the present model still can give useful information about the relative outcome of various options.

Figure 3. Trend of the ratio of simulated conditioned to non- conditioned swath water content, on the 12th of July, 1994. Average sun radiation for the period represented here was 580 W m⁻². Also given are the initial and final tissue moisture contents, non-conditioned, on a % dry-weight basis.
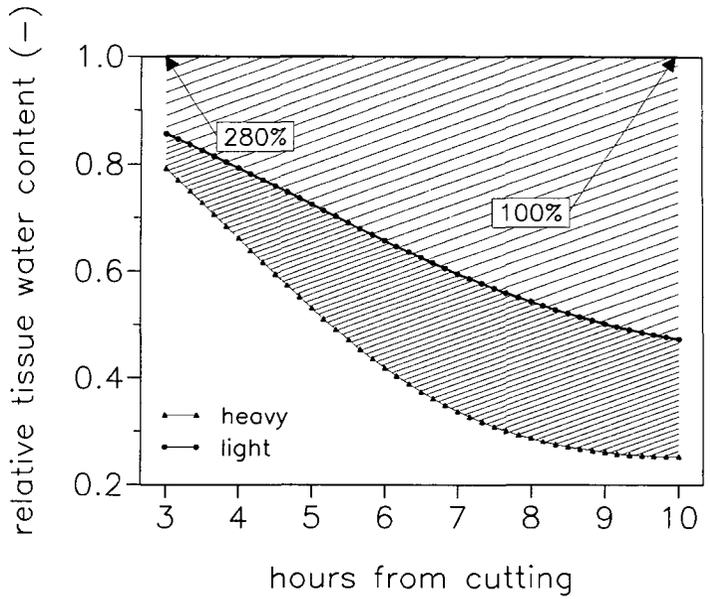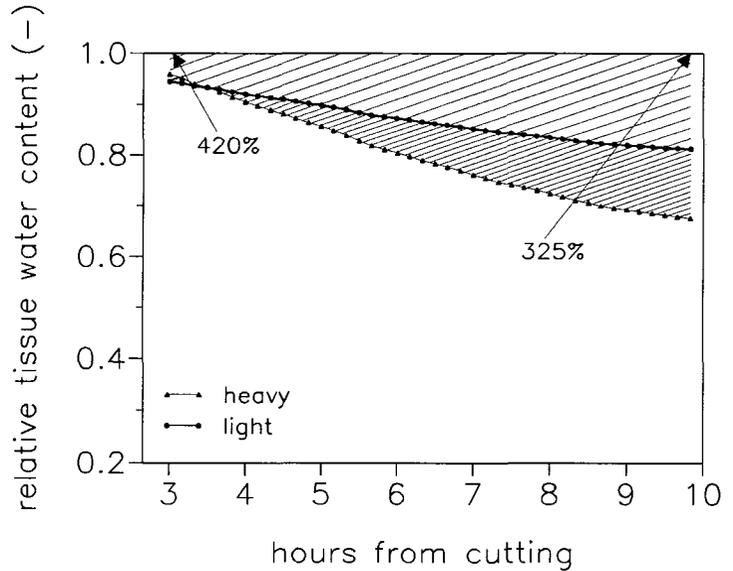

Figure 4. Trend of the ratio of simulated conditioned to non- conditioned swath water content, on the 19th of May, 1994. Average sun radiation for the period represented here was 350 W m⁻². Also given are the initial and final tissue moisture contents, non-conditioned, on a % dry-weight basis.

4. Conclusion

Coupling grass handling procedures to parameters of a mechanistic model of the drying process provides tools for optimising such procedures. The model described here is able to give good predictions of the effect of both the weather and surface treatments on the

water content of wilted grass after exposure. Hence such a model can be used as a decision supporting tool for grassland management. It can help the farmer in selecting an harvesting schedule and/or treatment basedon weather forecasts. In addition, such a model, by quantifying the effect of various degrees of maceration, can be applied as well in the design of harvesting machinery.
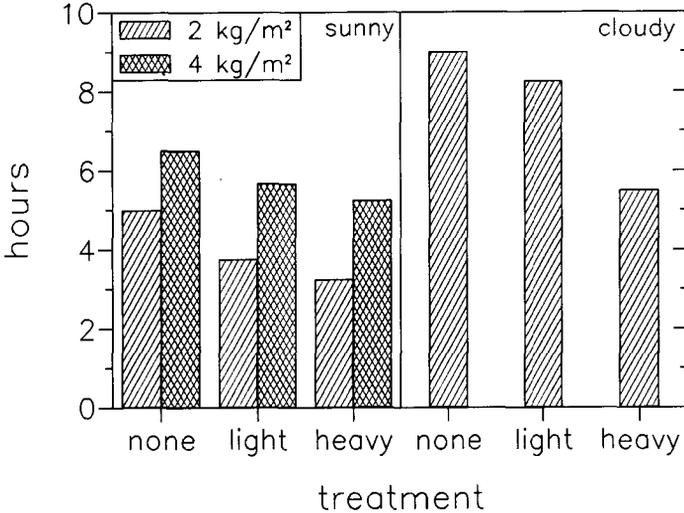

Figure 5. Time required for a moisture reduction to 50% of its initial value. Values are deduced by interpolation from field measurements. The 50% reduction could not be achieved by the 4 kg m^{-2} yield during the cloudy day.

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