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Comparison of different hay drying techniques

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Abstract

At the federal research institute Raumberg-Gumpenstein four different grassland-forage conservation systems ((1) round bale silage, (2) hay making under field conditions, hay drying under artificial conditions (3) cold-air ventilation and (4) with an air heating equipment – roof solar collector combined with a heat pump dehumidifier) have been investigated over three years (2010–2012). Differences were measured in the length of the field drying period (period between mowing and self loading trailer harvesting). The general range goes from two (silage, second cut) to 72 hours (conservation system (2), fourth cut). Related to crumble losses at the forage preservation system (2) 386 kg DM.ha^{-1}.cut^{-1} got lost, 190 kg DM more compared to the forage preservation system (4). Under regular conditions, the drying time under artificial conditions (3) and (4) was less than 72 hours. Conservation experts recommend drying times less than 72 hours in order to prevent microbial damage.
The lowest energy consumption was measured at the forage preservation system (3) – 80 kWh.t^{-1} DM. The energy demand for the humidifier pump heater system (4) was 150 kWh.t^{-1} DM. The costs for electricity per kilogram hay differ between 0.4 and 2.4 cent for hay making with system (3) and between 0.7 and 5.5 cent for hay drying with system (2) - 18 cent per kWh were calculated. The fixed costs per kilogram hay are 5.5 cent for the hay making system (2) and 1.7 cent for the hay making system (3). This example was calculated without any building and indoor crane costs. If you want to run a professional dairy farm, forage based on hay only, you will have to investigate in highly efficient hay drying techniques. The dehumidifier pump heat is one good possibility to achieve the goal of a high forage quality, less crumble losses also under difficult weather conditions.

Keywords: forage, hay, drying process, heat pump dehumidifier, costs

1 Introduction

During the last 10 years the trademarks "hay milk" and "cheese from hay milk" (hay milk: milk from cows that neither get grass silage nor corn silage) has been able to be established by means of vigorous marketing action and because of a modified consumer behaviour.
High milking dairy cows have a nutrient demand, which cannot be fulfilled by field dried hay. There are no or only a few occasions for cropping at the first and at the fourth (fifth) cut (Formayer et al., 2000 and Luder, W., 1982). If the first cut does not start before the meantime or end of grass flowering instead of in the growth stage of heading because of bad weather conditions, this will mean a loss of about 0.6 MJ NEL per kg dry matter (Gruber et al., 2009). The date of the process severely influences crude fibre content and in the sequel also content of energy and crude protein content of the forage. In the meantime similar cropping results as with pure silage can be achieved with modern efficient hay drying plants by making use of short fine weather periods. With a modern measurement and control technology the energy consumption should be kept as small as possible, additionally.

2 Material and methods

At the AREC Raumberg-Gumpenstein three hay drying techniques (processes) have been compared during the year 2010 to 2012 – Field drying (FD), cold-air ventilation (CAV) and

heat pump dehumidifier processing (HPD). The heat pump dehumidifier is combined with a roof solar collector for natural air heating. From the view of engineering these techniques (processes) were analysed in terms of use of machines on the field, field losses, constructional-technical costs (capital cost) as well as energy demand and energy costs. Because of technical problems in 2010 the drying results for this harvesting year are not considered, here. In the year 2013 higher batches of forage were dried with the dehumidifier plant in order to be able to refer to practice relevant crop mass in the hay box in terms of energy costs. The deployed machines and equipment, used for forage harvesting are listed in *table 1*.

Table 1: Deployed machines and equipment for forage harvesting, hay project, AREC Raumberg-Gumpenstein, 2010 to 2013

Activity	Machine, type	Activity area, Tractor type	Technical data
Tractor	Fendt 310 Vario	Mowing, harvesting	77 kW
	Steyr Profi 4115	Mowing, harvesting	85 kW
	Steyr 975	Tedding	55 kW
	Fendt 209	Tedding, swathing	67 kW
Mower	Krone EasyCut R280 CV + EasyCut 32CV	Fendt 311 Vario	WW: 5.49 m [1)]
	Pöttinger NovaCut 305 + NovaCut 305 α Motion	Steyr Profi 4115	WW: 5.68 m [1)]
Tedder	Lely Lotus 900 P	Steyr 975	WW: 9.0 m
Rake	Pöttinger EuroTop 620 Multitast	Fendt 209	WW: 5.90 m
Harvesting	Pöttinger Ladeprofi IV	Steyr Profi 4115	29 DIN m^3
	Pöttinger Ladeprofi IV	Fendt 310 Vario	29 DIN m^3

WW = Working width, [1)] calculated with 40 cm overcut

2.1 Cold-air ventilation

The hay box has a height of 3.90 m and a grating height of 45 cm. This yields an appropriable volume of 241 m³. The plant is ventilated by a centrifugal fan type Buchmann RE 901 with 5.5 kW.

2.2 The heat pump dehumidifier plant

This hay drying plant at the AREC Raumberg-Gumpenstein consists of a heat pump dehumidifier and a centrifugal fan with the necessary measurement and control technique. Additionally, a solar collector with a surface of 410 m² was installed. The centrifugal fan with a rated power of 22 kW delivers the necessary flow rate of 30,000 $m^3.h^{-1}$ (28 Hz) and a max. capacity of 55,000 $m^3.h^{-1}$ (50 Hz).
The heat pump dehumidifier needs an electric delivery rate of 16 kW. The net cross-sectional area of the register is 4 m². The arrangement of the dehumidifier heat pump takes place in the main current. Measurement of the hay drying plant happens by means of SPS-controlling and regulation measurement.

2.3 Measuring techniques and data collection

The weather conditions were taken from the meteorological station in Raumberg-Gumpenstein. The data for energy consumption of the plant as well as the measured data of air were registered every minute. Likewise temperature and humidity in the heating and ventilating chamber, above the hay box and beneath the solar roof were measured. Airflow velocity was directly measured after the humidifier register. The progress of drying was

defined on the basis of temperature difference between hay box and the heating and ventilating chamber.

2.4 Crumb losses on the field

Crumb losses were determined directly after harvesting by hoovering the lost plant materials. Ten monitoring stations per variation were exhausted – 5 sectors and two monitoring stations per sector. Exhausting happened in a measuring frame of 1 m² by means of an industrial hoover with a round ending of the suction hose. The cursorily lying plant material (parts of clover, grass and herb leaves) was exhausted in a distance of 3-5 cm to soil. Exhausting was carried out in both directions and in double iteration. Afterwards, the forage remained in the bags being dried in the drying plant to a constant weight (hay weight), bags were separately weighed and dry substance was determined from a composite sample. In each sample the fine part of soil was separated by hand before weighing the mass. In case of no possibility to do that the samples were cleaned by means of a precipitator powered by air.

3 Results and discussion

In *table 2* the averagely measured idle periods on field (hours between cutting and harvesting) of the single preservation types from 2010 until 2012 are listed. Especially at the first, second and third cut the forage which is dried by the heat pump dehumidifier plant, combined with the solar collector, can be harvested a half-day before the cold-air-variation. Idle periods on field for the field drying ("field drying period") exactly show the problem of this type of preservation. Already at the third cut the forage had to dry more than two days on the field on average. At the fourth cut – from the middle of September on – no well storable hay was to be harvested with this preservation type.

Table 2: Average "field-drying-period" during the years 2010 to 2012, hours between cutting and harvesting, hay project, AREC Raumberg-Gumpenstein

Cuts	Silage	HPD	CAV	FD
1st Cut	10.2	18.8	26.4	37.3
2nd Cut	3.2	16.5	25.1	34.5
3rd Cut	6.2	20.0	28.8	51.3
4th Cut	23.2	41.9	49.9	58.6[1)]

[1)] Hour values are not realistic, because the hay was dried under artificial conditions (naturally, under the roof, in thin layers). HPD = heat pump dehumidifier; CAV = cold-air ventilation; FD = field drying

In *table 3* crumb from all three years (2010 until 2012) are summarized. Tedding was – after recommendation – carried out with high revs per minute at p. t. o. shaft at the broadcasting (470 to 500 RPM) and small RPM at the turning (380 RPM).

Table 3: Crumb losses kg DM.ha^{-1}.cut^{-1}, permanent grassland, average value between 2010 and 2012, hay project, AREC Raumberg-Gumpenstein

Conservation techniques	1st cut	2nd cut	3rd cut	4th cut	average
Silage	160	169	127	162	154
Heat pump dehumidifier	234	204	155	191	196
Cold air ventilation	292	264	258	273	272
Field drying	383	383	m. d.	392	386

m. d. = missing data

If the hay drying techniques are compared with silage, the variation "heat pump dehumidifier combined with solar collector" (HPD) with on average only 42 kg DM/ha and cut will only concisely stay behind in terms of crumb losses. The same comparison is also made between

the hay drying techniques. The variation cold-air ventilation (CAV) will show 76 kg more and the field dried hay variation (FD) 190 kg DM/ha more fine forage rates on field compared to the dehumidifier variation. In *table 4* the most important data of 2012 for the calculation of energy costs are listed. The year 2011 was very similar to 2012. In 2013 practice-relevant lots were stored and dried in the dehumidifier plant. In terms of the energy costs per kg hay the cold-air ventilation scored best with values from 0.4 to 2.4 cent, whereas energy costs for the heat pump dehumidifier combined with solar collector (HPD) drying lay between 1.4 and 5.0 cent/kg hay in the years 2011 and 2012.

Table 4: Harvesting amount, dry matter and energy consumption data during the year 2012, hay project, AREC Raumberg-Gumpenstein

Cut		**1st cut**			**2nd cut**		**4th cut**	
activity data:	**value**	**HPD**	**CAV**	**HPD**	**HPD**	**CAV**	**HPD**	**CAV**
date of harvesting:		19.5.	19.5.	26.5.	29.6.	29.6.	17.9.	18.9.
harvesting amount	kg	13,230	4,145	38,830	18,805	9,850	14,120	6,080
DM (dry matter)	%	56.6	66.1	60.2	62.4	75.9	65.2	72.8
DM amount in the box	kg	7,491	2,739	23,358	11,727	7,475	9,208	4,427
Amount of hay in the box	kg	8,465	3,095	26,395	13,251	8,447	10,405	5,002
Water amount for drying	kg	4,765	997	12,435	5,554	1,258	3,715	992
Energy consumption:								
per ton DM	kWh	87	66	146	140	25	306	111
per ton hay	kWh	77	57	129	124	22	271	97
spezific energy consumption	W/kg	137	180	275	297	149	758	497
Energy costs (18 Cent/kWh)								
per kg DM	Cent	1.6	1.2	2.6	2.5	0.5	5.5	2.0
per kg hay	Cent	1.4	1.0	2.3	2.2	0.4	4.9	1.7

Remark: The 3rd cut could not be harvested in 2012, because of flooding in the experimental area
HPD = heat pump dehumidifier; CAV = cold air ventilation;

Table 5: Costs of the hay drying techniques (cold and heated air ventilation), model calculation

Investigations	**Value**	**Heated air**	**Cold air**	**Remarks**
Fan	€	10,000 [1)]	7,000	[1)] inkl. frequency converter; UL 15year
Hay box, grating, tube	€	15,000	15,000	100 m^2, self-made; UL 30 years
Solar collector	€	10,000		250 m^2, self-made; UL 30 years
Heat pump dehumidifier	€	30,000		incl. regulation equip.; UL 30 years
Total fixed cost.a^{-1}	€	6,317	1,607	
DM production.a^{-1}	kg	130,000	130,000	20 ha, yield: 6.500 kg DM.ha^{-1}.a^{-1}
Hay production.a^{-1}	kg	96,954	96,954	2/3 hay making
Fixed cost.kg^{-1} hay [2)]	Cent	5.54	1.66	
Energy consumption	kWh	12	8	per 100 kg hay
Variable cost.kg^{-1} hay	Cent	2.16	1.44	18 Cent/kWh
Total cost.kg^{-1} hay [2)]	Cent	7.70	3.10	hay: 87 % DM content

[2)] without costs for building and crane; UL: Useful live

In 2013 values for energy consumption were notably lower at the first (May 18) and second (August 2) cut with 0.8 and 0.7 cent/kg hay; the mean value over all trials, however, did not change. In the further drying processes hay was dried for 2.8, 3.6 and 5.5 cent per kg. In *table 5* the both drying processes, which take place under roof are compared in terms of costs (fix and variable costs). Costs for buildings and hay crane are not included in this calculation.

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