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# An empirical model to predict infield thin layer drying rate of cut switchgrass

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ABSTRACT

A series of 62 thin layer drying experiments were conducted to evaluate the effect of solar radiation, vapor pressure deficit and wind speed on drying rate of switchgrass. An environmental chamber was fabricated that can simulate field drying conditions. An empirical drying model based on maturity stage of switchgrass was also developed during the study. It was observed that solar radiation was the most significant factor in improving the drying rate of switchgrass at seed shattering and seed shattered maturity stage. Therefore, drying switchgrass in wide swath to intercept the maximum amount of radiation at these stages of maturity is recommended. Moreover, it was observed that under low radiation intensity conditions, wind speed helps to improve the drying rate of switchgrass. Field operations such as raking or turning of the windrows are recommended to improve air circulation within a swath on cloudy days. Additionally, it was found that the effect of individual weather parameters on the drying rate of switchgrass was dependent on maturity stage. Vapor pressure deficit was strongly correlated with the drying rate during seed development stage whereas, vapor pressure deficit was weakly correlated during seed shattering and seed shattered stage. These findings suggest the importance of using separate drying rate models for each maturity stage of switchgrass. The empirical models developed in this study can predict the drying time of switchgrass based on the forecasted weather conditions so that the appropriate decisions can be made.



## 1. Introduction

In order to provide a continuous supply of biomass to biorefineries, harvest time and frequency must be optimized. Depending on the climatic conditions, drying in windrows is required to reduce the moisture content to safe storage level. Moisture content is defined as $wH_2O$ i.e. the mass fraction of water. Moisture content of switchgrass also changes with maturity. At early vegetative growth stage, moisture content of switchgrass is about 70% and declines to 40–50% after flowering and seed set stage. Moisture content can further decline to less than 10% after a killing frost under dry field conditions [1,2]. To reduce dry matter loss during storage, moisture content of less than 18% is desirable [3].

Several factors other than rainfall influence the drying rate of the crop during field drying. Solar radiation, wind speed, air

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temperature, relative humidity, soil moisture, and other environmental factors affect the time required to bring the crop moisture content to a desired storage level. Crop yield, stem diameter, leaf to stem ratio, swath structure and other crop parameters can increase or decrease the moisture migration [4]. Generally field drying time of grasses varies from 2 to 7 days. Drying time is reduced to 3–4 days when the grasses are spread in thin layers and weather conditions are favorable [3,5].

The main objective of field drying studies is to develop mathematical models to predict the time needed to dry a crop by utilizing the weather conditions. In addition, the effect of individual weather parameters on drying rate of cut crops is also of particular interest. A number of models have been developed, that can simulate the environment and conditioning effects on field drying of crops. Both field drying and lab drying studies have been conducted to evaluate the effect of crop architecture, weather conditions, and plant characteristics. A model was developed by Hill et al. [6] to use vapor pressure deficit to predict drying time of alfalfa hay. Savoie & Mailhot [7] evaluated the effect of eight factors: dry bulb temperature, vapor pressure deficit, wind speed, radiation, conditioning, soil moisture, forage density and initial moisture content on drying rate of timothy hay. A mathematical model was also developed by Wright et al. [8] to predict drying rate of cut ryegrass. They evaluated the effect of material density, effect of conditioning and effect of inverting and mixing on the drying rate of ryegrass. However, an empirical model that can calculate the drying rate of switchgrass based on the environmental conditions is still unavailable in literature.

Predicting in-field drying rates is important to maintain the quality and quantity of harvested biomass. The study of parameters for field experiments may require several years of experimentation to cover a wide range of variables. Rotz and Chen [9] collected data from 1977 to 1984, to develop a model that can determine the effect of environmental factors on in-field drying rate of alfalfa. Weather parameters were correlated with each other and moreover, the environmental conditions changed continuously with time. All these variations make it difficult to understand the effect of individual weather parameters when evaluating processes under field conditions. Alternatively, useful data for empirical drying models can be collected in much less time by using drying chambers to cover a wide range of parameters. It is difficult to simulate field conditions in drying chambers, but laboratory conditions offer more control over the variables that affect drying rate. To better understand the effect of environmental variables, thin layer drying of plant material under controlled conditions is helpful [10]. The data obtained from thin layer drying experiments can provide a better understanding of physical processes by which moisture is removed from plant materials [11]. Field drying of crops in windrows can be approximated as the drying of a series of thin layers of the crop, lying on top of each other. The overall drying rate of windrows can be estimated from the drying rate of each successive layer [10].

Studies related to drying rate estimation for switchgrass are limited. Shinners et al. [12] evaluated drying rates of two perennial grasses: switchgrass and reed canary grass. They reported that under similar crop yields, switchgrass dries faster than reed canary grass. Drying rates of both crops were higher than typically experienced with forage crop such as alfalfa. There is lack of literature that can predict the drying rate of switchgrass, based on the environmental conditions. A drying rate prediction model is also highly desirable for several logistics models which require calculation of drying time based on weather conditions [13]. In order to develop a model to estimate the effect of environmental variables on the drying rate of switchgrass, the present study had three specific objectives:

- Design and construction of an environmental chamber that can simulate field conditions for drying switchgrass
- Evaluation of the effect of individual weather parameters on the drying rate of switchgrass
- Development of an empirical model to predict drying rate of switchgrass based on environmental variables

## 2. Material and methods

### 2.1. *Construction of environmental chamber*

The environmental chamber or wind tunnel constructed was a wooden framed structure 2.44 m long, 0.46 m high, and 0.46 m wide. The chamber was divided into three sections: a settling section (0.91 m in length), the test section (1.22 m in length) and the diffuser section (0.31 m in length). The dimensions of the environmental chamber were selected to achieve the desired range of wind speed in the test section. The chamber had a door with a plexiglass inspection window located on the side of the test section for loading and unloading drying trays.

### 2.2. *Control of vapor pressure deficit*

Temperature and humidity were maintained by an air conditioning unit manufactured by PGC unit Model No. 1080 (Parameter Generation & Control Inc., Black Mountain, NC). The air conditioning unit maintained chamber air temperature and relative humidity levels within 0.1 °C and +/−0.5% RH from the set values. The intake and outlet of the air conditioning unit were located in the chamber settling section in front of the honeycomb and screens (Fig. 1).

### 2.3. *Control of wind speed*

A honeycomb is an effective device for removing swirl and lateral mean velocity variation created by the fan. A honeycomb with a cell length of at least six to eight times the cell diameter are preferable for improving the flow characteristics in a low speed wind tunnel [14]. In the present study, a honeycomb made of PVC tubing having a cell diameter of 0.0254 m and a length of 0.15 m was used. Screens are also helpful to control separation of flow and reduce turbulence in wind tunnels. Screens are characterized by porosity ($\beta$), which is a function of wire diameter ($d$) and weave density ($\rho$) [15]. If $w$ is the width of 1 square mesh cell, then the weave density ($\rho = 1/w$) and the porosity is related by Ref. [15]: