Post-drying of energy sorrel in a grate stock

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ABSTRACT: Energy sorrel is a crop with high-yield potential and belongs among the most promissing energy crop for the Czech Republic. The suitable processing technology is harvest by the harvesting cutter with subsequent short-time storage and post-drying of chopped material in the large-capacity hayloft. For chopped sorrel were found-out hydraulic air losses during its passing through the stored layer and they were compared with values for stored forage. Two methods of drying ventilators controlling in the large-capacity heyloft were compared with the regime of time switching within chopped sorrel drying. Electric energy comsumption for ventilators drive in different regimes depends on water content in the material. Method of ventilators or time switching controlling has no effect on drying process result, thus even on water content reduction in the dried material. Under operational conditions the possibility of the chopped energy sorrel in large-capacity heyloft was verified.

Keywords: pressure drops; large-capacity hayloft; chopped energetic straw; energy sorrel

Growing and consequent processing of energy crops is becoming more topical in the Czech Republic. This situation is supported by the commitment by which the Czech Republic has committed to reach 6% share of renewable energy sources in total primary energy consumption by 2010. Energy from biomass has the highest useful potential in the Czech Republic and therefore plays a significant role in the fulfillment of the commitment (Váňa 2003). Energy sorrel (*Rumex tianschanicus* × *Rumex patientia*) variety Rumex OK-2, a perennial plant with a high yield potential, seems to be the most promising energy crop for the Czech Republic after a few years of pilot as well as commercial scale growing. Its cultivation is less labour-consuming and cheaper in comparison with the cultivation of fast-growing energy woods (poplars and willows) (Váňa 2003). For its cultivation it is possible to use all the common machinery for plant establishment, treatment during vegetation as well as for harvesting (Petříková 2003).

There are various ways of harvesting technology. Direct harvest by a field chopper is suitable particularly because of consequent operation eliminations in the field. The water content of energy sorrel at the harvesting time is about 25%. One alternative for reducing of water content in chopped sorrel is possibility of post-drying in large-capacity haylofts in which material is bedded on grates. The haylofts construction is either steel with roof and aluminum or galvanized coating or reinforced prefabricated facilities with wooden roof structure. Their standard technological equipment are floor grates with axial ventilators and a crane rail with a fork grab crane. Considering a significant reducing of the cattle number, the total capacity of large-capacity haylofts is unused for post-drying and storage of hay nowadays. A possible alternative of utilization consists in post-drying and storage of energy phytomass, e.g. energy sorrel. An advantage of such solution is the use of existing technologies, i.e. grates, drying ventilators and manipulating cranes. This technology requires relatively simple adaptation. The grates and the crane grab have to be adapted to small dimensions of the chopped sorrel to avoid their sagging during manipulation and storage on the grates. The ventilator operation is necessary to be optimized to reach an effective drying at minimum power consumption. Similar systems specially constructed for drying of energetic chips were published (Oberhuber, Simander 1999).

The drying processes controlling is in principle similar to drying of forage for which the haylofts are designated. Basically this is a typical plant with decisive controlling process. The function of these systems consists in the activity of ventilators in the time when the relative humidity of air blown into forage is low enough for an effective drying process, what is given by the known physical dependence (Sladký et al. 1985).

The complexity of drying process is given not only by properties of biological active material but also by the variability of ambient conditions. Drying characteristics depend on temperature and relative air humidity, water activity coefficient, initial and equilibrium value of water content of material (Patil et al. 1993). For hay as well as other materials drying, the relative humidity of drying air must be lower than the value corresponding to the equilibrium value of water content of material and air. These dependences, proved by Štencl (1999), are possible to be used not only for drying process

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Table 1. The range of hydraulic drops of drying air passing through forage of water content 35–40% dried in a hayloft in dependence on genus of forage in recalculation for 1 m of vegetation height (SLADKÝ 1986)

Genus and condition of forage	Hydraulic drop of drying air (Pa/m)	Notice
Young grass	60–100	chopped
Older stalky grass	30–60	unchopped
Young alfalfa	40–80	chopped
Older stalky alfalfa	20–50	unchopped

controlling, setting up the moment of automatic switching contactors of ventilators by means of contactor moisture indicators, but also for approximate assessment of remanent water content of forage (SLADKÝ 1986).

The internal logic structure of controlling is primarily based on ambient air relative humidity. The controlling consists in the automatic regulation of ventilators switching. It is the important factor for the quality and efficiency of drying process in haylofts and is necessary for low-energy drying as well (ŠTENCL et al. 1999). An effective way of forage drying controlling is mentioned by ŠTENCL et al. (1999).

For drying of chopped energy sorrel is essential the fact, that a stacked layer of energetic sorrel should have similar hydraulic air drops with those of hay in order to use existing ventilators. The range of hydraulic drops of drying air passing through forage of water content 35–40% in a hayloft is given in Table 1.

The hydraulic drops of drying air passing through a layer of material have been tested not only for hay but for other agricultural products as well (ASAE STANDARDS 1997). NEALE and MESSER (1976) determined hydraulic drops of drying air of stored onions, carrots and potatoes. TABIL et al. (1999) tested hydraulic drops of drying air passing through a layer of sugar beets. The hydraulic drops of drying air were tested in dependence on various sizes of bulbs, impurity and airflow direction. The measuring device consisted of a ventilator, pipes and square-shaped bulb bin, and was constructed in two airflow directions – vertical and horizontal. In most cases the hydraulic drops of horizontal airflow were higher than those of vertical one. KUMAR and MUIR (1986) tested the airflow resistance of cleaned and uncleaned grains of wheat and barley in dependence on airflow direction, filling method and dockage. The experiment was carried out in two devices – using horizontal and vertical airflow. It was found that horizontal airflow resistance is significantly lower than vertical airflow resistance while the same filling method.

The drying process of energy crops has some differences in comparison with the drying process of forage. For forage-drying process is typical the need to be ventilated for a reason of temperature reducing. The drying time is also necessary to be minimized in order not to lose nutrients. Thus, ventilators are in operation not only during disadvantageous weather but also at night when drying does not occur. However, the drying process of energy crops, particularly those harvested with relatively low water content, such as energy sorrel, is different. There is no danger of extremely temperature rising in consequence of running processes. In the short – dated period at the drying process time postponement the material quality loss through the microbiological processes does not occur. Hence, drying can be carried out only at extremely suitable conditions so at the low values of relative air humidity, i.e. during a day in mostly sunny weather.

Time dependences of drying process of forage as well as some other energetic biomaterials have already been tested in an experimental device which is described further. For wood chips drying when the water content was reduced from 50% to 20% four days were needed, whereas the relative air humidity was reaching the value lower than 70% only for one and half day (HUTLA, SLADKÝ 2001).

Objective

The work is focused on finding out drying process parameters of chopped energy sorrel in a large-capacity haylofts including hydraulic air drops of a vertical airflow through a material layer in comparison with the hay drying process in the same hayloft.

MATERIAL AND METHODS

The investigated material is chopped energy sorrel (*Rumex tianschanicus* × *Rumex patientia*), variety Rumex OK-2.

The field chopper, CLAAS Jaguar 820 was used for harvesting. The setting up of nominal chaff length was 8–10 mm; however, the half number of blades was removed. Therefore, this value was increased twice. The harvest was carried out on 17. 7. 2003 in the field which is situated about 500 m above sea level. The vegetation age was two years, thus it was the first harvest of energy biomass. The yield of dry matter was about 6 t/ha. The chopped structure is as follows (in % weight):

size	> 40 mm	6.5%
	25–40 mm	7.8%
	20–25 mm	8.5%
	15–20 mm	12.9%
	10–15 mm	13.5%
	< 10 mm	50.8%

The bulk of material is then smaller than 10 mm in the size. This difference in comparison with the nominal chaff size is likely to be caused by brittleness and fragility of material at cut in consequence of relatively low water content during harvesting. The recognized water content in harvested material was 23.8%. The recognized density of laid loose material was 86.36 kg/m^3.

Fig. 1. The device for measurement of pressure drops in a dried material layer

For the measurement of hydraulic air drops was used the device shown on Fig. 1.

The measured material is placed in a clear cylinder of inner diameter 0.29 m and length 1.5 m. The cylinder is set on a down pressurized part, in which a ventilator forces air through air pipe. The controller revolutions are regulated by the voltage height and allow then achieving overpressure under a grate up to about 400 Pa. The air pressure is measured under the grate and above the dried material. The difference of those pressures is recorded by the meter Digima LPU – Mod. 250 (manufacturer: Special instruments). Velocity of air is measured in a cone-shaped reductive outlet adapter. Here, the cross-sectional area of the main cylinder is reduced into the circular-cross section of diameter 0.039 m. For the measurement is used a propeller anemometer 1416 U 10 of Wilh. Lambrecht GmbH. The measuring propeller diameter is 15 mm.

The continuity equation applies to recalculation of measured values to values of velocity in the main cylinder diameter. A consequent coefficient of a diameter change and as well as of recalculations of velocities in the main cylinder (off material) and outlet aperture is

$$K_r = \frac{S_v}{S_h} = \left(\frac{d_v}{d_h}\right)^2 = 0.018 \qquad (–)$$

where: S_v – aperture area,
S_h – cross-sectional area of the measuring cylinder,
d_v – outlet aperture diameter,
d_h – measuring cylinder diameter.

For the drying process of chopped energy sorrel was used grate weighing device, which is reserved for experimental purposes in the large-capacity hayloft of Agrotel, joint stock company – farm Chrášťany (Hutla, Sladký 2001). The drying grate is divided into three particular sections. Each of them has a layout size of 6 × 6 m. Each of the section is self-supporting and bedded on four power sensors, from which information about weight of a device including storage material is collected.

The actual water content (w_e) in measured material is simply to find out by using the following equation:

$$w_e = \frac{m_v \cdot 100}{m_s + m_v} = (1 - \frac{m_s}{m_c - m_g}) \cdot 100 \qquad (\%;\ \text{kg, kg})$$

where: m_s – dry matter weight in dried material (kg),
m_v – water weight in material (kg),
m_c – drying grate section and dried material weight (kg),
m_R – drying grate section weight (kg).

Each section is ventilated by two axial ventilators VE 630/2. The air discharge of these ventilators is 2 × 2.8 m^3/s at overpressure 110 Pa. The rated input for each ventilator is 1.1 kW. These ventilators charge the outdoor air into the undergrate space. The undergrate space is divided by two partitions to avoid affection of the charged air under each section by the air from adjacent sections. In two sections is installed sensor of relative humidity in undergrate space. The controlling methods, i.e. ventilators switching in particular sections are as follows:

Regime 1

The ventilator is switched on by the time switcher in the interval of 8.30–16.30 o'clock MET, totally 8 hours a day.

Regime 2

The ventilator is switched in the same interval as in regime 1; however, only under condition that relative humidity of outdoor, i.e. input drying air $\varphi_e < 65\%$.

Regime 3

The ventilator is switched in the same intervals as regime 1 and 2; however, only under condition, when

Table 2. Pressure drops of chopped sorrel one-meter high layer; water content is 23.8%

Δp (Pa)	145	136	128	126	120	115	110	105	101	98	91	78	69	66
w_o (m/s)	15.9	15.5	15.5	14.5	14.1	13.8	13.4	13.2	12.8	12.4	12.0	10.5	10.0	9.5
Δp (Pa)	62	57	50	44	38	34	29	26	22	17	14	9	7	5
w_o (m/s)	9.2	8.7	8.1	7.5	6.9	6.2	5.7	5.3	4.7	4.1	3.6	2.7	2.2	1.9

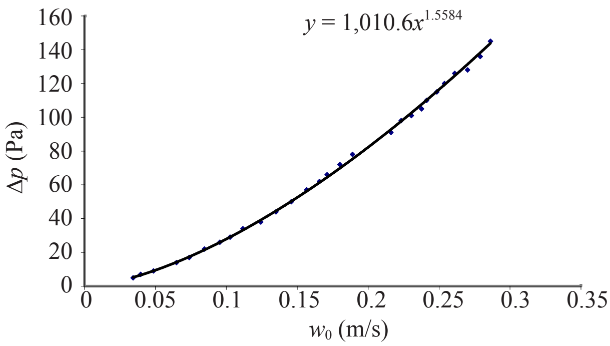

Fig. 2. Dependence of pressure drop Δp of chopped sorrel one-meter high layer on airflow velocity (w_o)

relative humidity of air getting out from material is $\varphi_i > \varphi_e + 2\%$.

The ventilator switching in regime 2 is technically provided by simple comparative regulator. Information on value φ_e is being acquired by psychrometric sensor in undergrate space. In regime 3 information on input and output relative air humidity is being acquired by psychrometric sensor in undergrate space. The ventilator is switched on in intervals of 2 hours and the φ_e value is found out. Then the ventilator is switched in reverse run and thus the undergrate space is filled by air passing through the dried material layer. The relative air humidity value acquired by the psychrometric sensor in undergrate space is substituting φ_e value (NEUBERGER, HUTLA 1996).

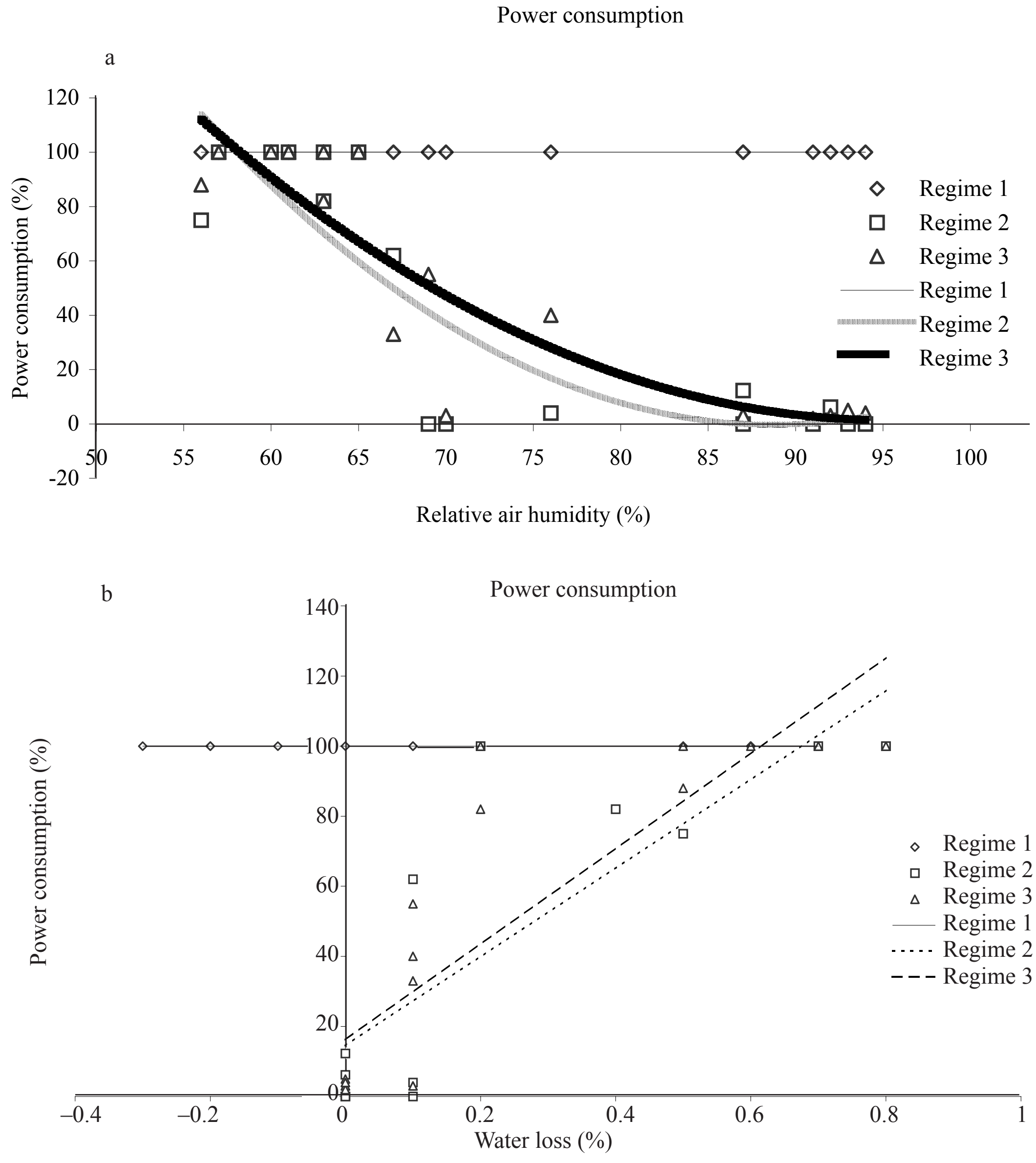

Fig. 3. Power consumption of drying ventilators drive in dependence on relative drying air humidity (a) and on water content change in one-hour interval (b) in chopped sorrel of water content 20–24%

Table 3. Drying of chopped sorrel according to particular regimes (1, 2, 3)

Date		$\phi_{e,\ mid.}$ (%)	Water content of material* (%)			Water content of material change (%/h)			Power consumption for ventilator drive** (%)		
			1	2	3	1	2	3	1	2	3
28. 7.	$8^{30}–9^{30}$	92	23.8	23.8	23.8	–0.3	0	0	100	0	3
	$9^{30}–10^{30}$	87	24.1	23.8	23.8	–0.1	0	0	100	0	3
	$10^{30}–11^{30}$	91	24.2	23.8	23.8	0	0.1	0	100	0	2
	$11^{30}–12^{30}$	87	24.2	23.7	23.8	0.1	0	0.1	100	0	3
	$12^{30}–13^{30}$	76	24.1	23.7	23.7	0.2	0.1	0.1	100	5	40
	$13^{30}–14^{30}$	69	23.9	23.6	23.6	0.1	0	0.1	100	0	55
	$14^{30}–15^{30}$	65	23.8	23.6	23.5	0.2	0.2	0.2	100	100	100
	$15^{30}–16^{30}$	63	23.6	23.4	23.3	0.2	0.2	0.2	100	100	82
29. 7.	$8^{30}–9^{30}$	70	23.3	23.0	23.1	0.2	0	0.1	100	0	3
	$9^{30}–10^{30}$	61	23.1	23.0	23.0	0.6	0.7	0.6	100	100	100
	$10^{30}–11^{30}$	63	22.5	22.3	22.4	0.5	0.4	0.5	100	82	100
	$11^{30}–12^{30}$	60	22.0	21.9	21.9	0.7	0.8	0.8	100	100	100
	$12^{30}–13^{30}$	57	21.3	21.1	21.1	0.6	0.8	0.7	100	100	100
	$13^{30}–14^{30}$	67	20.7	20.3	20.4	0.2	0.1	0.1	100	62	33
	$14^{30}–15^{30}$	93	20.5	20.2	20.3	– 0.2	0	0	100	0	5
	$15^{30}–16^{30}$	94	20.7	20.2	20.3	– 0.2	0	0	100	0	4
30. 7.	$8^{30}–9^{30}$	56	20.8	20.1	20.2	0.6	0.5	0.5	100	75	88
	$9^{30}–10^{30}$	51	20.2	19.6	19.7	0.8	0.7	0.8	100	100	100
	$10^{30}–11^{30}$	47	19.4	18.9	18.9	1.0	1.1	1.0	100	100	100
	$11^{30}–12^{30}$	46	18.4	17.8	17.9	0.9	1.0	1.1	100	100	100
	$12^{30}–13^{30}$	42	17.5	16.8	16.8	0.8	0.7	0.7	100	100	100
	$13^{30}–14^{30}$	37	16.8	16.1	16.1	1.2	1.1	1.3	100	100	100
	$14^{30}–15^{30}$	38	15.6	15.0	14.8	1.0	1.1	1.0	100	100	100
	$15^{30}–16^{30}$	37	14.6	13.9	13.8	0.8	0.7	0.7	100	100	100
31. 7.	$8^{30}–9^{30}$	60	13.8	13.2	13.1	0.1	0	0.1	100	100	93
	$9^{30}–10^{30}$	55	13.7	13.2	13.0	0.2	0.1	0.1	100	100	89
	$10^{30}–11^{30}$	51	13.5	13.1	12.9	0.2	0.2	0.2	100	100	100
	$11^{30}–12^{30}$	55	13.3	12.9	12.7	0.1	0.2	0.1	100	100	8
	$12^{30}–13^{30}$	59	13.2	12.7	12.6	0.1	0.1	0	100	100	3
	$13^{30}–14^{30}$	57	13.1	12.6	12.6	0.1	0.1	0.1	100	100	16
	$14^{30}–15^{30}$	60	13.0	12.5	12.5	0.1	0	0	100	100	7
	$15^{30}–16^{30}$	64	12.9	12.5	12.5	0.0	0	0	100	95	5
1. 8.	$8^{30}–9^{30}$	66	12.7	12.6	12.5	0.0	0	0	100	48	3
	$9^{30}–10^{30}$	61	12.7	12.6	12.5	0.1	0.1	0.1	100	100	7
	$10^{30}–11^{30}$	55	12.6	12.5	12.4	0.1	0.1	0.1	100	100	18
	$11^{30}–12^{30}$	48	12.5	12.4	12.3	0.1	0.2	0.1	100	100	20
	$12^{30}–13^{30}$	49	12.4	12.2	12.2	0.0	0	0	100	100	7
	$13^{30}–14^{30}$	46	12.4	12.2	12.2	0.0	0.1	0	100	100	11
	$14^{30}–15^{30}$	57	12.4	12.1	12.2	0.0	0.1	0	100	100	5
	$15^{30}–16^{30}$	50	12.4	12.0	12.2	0.1	0	0	100	100	8

*Before start of measuring

**Related to ventilator power consumption in regime 1

Within the drying time, i.e. from 8.30 to 16.30 o'clock of MET the relative air humidity was measured within ambient environment. From the measured values was computed an average value for one hour intervals. For every one hour interval of the drying process were determined – besides mentioned value of relative humidity of outdoor air – the water content of dried material, water content change of material

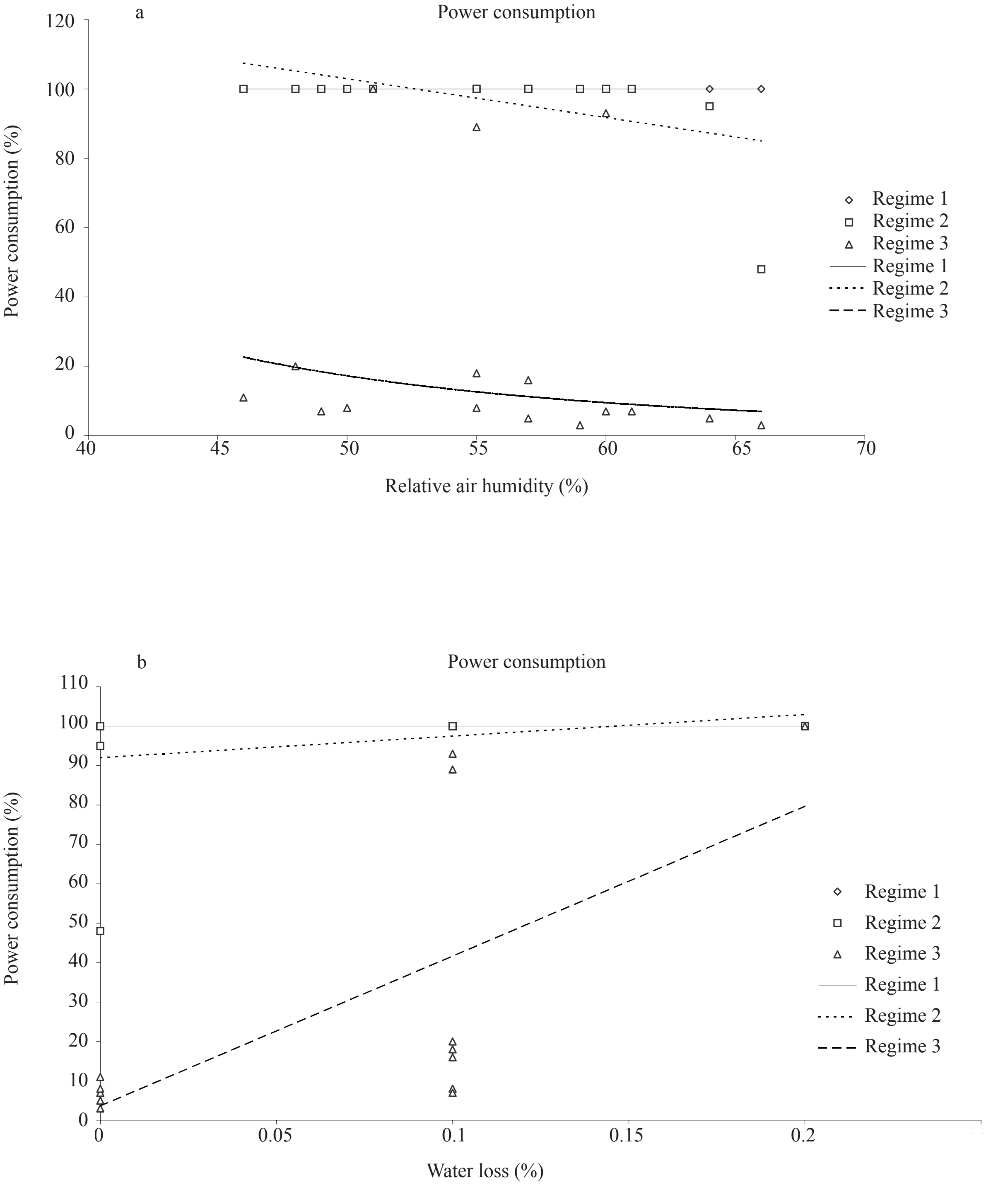

Fig. 4. Power consumption for ventilators drive in dependence on relative drying air humidity (a) and on water content change in one-hour interval (b) in chopped sorrel of water content 20–24%

and power energy amount consumed for ventilators drive.

RESULTS AND DISCUSSION

Measurement of hydraulic air drops

The material was stacked in the one-meter high layer. The measured pressure drop values and the corresponding values of air velocity in the input aperture are shown in Table 2.

In chart in Fig. 2 is given dependence $\Delta p = \Delta p\ (w_o)$ for recalculated velocity v in the measuring cylinder cross-sectional area. The dependence is also stated in an analytical expression for which a power function is used.

Drying of chopped sorrel

The drying was performed from 28. 7. to 1. 8. 2003 simultaneously in three sections of drying bay of the hayloft. The height of material layer was 1 m, in each

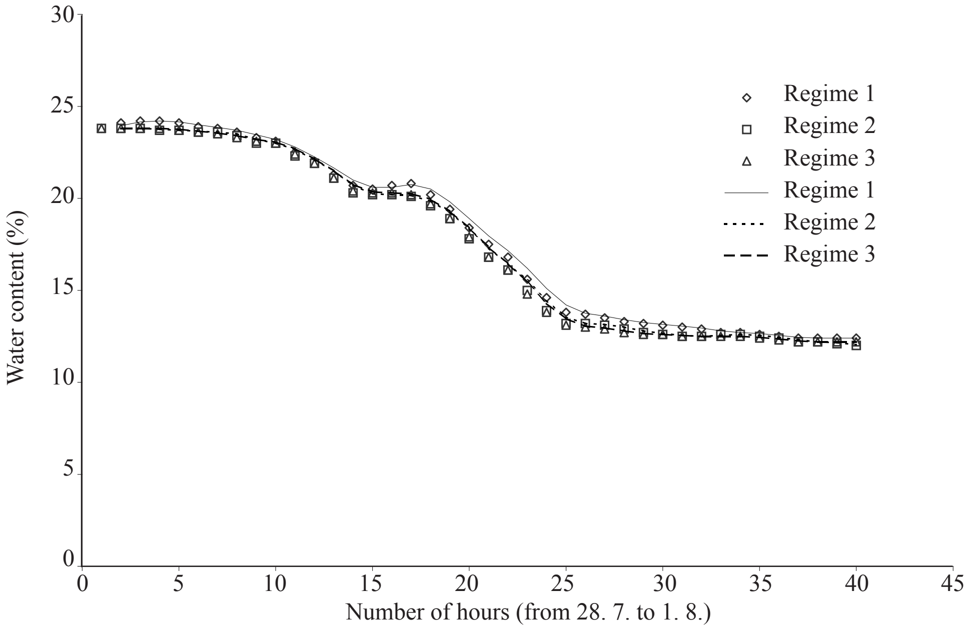

Fig. 5.Time dependence of chopped sorrel drying course

section was stocked 36 m^3, i.e. 3.11 t of material. The measuring results are presented in Table 3.

From Table 1 is possible to choose dependences of drying process for ventilators drive. In Fig. 3 is presented power consumption for relatively moist material of water content 20–24% in dependence on relative drying air humidity and on water content of material change in one-hour interval. The dependences in Fig. 3a are substituted by polynomial function so for regimes 2 and 3 no values of full power consumption were included in the graphs design at low relative air humidity. The resulting graphs for regimes 2 and 3 are valid for values situated between point of intersection with the graph of regime 1 for increasing values of air humidity.

In Fig. 4 are presented analogical dependences; however, for practically dried material of water content 12–14%, for the period of high air temperatures and low relative air humidity.

From the mentioned dependences results that in the case characterized according to Fig. 3 for relatively moist material, the controlling methods of regimes 2 and 3 do not practically differ in the influence on the value of power consumption for ventilators drive. However, the difference compared to regime 1 is significant when at high outdoor air humidity characterized by a low water loss is used power without any effect on the drying. From a certain value $\varphi_{e,\ mid.}$, situated closely to the value of 50% a considerable reduction of power consumption occurs in regimes 2 and 3 which do not differ each from the other.

The different situation is for the case characterized in Fig. 4. In that case, material is almost dried and is further ventilated by air of low relative humidity. In the ventilator controlling of regimes 1 and 2 occurs ineffective drying and power is consumed unnecessarily. Significant lower power consumption is reached in regime 3.

From Table 1 was created graph of time dependence of drying process presented in Fig. 5. There is evident a very similar course of water content reduction in dried material without dependence on the regime of drying ventilators controlling.

Significant water content reduction in material was recorded during two days (29.–30. 7.), when was sunny weather with low values of relative air humidity. The water content in material during the period when ventilators were in operation in dependence on controlling regimes, i.e. from 12.20 to 16 o'clock was reduced from ca 23% below 14%.

CONCLUSION

In comparison of hydraulic air drops passing through a chopped sorrel layer of defined structure, which is harvested by a field chopper, were found out the values comparable with those of stocked forage layer. For this reason it is possible to use the same drying system organization including the same ventilators used for forage drying for the drying process.

Under operative terms there was verified the possibility of drying of chopped sorrel direct harvested by field chopper in a large-capacity hayloft. For drying ventilators controlling is necessary to eliminate forced ventilator by too wet outdoor air which has a negative impact on the power consumption. Both chosen regimes of ventilator switching are derived from the drying air parameters. The difference between both regimes in the effect on the power consumption has not been proved in the case of relatively moist material, but significant is the difference in comparison with non-controlled ventilation. The power consumption reduction of forced drying has been proved at average relative air humidity in the range above 50%.

During the experiments no effect of the ventilator controlling method including its time switching without dependence on the drying air parameters was proved on the drying intensity.

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Dosoušení energetického šťovíku v roštovém skladu

ABSTRAKT: Energetický šťovík je plodina s vysokým výnosovým potenciálem; je nejnadějnější energetickou plodinou pro Českou republiku. Vhodnou zpracovací technologií je sklizeň sklízecí řezačkou s následným krátkodobým uskladněním a dosušením řezanky ve velkokapacitním seníku. Pro šťovíkovou řezanku byly zjištěny hydraulické ztráty vzduchu při průchodu naskladněnou vrstvou a srovnávány s hodnotami pro tímto způsobem skladovanou píci. Byly porovnávány dva způsoby řízení sušicích ventilátorů ve velkokapacitním seníku navzájem s režimem časového spínání při sušení šťovíkové řezanky. Spotřeba elektrické energie pro pohon ventilátorů v různých režimech závisí na obsahu vody v materiálu. Způsob řízení ventilátorů či časového spínání přitom nemá vliv na výsledek sušení, tedy na snižování obsahu vody v sušeném materiálu. V provozních podmínkách byla ověřena možnost sušení energetické šťovíkové řezanky ve velkokapacitním seníku.

Klíčová slova: tlakové ztráty; sušení; velkokapacitní seník; energetická řezanka; energetický šťovík

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