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An Electronic Weighing Laboratory System to Determine Drying Rate of Fresh Alfalfa Components

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Abstract. An electronic weighing laboratory system was designed and developed to determine the drying rate of fresh alfalfa components (leaves, stems and whole plant). The system consisted mainly of an electrical oven to dry the alfalfa components at controlled temperature and humidity and a load cell to measure the weight of the evaporated water from the alfalfa components. T type thermocouples were used to monitor temperature inside the oven. The signals from the load cell and the thermocouples were sampled and recorded by means of a datalogger. The performance of the system was evaluated through experiments where fresh alfalfa components from second cut at 10% bloom stage were dried. The temperature and the relative humidity inside the oven were maintained at 60°C and 5%, respectively. The experimental data are presented graphically and they showed that the developed system can be used successfully to determine the moisture content as well as the drying rate of fresh alfalfa components.

Introduction

In Saudi Arabia, alfalfa (*medicago sativa L.*) produces green biomass throughout the year. Although it is a major forage crop, there is still shortage of research data on alfalfa in various aspects. Therefore research on alfalfa is needed to show annual production and losses during harvest, storage and feeding and to suggest the related measures to reduce these losses.

The determination of the physical condition of alfalfa during drying and storage is one of the major points to be considered. Moisture content is an important factor in determining alfalfa quality, because it is continuously changing during drying and storage. Monitoring moisture content is essential to minimize losses and to preserve the quality of alfalfa. Moisture content in alfalfa is traditionally determined by drying in an oven or dryer. Cubes and pellets of alfalfa are produced from dry chopped alfalfa at a moisture content ranging from 8 to 10% [1]. Rotz and Abrams [2] reported that dry matter losses for the full process during the harvest and storage of alfalfa can be very high (in the range 15 to 25%) for hay under good drying conditions and 35 to 100% for hay damaged by rain. Storage losses attributed to respiration and micro-organism activities are 2 to 5%. The authors also determined field curing losses of alfalfa hay as 3% without rain damage and an average of 11% with rain damage, quality losses as 7.2%; and storage losses as 4.5% for dry hay to 10.9% for hay containing 25 to 34% moisture.

Chopped alfalfa must be dried as fast as possible in the field to avoid high losses that occur when it is exposed to adverse weather condition and be distributed as uniformly as possible in the dryer to produce good quality cubes and pellets of alfalfa. Rotz *et al.* [3] reported that substantial progress has been made in rapid field drying through the processes of mechanical and chemical conditioning. Researchers are continuing to develop new processes to further reduce the field curing time. One process that provides rapid drying is shredding or macerating alfalfa [4]. In this method, shredded alfalfa was pressed into a mat and laid back on the hay stubble to dry. This process reduces field curing time as well as the losses associated with field curing. It may also improve the feed value of the forage to the animal. The economic benefit of this process of maceration and mat drying was determined by Rotz *et al.* [3]. Patil *et al.* [5] reviewed research studies on the drying rate of alfalfa with emphasis on field drying. They also conducted experiments to determine the drying rates of chopped stems and leaves of alfalfa to determine the length of chopped stem that gives drying time equal to that of leaves.

The objectives of this study were to design an electronic weighing laboratory system to measure the amount of water evaporated during the drying process of alfalfa components and to determine the drying rate of chopped stems, leaves and whole plants.

Materials and Methods

The drying system

An experimental oven was used to dry and measure continuously the moisture content of the fresh alfalfa components. The oven consisted of a drying chamber provided with a temperature controller that had a wide range [0 - 250°C] temperature control unit. The tray used for carrying the alfalfa sample during drying process was connected to the weighing system as shown in Fig. 1. A copper rod passing through the small opening at the top of the oven was used to connect both the tray and the load cell. An insulator was used to thermally isolate the tray and the copper rod unit from the weighing system.

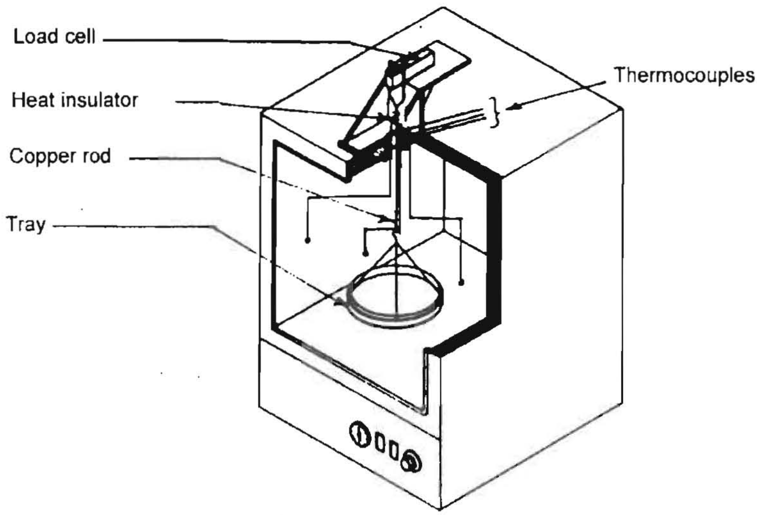

Fig. 1. The experimental oven with the weighing system.

The weighing system and calibration

The weighing system consisted of an RS load cell of 2000 g capacity. This load cell is basically a beam at which an applied load will cause a proportional strain at certain fixed points on the device. An internal bridge circuit of strain gauges can detect this strain. These gauges convert the strain into an electrical signal that can be monitored and measured using a datalogger. The complete electrical circuit of the weighing system is shown in Fig. 2.

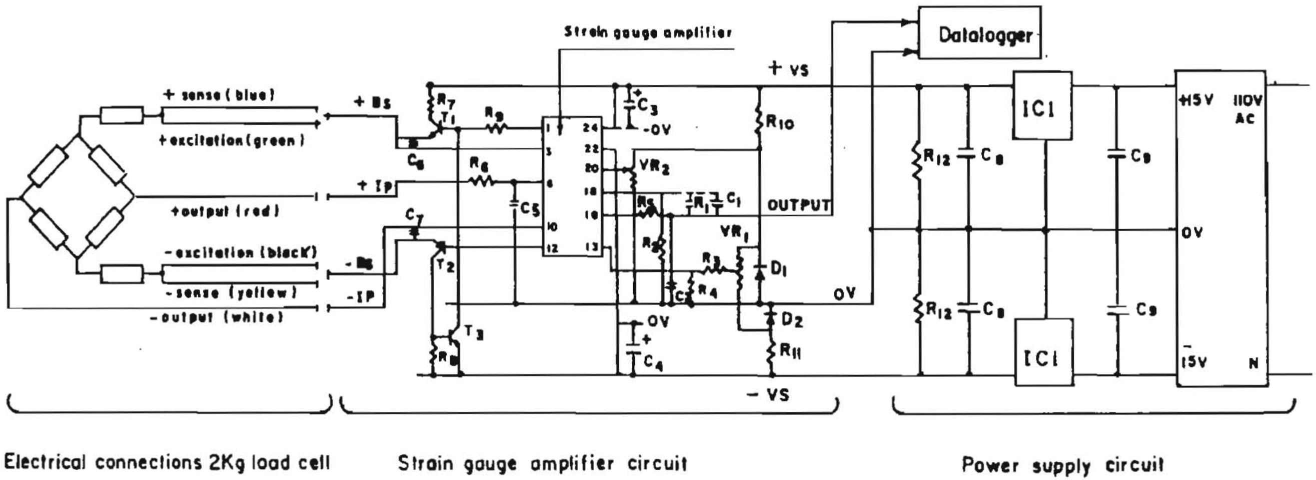

Fig. 2. The complete electrical circuit of the weighing laboratory system.

The load cell with the full wheatstone bridge of four strain gauges was connected to an RS strain gauge amplifier. This amplifier is a hybrid, low noise, low drift, linear dc amplifier specially configured for strain gauge measurement. The load cell produced very small changes in outputs typically less than 1 mV. This low level signal was amplified to suit the 5000 mV maximum range of the datalogger.

A regulated power supply circuit built around two regulator chips, 7812 and 7912 provided constant voltages of +12V and -12V, respectively, to the strain gauge amplifier circuit. This was internally used to provide excitation voltages of +5V and -5V, respectively, to the bridge circuit of the load cell. The chips were automatically current limiting and protected themselves and the rest of the power supply circuit from short circuit damage. Capacitors were also provided in the circuit to stabilize the regulator chips.

The load cell was calibrated using known loads and the calibration data was obtained using the datalogger. The datalogger was programmed to measure the load cell output in millivolts for each applied load in grams leading to the calculation of calibration constant and coefficient of the load cell under test (Appendix I). Load was applied in equal steps from no load to the maximum allowed load and then reduced in approximately the same steps back to no load. This test was repeated several times to obtain reasonable data for regression analysis. The result of the calibration test is shown in Fig. 3. The measured load exhibited excellent agreement with the applied load with a coefficient of regression (R^2), 0.99. The sensitivity of the load cell was calculated as 0.25 $mV.g^{-1}.V^{-1}$ and this value was within the specified range. No significant hysteresis was observed and practically identical calibrations were obtained for both the loading and unloading conditions. The output of the load cell in response to the applied load can be expressed in the straight-line equation form as:

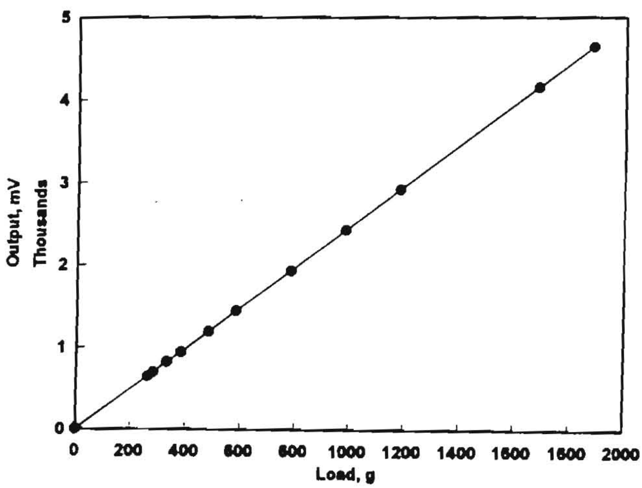

Fig. 3. The calibration curve for the 2 kg load cell.

$$Y(\text{load, g}) = 0.404\ (\text{g/mV}) \,.\, X\ (\text{output, mV}) - 1.325\ (\text{g}) \qquad (1)$$

Thermocouples of type T were placed at equidistant points in the oven chamber to monitor the variation of temperature. These thermocouples were checked for proper operation with a standard thermometer.

The data acquisition system

The data acquisition system consisted of a CR7 datalogger, a personal computer and a cassette tape system. The datalogger had a wide range of instructions for scanning and sampling signals from transducers. The cassette tape system was used for loading programs from computer to the datalogger as well as for data storage during experiments. A performance test program was documented for the datalogger to scan and sample the load cell and the thermocouples every one-second. The load cell output decreased gradually with increased drying time and the difference between two consecutive readings was very small. So the reading at the 3600^{th} second was taken as an hourly reading. At the end of the experiment, the data stored in the cassette tape for several replicates were transferred and stored in the computer for further processing using the Lotus software package.

The experimental procedure

Alfalfa grown at the Agricultural Research and Experimental Farm of King Saud University in Dirab was used for conducting the drying experiment. The crop from the second cut at prebloom and 10% bloom stages was harvested manually using a sickle. The samples for the experiment were packed in polyethylene bags and brought immediately to the laboratory where the experimental setup was arranged. Three types of sample were prepared: stems with leaves removed, leaves only and whole plants (stem with leaves). The experiment was conducted with 3 replications of 30 samples for each alfalfa component. The experimental oven was set at 60°C and 5% relative humidity. The alfalfa samples were placed into the tray by hand and evenly distributed. The output signals from the load cell and the thermocouples were recorded by the datalogger. The load cell output was converted to instantaneous evaporative water weight using the calibration constant and coefficient. Then the instantaneous moisture content values were calculated on dry basis. The initial moisture content of the alfalfa samples was determined by drying the samples in a separate electrical oven at 60°C for 48 h.

To determine the equilibrium moisture content of fresh alfalfa during the experiment, drying was continued until the difference between two consecutive hourly mass readings was less than 10 mg. At that time, sample moisture content was considered to be in equilibrium with the drying air.

The accepted model for drying of forage neglects the moisture gradient within the material. The model leads to the following expression relating moisture content and time [4;6;7]:

$$\frac{M - Me}{Mi - Me} = e^{-kt} \tag{2}$$

where

Mi = initial moisture content, db
M = instantaneous moisture content at time t, db
Me = equilibrium moisture content, db
k = drying constant, min^{-1} which characterizes the rate of moisture removed from alfalfa
t = elapsed time, min

Results and Discussion

The experimental data were analyzed to obtain the drying characteristics of the alfalfa components. Equation (2) was fitted to the sampled data to determine the drying rate (k). A faster drying rate results in a larger value of k. The summary of the results of drying fresh alfalfa components at 10% moisture content (dry basis) is shown in Table.

Table. Summary of the drying experiments

Alfalfa components	Drying time, h	Mi, %db	Me, %db	k, min^{-1}	R^2
Leaves	22	5.03	0.0241	0.0028	0.8455
Stem	26	4.38	0.0333	0.0023	0.8244
Whole plants	27	4.99	0.0494	0.0022	0.8239

The initial moisture content of the leaves and whole plants were very close and slightly greater than the stems. This could be due to the fact that the stems were taken for the experiment after finishing the leaves. The time elapsed might have caused the stems loosing some initial moisture content while staying in the polyethylene bags. The lower initial moisture content of the stems compared to the leaves is not significant in this study because the study was focussed only to determine the drying rate of fresh alfalfa components. The drying rates (k) for whole plants, leaves and stems are 0.0022, 0.0028 and 0.0023 respectively. It is clear that the leaves dried faster than the stems and whole plants. This trend of drying was similar to that presented by Patil *et al.* [5]. The faster drying of leaves can be due to the larger surface area and the presence of a number of stomatal openings associated with the leaves. For the whole plants, once the leaves on the stems were dried, the entry of water from the stems to the leaves was blocked. This retarded drying of whole plants compared to the drying of the other two components. The stems dried faster than the whole plants because the scars left due to the removal of the leaves allowed the free movement of water from the stems to the atmosphere. The experimental drying data are presented graphically in Fig. 4. From the coefficient of determination of the equation (2), it is clear that the experimental data are relatively within the acceptable range.

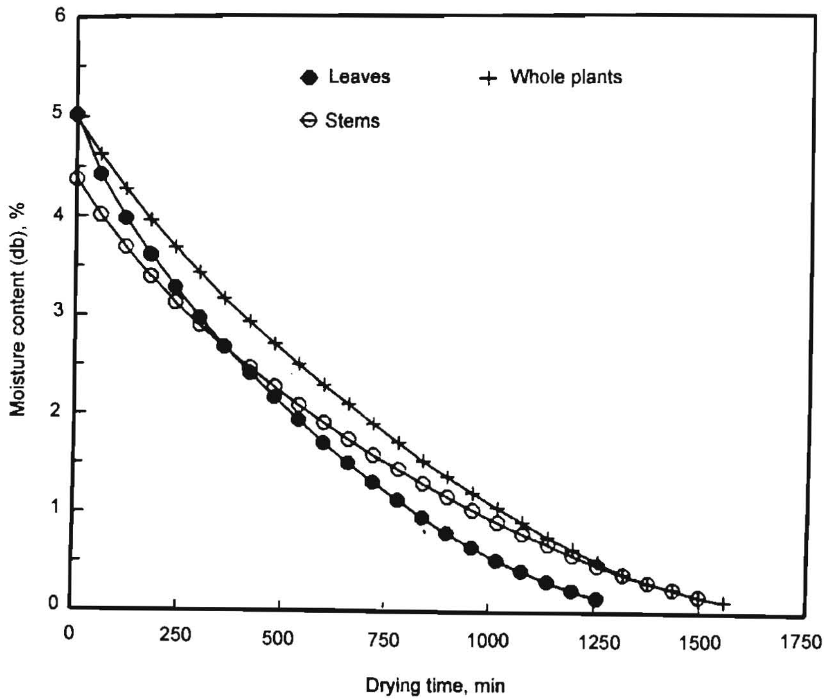

Fig. 4. Typical drying curves for fresh alfalfa components.

Conclusions

1. An electronic weighing laboratory system was designed and developed for conducting drying experiment on fresh alfalfa components (leaves, stems and whole plants) to determine the moisture content and the drying rate.
2. The experimental results showed the developed system could be used as a dryer for conducting experiments on fresh forage.
3. The drying rates,(k) for leaves, stems and whole plants were found to be 0.0028, 0.0023 and 0.0022 respectively.
4. The leaves dried faster than the stems and the whole plants.

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Appendix I

Datalogger program for the calibration of 2 kg load cell

*		1	Table 1 program
	01:	1	Second, Execution Interval
01		P 91	If Flag
	01:	11	1 is set
	02:	30	Then Do
02:		P 1	Volt (Single Ended)
	01:	1	Repetition
	02:	18	5000 mV full scale range
	03:	1	Input Card
	04:	1	Input Channel
	05:	1	Location
	06:	1	Multiplier
	07:	0	Offset
03:		P 86	Do
	01:	10	Set Flag 0 (Output)
04:		P 77	Real time
	01:	11	Hour, Minute, Second
	05:	P 70	sample
	01:	1	Repetition
	02:	1	Location
06:		P 95	End Table 1
*		4	Output Options
	01:	10	Tape ON, Printer OFF
	02:	00	300 baud to printer

منظومة وزنة إلكترونية معمليـــة لتقدير معدل تجفيف مكونات البرسيم الحجازي

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(قدم هذا البحث في ١٤١٨/٧/١٢هـ؛ وقُبل للنشر في ١٤١٩/٢/٧ هـ)

ملخص البحث. تهدف هذه الدراسة أساساً إلى تصميم وتنفيذ منظومة وزنة إلكترونية معملية لتقدير معدل تجفيف مكونات البرسيم الحجازي و تنفيذها . تم عرض الخطوات التصميمية والدائرة الإلكترونية المستخدمة في تلك المنظومة والتي تتكون أساساً من فرن كهربائي ومقياس الانفعال الدقيق (Load cell) لتحويل وزن الماء المتبخر من البرسيم إلى إشارات كهربائية (مللي فولت). تم استقبال هذه الإشارة وتسجيلها على جهاز تسجيل وقراءة البيانات السريعة والدقيقة (Datalogger). وأستخدم ، أيضا ثرموكبل من النوع T لقياس درجات الحرارة داخل الفرن بعد معايرته . أجريت التجارب على مكونات البرسيم الحجازي لمعرفة أداء المنظومة وكذلك لتقدير معدل تجفيف مكونات البرسيم (الأوراق منفصلة ، السيقان منفصلة والنبات الكلي). كررت التجربة ثلاث مرات وقد تم أخذ مكونات البرسيم من الحشة الثانية عند مرحلة تزهير حوالي ١٠ %. تم المحافظة على درجة الحرارة والرطوبة النسبية داخل الفرن عند ٦٠ م° و ٥ % على الترتيب. وتبين من التجارب إمكانية استخدام هذه المنظومة الوزنة الإلكترونية في حساب المحتوى الرطوبي لكل مكون للبرسيم ومن ثم تقدير معدل التجفيف لمكونات البرسيم الحجازي.