LANDWIRTSCHAFTLICHES ZENTRUM
für Rinderhaltung, Grünlandwirtschaft, Milchwirtschaft, Wild und Fischerei
Baden-Württemberg (LAZBW)
Atzenberger Weg 99, 88326 Aulendorf

Use of the PistenBully 300 (Kässbohrer) for spreading and compacting green rye
Effects on density, silage temperature and fermentation quality
- Project 2009 -

Created by:

Dr. Hansjörg Nußbaum

1.Test question

How does green rye spreading work when using a snow groomer for silo storage and how are compaction, silage temperature and fermentation quality affected?

The LAZBW (Baden-Württemberg agricultural centre for ruminant production, grassland management, dairy management, wildlife and fisheries) has performed laboratory analyses on the harvested crop and all silage samples for its own interest and at its own cost. These results are also presented in this report.

2. Material and methods

2.1 Firm: Bioenergie Pfullendorf
Dorfstr. 10
88630 Pfullendorf
Tel.: +49(0)7552/5078

2.2 Harvest technology:

2.2.1 Mowing technology:

Krone BIG M400 with 9.7-m working width (effective 9.1 m)

Subcontractor Heinrich vom Berge
Wangen 31
88356 Ostrach
Tel.: +49 (0)758 532 17

2.2.2 Chaff choppers:

Claas Jaguar 950
Claas Jaguar 840

Subcontractor Markus Wahl
Ortsstr. 28
88630 Pfullendorf-Zell am Andelsbach
Tel.: +49 (0)755 293 8743

2.2.3 Transport:

- Dumper Oehler (approx. 30 m³)
- 2 dumpers Brandner TA 20053 (approx. 30 m³)
- Strautmann Giga-Trailer 1840 (approx. 30 m³)
- Loader Mengele Garant 543

2.3 Silage crop:
The green rye sown in autumn 2008 was (2 to 3 days before ensilaging) mowed in swaths (swath formation) and not turned. Almost 10 % of all samples (19 of 220) were analysed in the lab (Table 1). The tested fresh green rye samples had a mean 19.6 % (n=19) (spread 14.3 to 25.7 % DM). The harvested crop had a mean DM content of 17.8 % (spread from 12.9 to 29.9 % DM) of all DM samples (n=220).

Table 1: Content of harvested crop (19 of 220 samples were analysed)

Load Serial no.	DM	Crude prote-in	Crude fibre	Crude ash	Energy MJ/kg DM		Sugar	BC*	S/BC ratio
	%		% i. DM		ME	NEL	% i.DM		
39	15.6	11.7	36.9	7.5	9.35	5.47	3.7	7.2	0.5
45	16.2	9.8	39.6	6.7	9.26	5.40	4.3	6.2	0.7
49	15.5	11.7	36.6	7.4	9.38	5.49	4.3	6.7	0.6
51	14.3	15.0	33.0	7.5	9.63	5.66	2.9	7.6	0.4
58	14.5	14.0	37.5	8.1	9.66	5.69	3.0	6.6	0.5
89	21.9	7.6	28.9	7.6	10.22	6.08	22.0	6.7	3.3
94	16.9	12.7	37.8	7.3	9.55	5.60	2.5	6.7	0.4
96	16.5	11.8	38.3	8.9	9.51	5.59	2.6	6.2	0.4
100	18.0	12.7	34.5	7.1	9.79	5.77	3.9	5.8	0.7
112	18.2	12.0	40.9	7.8	9.55	5.61	4.1	4.5	0.9
140	20.0	11.1	38.7	7.4	9.28	5.42	4.4	6.5	0.7
143	24.0	9.0	36.8	6.4	9.36	5.46	10.2	6.0	1.7
147	20.5	11.2	42.3	6.6	9.49	5.56	3.5	5.5	0.6
163	18.8	13.4	38.7	8.2	9.44	5.54	1.7	7.0	0.2
165	24.8	15.2	34.8	7.9	10.36	6.18	4.1	6.5	0.6
184	25.7	12.3	36.8	7.0	9.91	5.85	4.7	5.8	0.8
190	24.6	14.3	35.3	7.4	10.22	6.07	4.3	6.4	0.7
202	23.1	10.9	39.7	6.9	9.13	5.31	3.0	5.8	0.5
208	23.0	10.2	40.6	7.7	9.23	5.39	4.6	5.2	0.9
Mean	**19.6**	**11.9**	**37.2**	**7.4**	**9.60**	**5.64**	**4.9**	**6.3**	**0.8**
Min	**14.3**	**7.6**	**28.9**	**6.4**	**9.13**	**5.31**	**1.7**	**4.5**	**0.2**
Max	**25.7**	**15.2**	**42.3**	**8.9**	**10.36**	**6.18**	**22.0**	**7.6**	**3.3**

*BC: Buffer capacity = gram lactic acid up to pH 4.0

The green rye was at the growth stage "end of heading" to the "beginning of bloom" for harvest depending on land use planning. Therefore, the silage had a mean crude fibre content of 37.2 % in DM (spread of 28.9 to 42.3 % in DM) and a mean crude protein content of 11.9 % in DM (spread 7.6 to 15.2 in DM). Thus, the optimum growth stage for silaging had already passed. This was also noticeable in the low sugar content. Sugar levels of 2-3 % in FM and 8-9 % in DM are the aim for definite lactic acid fermentation. In this context, the ratio between sugar and buffer capacity (S/BC ratio) should be at least 2. This ratio was 0.8 in this test and, thus, confirms difficult fermentability. The mean fermentability coefficient (FC = DM + (8x S/BC) was 25.9. From an FC of 35, a harvested crop is moderately to silage and, from 45, is easy to ensile. The contamination of the harvested crop was low and unproblematic with a mean 7.4 % crude ash in DM (spread 6.4 to 8.9 % in DM). The high crude fibre content combined with low sugar and crude protein levels led to an mean energy value of 9.6 ME and 5.6 MJ NEL per kilogram of dry matter.

2.4 Silo type:
Bunker silo with side walls (2.50 – 2.60 wall height); covered with tarpaulin

On the road side the top edge of the silo wall ends flush with the road and, thus, forms a dumping edge. The bunker silo is open to the biogas plant and vehicle-accessible. The bunker silo was lightly filled with grass silage the day before (approx. 300 m³ to the dumping edge on the road side); litter manure was stored laterally on the open side toward the biogas plant (see Figures 1 and 2) almost up to the middle of the silo. The ensilaged grass silage and the litter manure were measured immediately before the test.

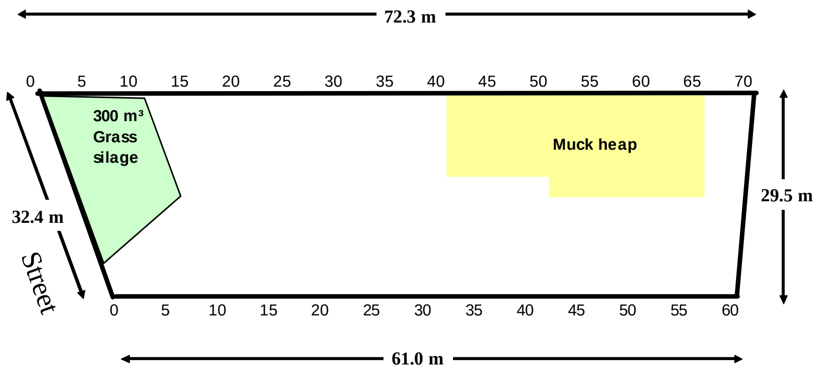

Figure 1: Outer dimensions of the bunker silo (plan view) and position of the grass silage and the litter manure in the silo (illustration not to scale).

Figure 2:

Bunker silo (seen from the biogas plant) just before the test started. In the background you can see the office trailer by the scales (tipper is on the scales) and the field cutter on the adjacent land. Litter manure is stored to the right, next to the dumping edge of the grass silage (dark brown).

2.5 Data collection during harvest

The time the harvested volumes were delivered, the behaviour of the vehicle in the feed and the mean compaction in the silo were determined when the green rye was unloaded. Each transport vehicle was weighed (Figure 3) and a sample was taken from the tipper content to determine the dry mass content (DM). The PistenBully was filled up with fuel on 19th May just before the test began.

During unloading of the feed, the quality of the work was evaluated and the fill level in the silo was recorded hourly at first and then every two hours later on. To this end, markings were made on the silo walls at intervals of 25 cm spaced 5 metres apart like a water depth gauge (Figure 5). During work in the silo, the push manoeuvres needed for spreading were counted, the behaviour of the machine on slopes and on the wall was observed, and technical difficulties or failures were noted.

Figure 3:

Calibrated platform scales with radio-controlled vehicle recognition and automatic data storage (vehicle, time, weight)

Figure 4:

PistenBully 300 with altered cooler on the loading platform and rear and additional weight (600 kg).

Figure 5:

Coloured markings were made every 5 metres at 25-cm intervals on the silo wall and checked regularly.

2.5 Silage sampling dates on site:

1. **D1** 7th August 2009 approx. 41 m from the front (dumping edge)
2. **D2** 31st August 2009 approx. 31 m from the front
3. **D3** 28th September 2009 approx. 22 m from the front

2.6 Silage sampling positions:

1. **P1** on the right-hand side approx. 0.50 m from the side wall (**edge 1**)
2. **P2** on the right-hand side approx. 1.00 m from the side wall (**edge 2**)
3. **P3** in the middle of the silage pile, 7.0 m from the right-hand wall (**middle**)

2.7 Silage layers:

1. **L1** approx. 0.30 m from the top
2. **L2** approx. 1.00 m from the top
3. **L3** approx. 0.50 m above the silo floor

2.8 Analyses:

Harvest

1. DM content of all tipper loads (220 samples) using drying at 60 °C and 105 °C
2. Raw nutrients: acc. VDLUFA (19 of 220 samples)
3. Ensilability 19 samples (LTZ Augustenberg)

Silage:

1. Density using Pioneer borer in kg FM/m³ and kg DM/m³
2. DM content using drying at 60°C and 105 °C; for the silage dry mass corrections acc. WEISSBACH (1994); figures then in % in DMc
3. pH values using rapid determination on-site (indicator paper Macherey & Nagel, no. 095300) and additionally using measuring equipment in the lab
4. Sensory evaluation of the silage on-site
5. Raw nutrients: acc. VDLUFA

6. Energy content: calculated using HFT (formula for grass silage acc. STEINGASS and MENKE, 1987)
7. Fermentation acid and residual sugar: using HPLC, modified acc. SIEGFRIED et al. 1984

2.9 Procedure for silo removal

After filling with green rye (20th May) the silo was half-filled (side to the field in the extension of the litter manure) with further grass silage on the following days (21st and 22nd May) and completely covered with tarpaulin on 22nd May.

The silo was opened on 4th August 2009 after 2.5 months of storage (75 days). The samples were taken on 7th and 31st August and on 28th September 2009. Between the first two dates the mean removal rate was 2.9 metres per week, and 2.12 metres per week between dates 2 and 3.

Sampling was effected at three positions in each case (P1 to P3) and three layers (L1 to L3) using a sample borer (Pioneer). Core samples (3 bores per position and layer; diameter 4.5 cm, 45 cm long) were removed and weighed (Figure 6). Mixed samples were created from the three core samples from the individual positions and layers. The mixed samples were tested immediately using sensory analysis for faulty fermentation and using indicator paper for the pH value. The samples were then weighed on site (500 g fresh material in crisp packs) to determine the dry mass content (Mettler PM 54). The samples were transported to Aulendorf in a cool box and dried out to a constant weight for at least 24 hours at 60°C and 105 °C in the drying chamber.

Fresh material from each mixed sample was deep frozen to analyse feed value and fermentation quality.

The temperature was measured using two temperature probes (Testo) at three depths (15 cm, 50 cm, 150 cm from the front edge of the bore hole) in each bore hole (Figure 7).

The ambient temperature was 18.1 °C on 7th August 2009, 25.2 °C on 31st August 2009 and 15.6 °C on 28th September 2009.

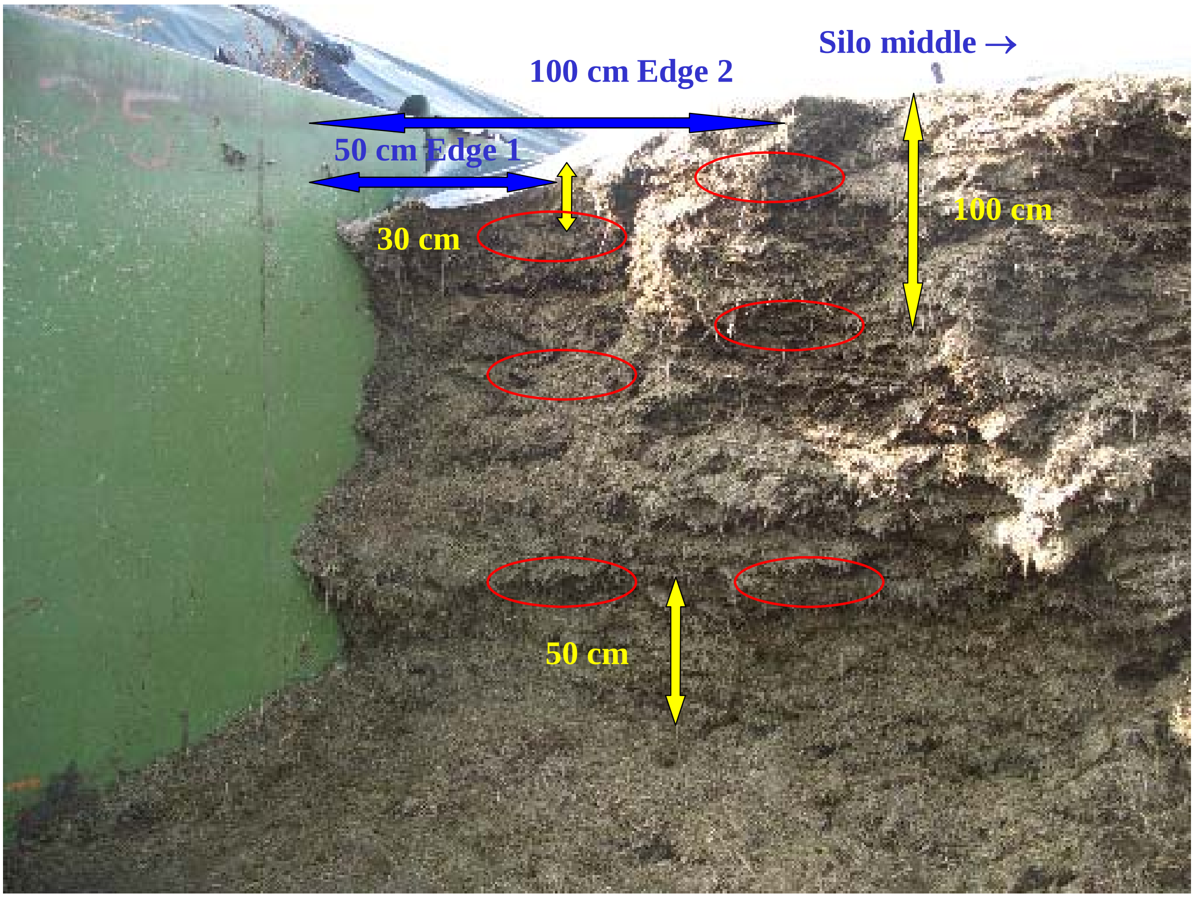

Figure 6: Schematic arrangement of the bore holes around the edge of the grass silage (illustration not to scale)

Figure 7: Temperature measurements in the bore wholes

3. Results

3.1 Unloading the green rye

On the first day, two self-propelled choppers and five transporters were in use in the direct vicinity of the silo for almost the whole day. 1,480 tonnes of fresh mass (FM) were delivered in 12.8 working hours in 145 loads with a mean DM content of 16.1 % (Table 2). The mean output was 115.6 tonnes of fresh mass (and 18.6 t DM) per hour, with a maximum value of 230 tonnes FM/h. On the second day, only one chopper was used because of the greater transport distance (approx. 5-6 km silo-to-field). 671 tonnes of fresh mass with a mean DM content of 20.8 % were delivered in 75 loads and unloaded in 8.6 hours. The mean unload rate on the second day was 78 tonnes of fresh and 16.3 tonnes of dry mass per hour.
A total of 850 pushes were counted to distribute the entire harvested crop. This resulted in a mean mass of 2.5 tonnes of fresh mass per push, which is around 10 tonnes FM per tipper, 4 pushes per tipper to spread in the silo.

Table 2: Values measured during unloading

	Output		Mean content	Labour time	Tipper	t/tipper	
Date	**t FM**	**t DM**	**DM %**	**h (net)**	**number**	**FM**	**DM**
1st day 19th May 10	1,480	238	16.1	12.8	145	10.2	1.6
2nd day 20th May 10	671	140	20.8	8.6	75	8.9	1.9
Total:	**2,151**	**378**	**17.6**	**21.4**	**220**	**9.8**	**1.7**

Table 2 continued

	Pushes	Mass/push	Unload rate	
Date	**number**	**t FM**	**t FM/h**	**t TM/h**
1st day 19th May 10	544	2.7	115.6	18.6
2nd day 20th May 10	306	2.2	78.0	16.3
Total:	**850**	**2.5**	**100.5**	**17.7**

In total, 2,151 tonnes of fresh mass and 378 tonnes of dry mass were delivered on both days in 21.4 hours in 220 loads. Each tipper was loaded with an average of almost 10 tonnes of fresh mass. The mean DM content was 17.6 %. The mean unload rate for both days was 100.5 tonnes of fresh and 17.7 tonnes of dry mass per hour.

The volume unloaded was around 2,700 m³. This results in a mean density of 797 kg FM/m³ and 140 kg DM/m³ (Table 3).

Table 3: Calculated volume (m³) and calculated density

Volumes:	**2,700 m³**		
		FM	**DM**
Density	**kg/m³**	**796.7**	**140.0**

Diesel consumption of 190 litres was calculated on the first day in 12.8 working hours. This results in a mean consumption of 14.8 litres per hour and 0.13 litres per tonne of fresh mass or 1.25 litres per tonne of dry mass. Diesel consumption was not recorded on the second day. The following two pages graphically illustrate the progress of unloading using the fill level (Figures 8 and 9).

	Positior	Left side (next to field)														
		Metres (from tipping edge to weighing)														
Day	Time:	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
19th May 2010	10:00	1.75	1.75	1.25	0.25	0.00										
	11:00	1.75	2.00	1.88	1.25	0.50	0.00									
	12:00	2.55	2.60	2.38	1.50	0.88	0.38	0.00								
	13:00	2.50	2.60	2.50	1.50	1.10	0.50	0.00								
	14:00	2.60	2.60	2.60	1.75	1.38	0.80	0.00								
	15:00	2.60	2.60	2.60	2.25	1.75	1.00	0.25	0.00							
	16:00	2.60	2.60	2.70	2.25	1.75	1.25	0.25	0.00							
	17:00	2.60	2.60	2.70	2.25	2.00	1.63	1.00	0.00							
	18:00	2.60	2.60	2.60	2.38	2.00	1.63	1.00	0.25	0.00						
	19:00	2.60	2.60	2.60	2.38	2.00	1.63	1.00	0.63	0.13						
	20:00	2.60	2.60	2.60	2.38	2.00	1.63	1.13	0.75	0.50						
	21:00	2.60	2.60	2.60	2.38	2.00	1.63	1.13	0.75	0.50						
	22:30	2.60	2.60	2.60	2.25	2.00	1.75	1.50	0.75	0.50		**Muck heap**				
20th May 2010	10:00	2.60	2.60	2.60	2.25	1.75	1.75	1.50	0.75	0.50						
	12:00	2.60	2.75	2.75	2.60	2.00	1.75	1.00	0.75	0.50						
	14:00	2.60	2.75	2.75	2.60	2.00	1.50	1.00	0.75	0.50						
	18:00	2.60	2.60	2.60	2.60	2.50	1.50	1.00	0.75	0.75						

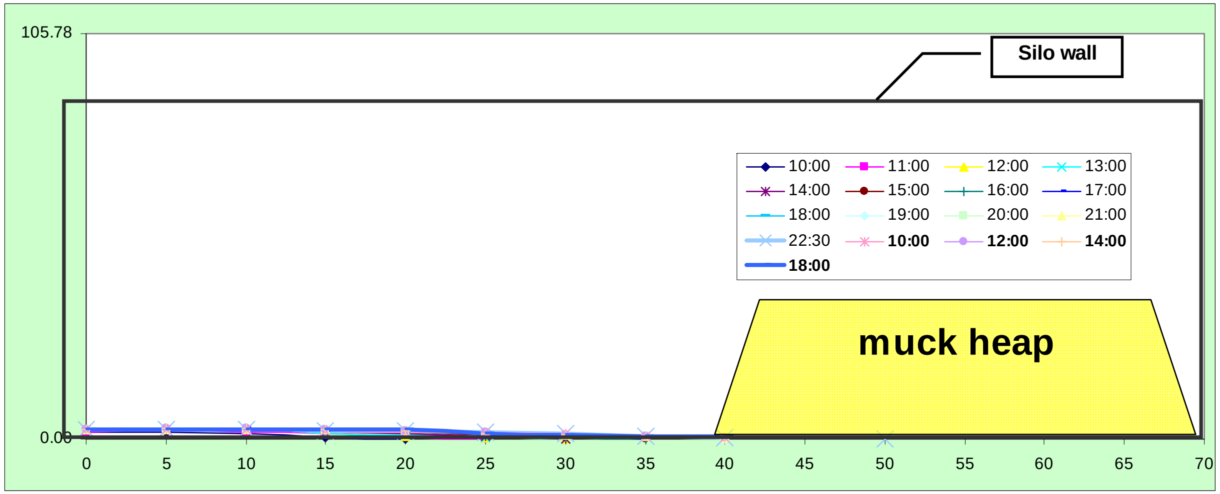

Figure 8: Progress of silo filling, illustrated by fill level on the left-hand silo wall. The fill levels on 19th May at 10.30 pm and on 20th May at 6 pm can both be seen on the thicker lines.

Location		right side (next to corn silo)														
		metres (from tipping edeg to weighing)														
Day	Time	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
19th May 2010	10:00	0.50	0.50	0.25	0.00											
	11:00	2.00	1.50	1.00	0.00											
	12:00	2.60	2.00	1.38	1.00	0.00										
	13:00	2.55	2.00	1.38	0.75	0.13	0.00									
	14:00	2.60	2.55	2.25	1.50	1.00	0.50	0.00								
	15:00	2.60	2.60	2.50	1.75	1.50	0.50	0.00								
	16:00	2.60	2.60	2.25	1.50	1.13	0.50	0.00								
	17:00	2.60	2.50	2.25	2.00	1.50	0.50	0.00								
	18:00	2.60	2.25	2.25	2.00	1.50	1.00	0.75	0.25	0.00						
	19:00	2.60	2.60	2.50	2.00	1.63	1.25	0.75	0.25	0.00						
	20:00	2.60	2.60	2.50	2.00	1.50	1.25	1.00	0.75	0.25	0.00					
	21:00	2.60	2.60	2.50	2.50	2.00	1.25	1.25	1.00	0.50	0.00					
	22:30	2.50	2.50	2.50	2.50	1.75	1.25	1.25	0.75	0.50	0.25	0.00				
20th May 2010	10:00	2.50	2.50	2.50	2.50	2.00	1.75	1.50	1.25	1.00	0.75	0.25	0.00			
	12:00	2.55	2.60	2.60	2.50	2.25	2.00	1.75	1.50	1.25	1.00	0.50	0.00			
	14:00	2.60	2.60	2.60	2.60	2.50	2.50	2.00	2.00	1.63	1.25	1.00	0.25	0.00		
	18:00	2.60	2.60	2.60	2.60	2.60	2.60	2.50	2.25	1.75	1.50	1.25	0.50	0.00		

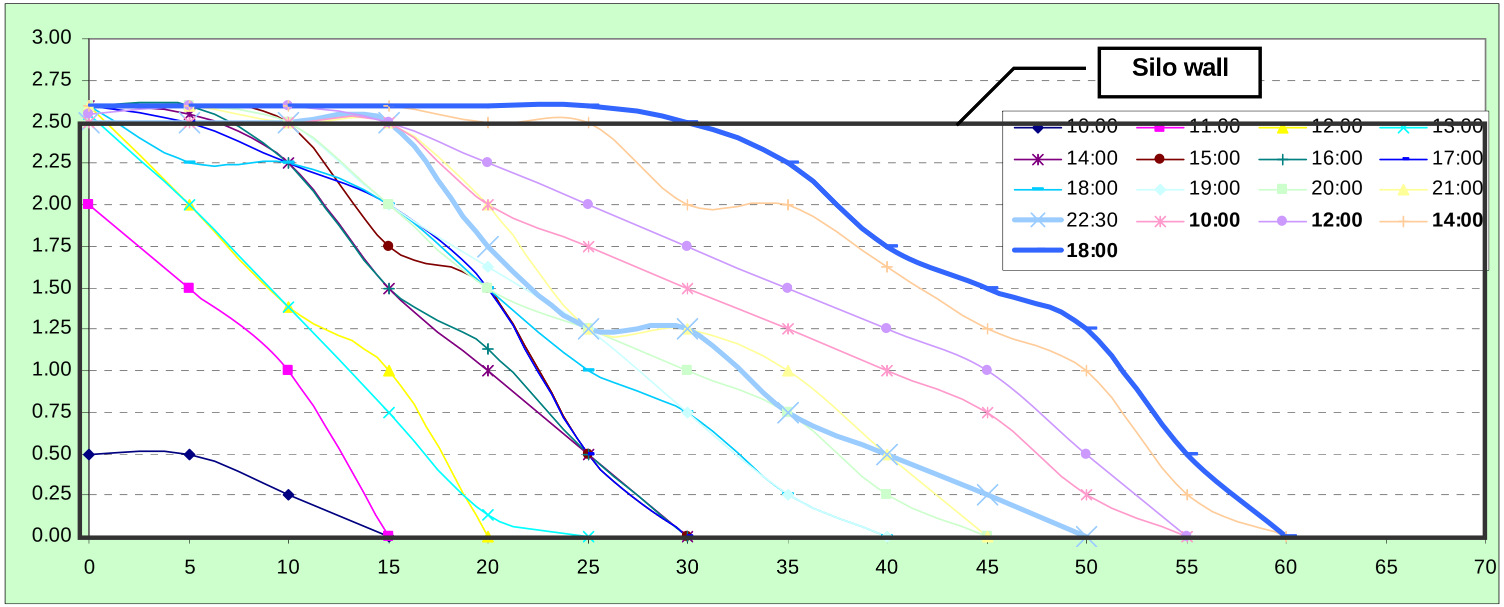

Figure 9: Progress of silo filling, illustrated by fill level on the right-hand silo wall. The fill levels at the end of the day can be seen on the thicker lines. The red points denote the sampling positions on removal.

3.2 Observations

3.2.1 Clogging of the track

The track did not clog up at any point, although the feed was cut finely and had different DM levels throughout the test. Feed between the track parts came out again quickly and easily.

3.2.2. Cooler and engine

A visual check of the cooler and motor (cabin was tilted) revealed no dirt or feed penetration after around 8.5 working hours.

3.2.3 Quality of the work

The PistenBully was able to spread a freshly tipped load with a mean 10 t fresh mass thinly (to under 10 cm) in three to four pushes over a broad stretch (up to 50 metres). A light vibration was noticeable when the vehicle drove over feed that had already been unloaded. The results were unfavourable when a tipped load was pushed head on. This mainly led to skidding, especially when concrete or asphalt was beneath the drive chains. Full traction was achieved once there was a layer of feed of 20 to 25 cm beneath the vehicle. Driving over the load precompressed it and made it more difficult to manoeuvre. In terms of power and time expenditure, it was better to “cut” the load laterally and, thus, to reduce it.

The PistenBully was very agile and was able to spread the feed up to the side walls and into the corners thanks to the manoeuvrable side parts of the blade. The uppermost layer was scattered in the silo in the event of fast turning movements (pirouettes) or fast bends; otherwise a very even and smooth surface was produced.

Figure 10: Observations on unloading the green rye

The rubberised tracks cleaned themselves quickly and easily.

Even with retracted blade a minimum distance of 40-50 cm to the silo wall remained.

Cooler and engine remain clean.

It was able to reverse right up to the silo wall.

Lateral “cutting” of the load made spreading easier.

Traversing tippers created a track around 17 cm deep.

Quickly performed “pirouettes” scattered the even surface of the feed.

“Entrenched” vehicles were freed quickly and easily.

3.2.4 Behaviour on the slope

The PistenBully was also able to move and spread larger feed volumes on the slope from the bottom upward. Stability was high.

3.2.5 Behaviour on the wall

It was possible to drive very safely along the wall with the blade, thanks to the distance rolls on the blade. When rolling, a distance of at least 40 to 50 cm between wall and vehicle remained even when the blade was retracted. As the silo filled up it was possible to push loads laterally across the silo wall and roll them right at the silo wall. The PistenBully was also able to roll directly to the wall by reversing along the silo wall. However, this mainly necessitates the driver turning around and paying very close attention whilst driving slowly.

3.2.6 Other observations

The PistenBully can spread the feed evenly whilst driving forwards or backwards. “Entrenched” vehicles were “freed” quickly and easily. The silo was filled safely and easily with feed.

3.3. Silage

3.3.1 DM content

The 27 silage samples had a mean 20.4 % DM with a spread of 13.9 % DM to 27.1 % DM (Table 4). Thus, the tested silage was definitively 1.4 % DM above the mean (19.0 % DM, spread 14.3-25.7 % DM) of the completely analysed tipper samples (n=19) and absolutely 2.6 % DM above the mean DM content (17.8 %, spread 12.9-29.9 % DM) of all tipper samples (n=220). The increase is mainly due to the build up of fermentation liquid, which occurs in harvested crops of less than 30 % DM.

The mean DM content at first sampling (silo end) was 22.5 % DM, 20.2 % DM in the middle of the silo and 18.6 % DM at final sampling (Table 4). As the first sampling corresponds to the last ensilaged crop, this reveals that the silo was filled in a wedge shape from the dumping edge (Figures 8 and 9). The DM content tended to increase as the fill level increased (Table 1).

Slightly lower DM content of a mean 18.8 % DM was detected in edge section 1, i.e. right next to the silo wall, than the 20.9 % in edge section 2 (1 metre from the wall) and the 21.4 % DM in the middle of the silo (Table 5). Some rainwater probably seeped into this area, although the silage was very carefully covered with tarpaulin and undersheet. The fact that the tarpaulins were butted up against the wall certainly contributed to this. It was not possible to pull the tarpaulins over the silo wall because of the type of construction.

The DM content in the silo reduced by a absolutely 6.2 % DM from a mean 23.4 % DM at the top to 20.6 % DM to a mean 17.2 % DM at the bottom (Table 6). This effect was also observed on the individual dates and positions and is because more wilted green rye was unloaded as filling progressed. Additionally, fermentation liquid had formed in the damp crop, which trickled from the top downward.

The test results showed that the PistenBully had no effect on the DM content of the silage as expected.

3.3.2 Density

According to RICHTER (2009), grass-like silage with around 17.5 % DM should have a density of at least 150 kg DM/m³ and 850 kg FM/m³ (Figure 11).

The green rye unloaded by the PistenBully had a lower compaction of an arithmetic mean of 112.2 kg DM/m³ and 850 kg FM/m³ (Table 5). It was around 25 % beneath the target of 150 kg DM/m³. The spread within the silo was high with 88 to 145 kg DM/m³ (Figure 11). Effects were noted between the layers and positions (Tables 6 and 7). However, the mean density hardly changed from the first sampling (date 1) with 111.8 kg DM/m³ to date 2 with 107.9 kg DM/m³ to date 3 with 117.0 kg DM/m³. Thus, the harvested crop was unloaded and compacted very evenly from the back to the front in the silo. The DM content differed on the individual dates, but the mean compaction related to the fresh mass weight increased from date 1 with 503 kg FM/m³ to date 2 with 576 kg FM/m³ to date 3 with 659 kg FM/m³.

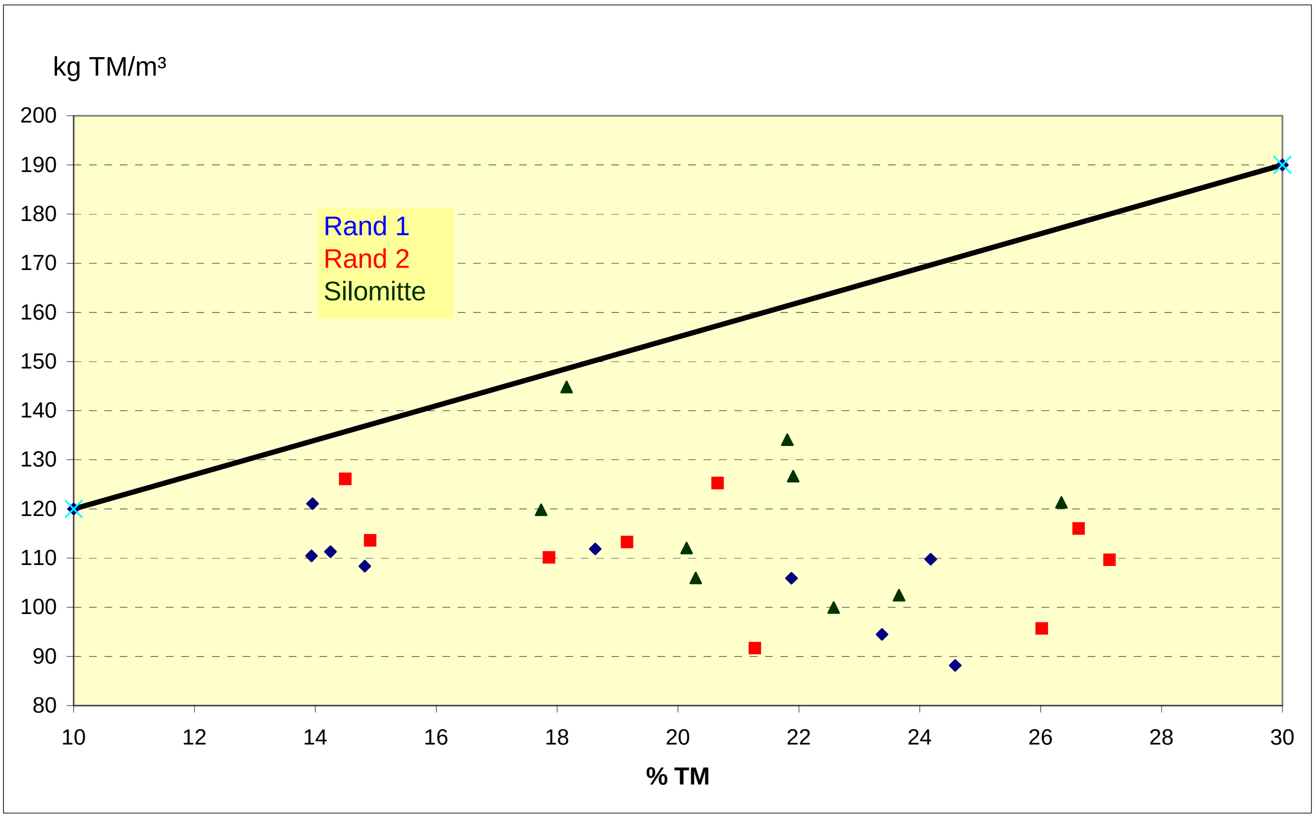

Figure 11: The target range of well compacted silage depending on the DM content and actually measured values of green rye in different sections of the silo.

The less well-compacted edge sections take a smaller proportion than the better compacted silo middle. Therefore, presentation of the arithmetic mean compaction from the measured values does not sufficiently reflect the actual ratios in the silo. Consequently, a trend line was laid through the measured values of the edge sections (R^2= 0.98 edge 1; R^2=0.98 edge 2; silo middle R^2=0.99) (Figure 12) and further compaction was calculated for each layer of 50 cm (Figure 13).

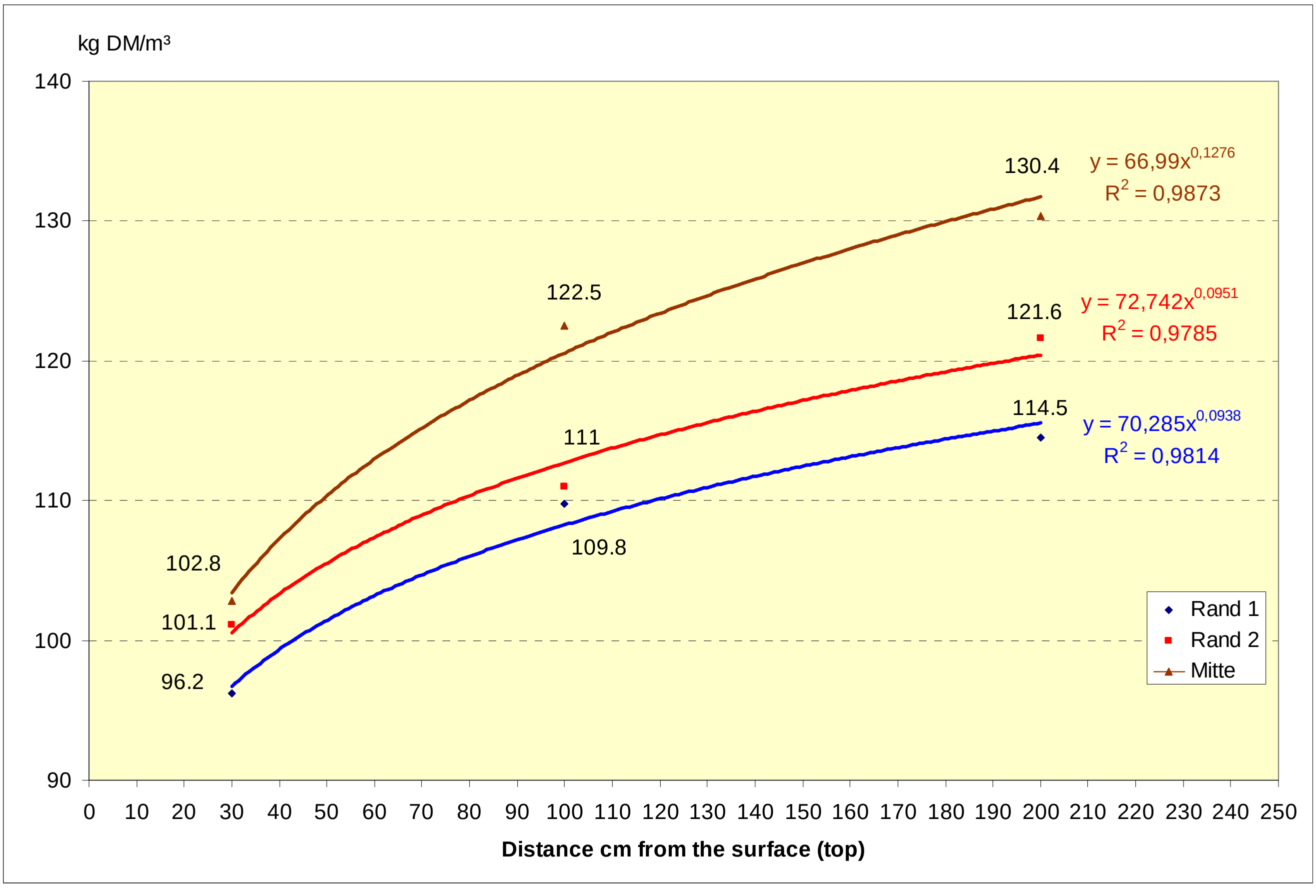

Figure 12: Density (kg DM/m³) depending on position (edge, middle) and location (distance in cm from the silo top surface). The measured values (points) and trend lines are shown (R^2 = coefficient of determination).

A weighted mean of 119.2 kg DM/m³ results from the volume shares of the individual layers and sections. This mean is around 20.5 % beneath the target of 150 kg DM/m³.

0.5m	1 m	27 m	1 m	0.5m	
91.6	95.2	97.7	95.2	91.6	50 cm
105.6	108.3	116.5	108.3	105.6	50 cm
111.2	114.0	124.8	114.0	111.2	50 cm
113.5	119.4	128.7	119.4	113.5	50 cm
116.3	122.3	133.0	122.3	116.3	50 cm

Figure 13: The compaction (kg DM/m³) of the individual layers (each 50 cm) and sections (width of the layers) calculated from the measured value and trend lines in the silo. The mean silo length with full fill level of 2.5 metres was calculated as 36 metres.

The evaluation and grading of the silage was effected according to Table 9. Consequently, the less well (75-100 kg DM/m³) compacted sections are shown in red in Figure 13, whilst the moderately (100-120 kg DM/m³) compacted sections are light blue and the well compacted (120-150 kg DM/m³) are light green. Thus, 20 % of the green rye silage is graded as less well, 25 % as moderately and 55 % as well compacted in the test. The sampling did not reveal any very well compacted (over 150 kg DM/m³) or very poorly compacted (less than 75 kg DM/m³) silage.

Table 4: Evaluating the compaction (kg DM/m³) in comparison to the minimum compaction of 150 kg DM/m³.

kg DM/m³	Target (150 kg DM/m³) achieved	Compaction grading	
< 75	< 50 %	Bad	- -
75 -100	50 - 66,6 %	Less good	-
100 - 120	66,6 - 80 %	Moderate	±
120 - 150	80 - 100 %	Good	+
> 150	>100 %	Very good	+ +

The lowest compaction was measured at the silo wall (edge 1) with a mean 106.8 kg DM/m³ (Table 6). The spread there ranged from 88.2 (-41 %) to 121.1 kg DM/m³ (-19 %). The compaction was around 29 % lower than the target of 150 kg DM/m³. The mean density around a metre from the silo wall (edge 2) was 111.3 kg DM/m³ and, thus, was around 26 % lower than the target. The spread in the "edge 2" section ranged from 91.7 kg DM/m³ (-39 %) to 126.1 kg DM/m³ (-16 %). The best mean compaction of 118.6 kg DM/m³ was measured in the middle of the silo. The mean compaction there was around 21 % lower than the target of 150 kg DM/m³. The spread in the middle of the silo section ranged from 99.9 kg DM/m³ (-33 %) to 144.8 kg DM/m³ (-3.5 %). Thus, the predefined target was almost achieved in the bottom section of the middle of the silo.

The compaction increased from the top downward in the silo from 100 kg DM/m³ to 114.5 kg DM/m³ with a mean 122.2 kg DM/m³ (Table 7). Accordingly, the uppermost layer was precisely one third (33.3 %), layer 2 (100 cm from the top) around 24 % and the bottom layer (50 cm from the bottom) around 18.5 % below the target of 150 kg DM/m³. It should be noted that almost 90 % of the target value was achieved in the middle of the silo on 7th August in the second layer (100 cm from the top) with 134.1 kg DM/m³.

3.3.3 Temperatures

Silage in the silo should be less than 20 °C from a depth of more than 15 cm. Sunshine can also cause higher values directly beneath the tarpaulin and at access areas.

Measurements were always taken at a fresh silo face for these investigations. This means that at least one layer of 30 to 50 cm silage was removed directly before sampling and temperature measurement. Consequently, the measured temperatures could not have been influenced by sunshine at the access.

A temperature of 26.2 °C was achieved in the middle of all measurements, which indicates reheating (Table 5). The spread of the individual values ranges from 19.0 to 38.4 °C, whilst the maximum temperature in the uppermost layer was measured right at the edge and just beneath the silo face (15 cm measured depth). The lowest compaction was also measured in this area at 88 kg DM/m³ (Table 5). Consequently, there is a connection between compaction and temperature development. From the total of 81 measurements (which were repeated 3 times for each value), only 6 measurements (7.4 %) were lower than the target of 20 °C. Temperatures in the lightly heated range between 20 and 25 °C were detected in around a third of the measured values. In total, almost 40 % of all the silage remained below 25 °C. A good 60 % of the silage measured over 25 °C, of which 35 measured values (43.2 %) were between 25 and 30 °C ("heated") and 14 measured values (17.3 %) were over 30 °C. Thus, every sixth measurement showed a clearly heated section.

Where increased temperatures were detected at low depths (15 cm beneath the fresh silo face), the silage there was also heated to a measured depth of 150 cm. However, there was a temperature drop overall from the top (15 cm) to the bottom (150 cm). Consequently, the temperature increase is caused by the air penetrating the silage from the silo face.

The connection between compaction and temperature increase is also clear in the temperature drop from the top with a mean 29.7 °C (100 kg DM/m³) to the middle 26.0 °C (114.5 kg DM/m³) to the bottom with a mean 22.7 °C (122.2 kg DM/m³) (Table 6). In contrast, the positions (edge 1, edge 2, silo middle) and sampling date only had a slight effect on heating (Tables 5 and 6).

3.3.4 Sensor technology

Butyric acid, sometimes in the form of a faecal-like odour, was always detectable during sampling of the silage. This finding is supported by the fermentation acid analysis (see chapter 3.2.6 Fermentation quality), which showed a high butyric acid content.

Mould only developed in places and over small areas up to a maximum layer thickness of 10 cm.

The green rye silage was mainly light yellow in the bottom layers, which indicates a liquid blockage caused by displacement of fermentation liquid from the top downward and is confirmed by the decreasing DM content (Table 6).

Table 5: Test results, arranged by the sampling date.

Date	Position	Location	DMc %	Density kg FM/m²	Density kg DM/m³	Temp.°C at measured depth 15 cm	50 cm	150 cm
07.08.2009	Edge 1	30 cm from the top	23.4	404.2	94.5	28.9	27.4	26.9
	Edge 1	100 cm from the top	24.2	454.0	109.8	26.8	26.4	25.9
	Edge 1	50 cm from the bottom	18.6	600.6	111.9	24.6	24.3	23.9
	Edge 2	30 cm from the top	21.3	431.0	91.7	31.9	31.8	32.0
	Edge 2	100 cm from the top	27.1	404.1	109.7	28.4	27.9	27.0
	Edge 2	50 cm from the bottom	20.7	606.4	125.3	25.8	25.3	24.6
	Silo middle	30 cm from the top	23.7	433.0	102.4	28.7	29.0	29.3
	Silo middle	100 cm from the top	21.8	614.9	134.1	27.4	25.5	25.0
	Silo middle	50 cm from the bottom	21.9	578.3	126.7	26.7	23.8	23.4
Date 1	**n=9**	**Mean**	**22.5**	**503.0**	**111.8**	**27.7**	**26.8**	**26.4**
		Min	**18.6**	**404.1**	**91.7**	**24.6**	**23.8**	**23.4**
		Max	**27.1**	**614.9**	**134.1**	**31.9**	**31.8**	**32.0**
31.08.2009	Edge 1	30 cm from the top	24.6	358.7	88.2	38.4	30.0	28.1
	Edge 1	100 cm from the top	14.8	731.4	108.4	24.5	23.6	23.5
	Edge 1	50 cm from the bottom	13.9	792.5	110.4	21.3	21.4	21.6
	Edge 2	30 cm from the top	26.0	367.8	95.7	32.1	30.3	29.2
	Edge 2	100 cm from the top	19.2	591.3	113.3	26.1	25.2	25.2
	Edge 2	50 cm from the bottom	14.9	762.0	113.6	22.5	22.2	21.9
	Silo middle	30 cm from the top	22.6	442.7	99.9	31.2	32.1	32.0
	Silo middle	100 cm from the top	26.3	460.7	121.4	32.9	31.1	30.8
	Silo middle	50 cm from the bottom	17.7	675.6	119.8	27.3	24.1	24.8
Date 2	**n=9**	**Mean**	**20.0**	**575.9**	**107.9**	**28.5**	**26.7**	**26.4**
		Min	**13.9**	**358.7**	**88.2**	**21.3**	**21.4**	**21.6**
		Max	**26.3**	**792.5**	**121.4**	**38.4**	**32.1**	**32.0**
28.09.2009	Edge 1	30 cm from the top	21.9	484.2	105.9	32.1	27.6	25.8
	Edge 1	100 cm from the top	14.3	781.0	111.3	22.2	20.8	21.3
	Edge 1	50 cm from the bottom	14.0	868.0	121.1	19.0	19.0	19.4
	Edge 2	30 cm from the top	26.6	435.7	116.0	27.3	26.2	26.2
	Edge 2	100 cm from the top	17.9	616.4	110.1	23.9	22.6	22.7
	Edge 2	50 cm from the bottom	14.5	869.9	126.1	19.7	19.2	19.5
	Silo middle	30 cm from the top	20.3	522.2	106.0	28.8	29.1	29.4
	Silo middle	100 cm from the top	20.1	556.4	112.1	29.4	29.1	29.2
	Silo middle	50 cm from the bottom	18.2	797.7	144.8	23.5	22.5	23.3
Date 3	**n=9**	**Mean**	**18.6**	**659.0**	**117.0**	**25.1**	**24.0**	**24.1**
		Min	**14.0**	**435.7**	**105.9**	**19.0**	**19.0**	**19.4**
		Max	**26.6**	**869.9**	**144.8**	**32.1**	**29.1**	**29.4**
Total	**n=27**	**Mean**	**20.4**	**579.3**	**112.2**	**27.1**	**25.8**	**25.6**
		Min	**13.9**	**358.7**	**88.2**	**19.0**	**19.0**	**19.4**
		Max	**27.1**	**869.9**	**144.8**	**38.4**	**32.1**	**32.0**

Table 6: Test results, arranged by sampling positions

Date	Position	Location	DMc %	Density kg FM/m²	Density kg DM/m³	Temp.°C at measured depth 15 cm	50 cm	150 cm
07.08.09	Edge 1	30 cm from the top	23.4	404.2	94.5	28.9	27.4	26.9
	Edge 1	100 cm from the top	24.6	446.5	109.8	26.8	26.4	25.9
	Edge 1	50 cm from the bottom	21.9	511.5	111.9	24.6	24.3	23.9
31.08.09	Edge 1	30 cm from the top	24.2	364.7	88.2	38.4	30.0	28.1
	Edge 1	100 cm from the top	14.8	731.4	108.4	24.5	23.6	23.5
	Edge 1	50 cm from the bottom	14.3	774.9	110.4	21.3	21.4	21.6
28.09.09	Edge 1	30 cm from the top	18.6	568.6	105.9	32.1	27.6	25.8
	Edge 1	100 cm from the top	13.9	798.7	111.3	22.2	20.8	21.3
	Edge 1	50 cm from the bottom	14.0	868.0	121.1	19.0	19.0	19.4
n=9	**Edge 1**	**Mean**	**18.8**	**607.6**	**106.8**	**26.4**	**24.5**	**24.1**
		Min	**13.9**	**364.7**	**88.2**	**19.0**	**19.0**	**19.4**
		Max	**24.6**	**868.0**	**121.1**	**38.4**	**30.0**	**28.1**
07.08.09	Edge 2	30 cm from the top	21.3	431.0	91.7	31.9	31.8	32.0
	Edge 2	100 cm from the top	26.0	421.5	109.7	28.4	27.9	27.0
	Edge 2	50 cm from the bottom	26.6	470.4	125.3	25.8	25.3	24.6
31.08.09	Edge 2	30 cm from the top	27.1	352.6	95.7	32.1	30.3	29.2
	Edge 2	100 cm from the top	19.2	591.3	113.3	26.1	25.2	25.2
	Edge 2	50 cm from the bottom	17.9	635.8	113.6	22.5	22.2	21.9
28.09.09	Edge 2	30 cm from the top	20.7	561.7	116.0	27.3	26.2	26.2
	Edge 2	100 cm from the top	14.9	738.7	110.1	23.9	22.6	22.7
	Edge 2	50 cm from the bottom	14.5	869.9	126.1	19.7	19.2	19.5
n=9	**Edge 2**	**Mean**	**20.9**	**563.7**	**111.3**	**26.4**	**25.6**	**25.4**
		Min	**14.5**	**352.6**	**91.7**	**19.7**	**19.2**	**19.5**
		Max	**27.1**	**869.9**	**126.1**	**32.1**	**31.8**	**32.0**
07.08.09	Silo middle	30 cm from the top	23.7	433.0	102.4	28.7	29.0	29.3
	Silo middle	100 cm from the top	22.6	594.0	134.1	27.4	25.5	25.0
	Silo middle	50 cm from the bottom	20.3	624.3	126.7	26.7	23.8	23.4
31.08.09	Silo middle	30 cm from the top	21.8	458.3	99.9	31.2	32.1	32.0
	Silo middle	100 cm from the top	26.3	460.7	121.4	32.9	31.1	30.8
	Silo middle	50 cm from the bottom	20.1	594.9	119.8	27.3	24.1	24.8
28.09.09	Silo middle	30 cm from the top	21.9	483.7	106.0	28.8	29.1	29.4
	Silo middle	100 cm from the top	17.7	631.9	112.1	29.4	29.1	29.2
	Silo middle	50 cm from the bottom	18.2	797.7	144.8	23.5	22.5	23.3
n=9	**Silo middle**	**Mean**	**21.4**	**564.3**	**118.6**	**28.4**	**27.4**	**27.5**
		Min	**17.7**	**433.0**	**99.9**	**23.5**	**22.5**	**23.3**
		Max	**26.3**	**797.7**	**144.8**	**32.9**	**32.1**	**32.0**

Table 7: Test results, arranged by the sampling layers

Date	Position	Location	DMc %	Density kg FM/m²	Density kg TM/m³	Temp.°C at measured depth 15 cm	Temp.°C at measured depth 50 cm	Temp.°C at measured depth 150 cm
07.08.09	Edge 1	30 cm from the top	23.4	404.2	94.5	28.9	27.4	26.9
	Edge 2	30 cm from the top	21.3	431.0	91.7	31.9	31.8	32.0
	Silo middle	30 cm from the top	23.7	433.0	102.4	28.7	29.0	29.3
31.08.09	Edge 1	30 cm from the top	24.6	358.7	88.2	38.4	30.0	28.1
	Edge 2	30 cm from the top	26.0	367.8	95.7	32.1	30.3	29.2
	Silo middle	30 cm from the top	22.6	442.7	99.9	31.2	32.1	32.0
28.09.09	Edge 1	30 cm from the top	21.9	484.2	105.9	32.1	27.6	25.8
	Edge 2	30 cm from the top	26.6	435.7	116.0	27.3	26.2	26.2
	Silo middle	30 cm from the top	20.3	522.2	106.0	28.8	29.1	29.4
n=9	**Mean**	**30 cm from the top**	**23.4**	**431.1**	**100.0**	**31.1**	**29.3**	**28.8**
	Min		**20.3**	**358.7**	**88.2**	**27.3**	**26.2**	**25.8**
	Max		**26.6**	**522.2**	**116.0**	**38.4**	**32.1**	**32.0**
07.08.09	Edge 1	100 cm from the top	24.2	454.0	109.8	26.8	26.4	25.9
	Edge 2	100 cm from the top	27.1	404.1	109.7	28.4	27.9	27.0
	Silo middle	100 cm from the top	21.8	614.9	134.1	27.4	25.5	25.0
31.08.09	Edge 1	100 cm from the top	14.8	731.4	108.4	24.5	23.6	23.5
	Edge 2	100 cm from the top	19.2	591.3	113.3	26.1	25.2	25.2
	Silo middle	100 cm from the top	26.3	460.7	121.4	32.9	31.1	30.8
28.09.09	Edge 1	100 cm from the top	14.3	781.0	111.3	22.2	20.8	21.3
	Edge 2	100 cm from the top	17.9	616.4	110.1	23.9	22.6	22.7
	Silo middle	100 cm from the top	20.1	556.4	112.1	29.4	29.1	29.2
n=9	**Mean**	**100 cm from the top**	**20.6**	**578.9**	**114.5**	**26.8**	**25.8**	**25.6**
	Min		**14.3**	**404.1**	**108.4**	**22.2**	**20.8**	**21.3**
	Max		**27.1**	**781.0**	**134.1**	**32.9**	**31.1**	**30.8**
07.08.09	Rand 1	50 cm from the bottom	18.6	600.6	111.9	24.6	24.3	23.9
	Rand 2	50 cm from the bottom	20.7	606.4	125.3	25.8	25.3	24.6
	Silomitte	50 cm from the bottom	21.9	578.3	126.7	26.7	23.8	23.4
31.08.09	Rand 1	50 cm from the bottom	13.9	792.5	110.4	21.3	21.4	21.6
	Rand 2	50 cm from the bottom	14.9	762.0	113.6	22.5	22.2	21.9
	Silomitte	50 cm from the bottom	17.7	675.6	119.8	27.3	24.1	24.8
28.09.09	Rand 1	50 cm from the bottom	14.0	868.0	121.1	19.0	19.0	19.4
	Rand 2	50 cm from the bottom	14.5	869.9	126.1	19.7	19.2	19.5
	Silomitte	50 cm from the bottom	18.2	797.7	144.8	23.5	22.5	23.3
n=9	**Mean**	**50 cm from the bottom**	**17.2**	**727.9**	**122.2**	**23.4**	**22.4**	**22.5**
	Min		**13.9**	**578.3**	**110.4**	**19.0**	**19.0**	**19.4**
	Max		**21.9**	**869.9**	**144.8**	**27.3**	**25.3**	**24.8**

3.3.5. Feed value

Use of the PistenBully had no negative effects on the feed value of the silage (Table 8). The fluctuations in the material predominantly correspond to those in the primary material (Table 1). However, the level of crude protein decreased from the first sampling date from 11.0 % in DMc to 8.4 to 7.6 % in DMc at the final sampling. On the one hand, this reflects the different primary material (Table 1), but also the increasing protein breakdown with the longer storage period. Protein breakdown is detectable in the high ammonia content. The proportion of NH_3-nitrogen in the total nitrogen should constitute less than 10 %. In this test the proportion increased from 18.2 % (1st date) to 22.7 % to 25.3 % (3rd date). The mean proportion was 22.1 %; the maximum value was 47.6 %!

The PistenBully had no discernible effect on the content of crude fibre, crude ash and energy. They fluctuated to the same extent as in the primary material. Overall, the crude fibre content of a mean 41.3 % in DMc was very high (33.1 to 50.7 % in DMc) and, accordingly, the energy content was very low with a mean 5.1 MJ NEL/kg DM (4.5 to 5.6 MJ NEL/kg DM). The mean crude ash contamination of 7.1 % in DMc was insignificant.

3.3.6 Fermentation quality

The green rye silage was badly fermented and had high pH values. It was always above the so-called 'critical' pH value (Figure 14). However, the unsatisfactory fermentation is predominantly due to the low sugar content in the damp harvested crop (Table 1). The residual sugar content indicates whether there was sufficient fermentation substrate for the fermentation process. If the content is close to zero, then the fermentation substrate for fermentation is limiting as in the test with green rye. The mean residual sugar content in this test was 0.1 % in DMc. Well-fermented silage has a content of more than 2-3 % in DMc. The residual sugar content decreased from date 1 with a mean 0.35 % in DMc to date 2 with a mean 0.04 % in DMc. The effects of layering or the positions (edge sections, silo middle) are insignificant. The scarce amount of substrate initially led to low lactic acid fermentation. However, the lactic acid that formed was changed into acetic, propionic and, above all, butyric acid as fermentation progressed. Consequently, the lactic acid content fell from a mean 2.2 % in DMc at first sampling to 0.4 % and a mean 0.2 % at final sampling. At the same time, the butyric acid content increased from a mean 1.2 % in DMc to 1.3 % in DMc to 1.45 % in DMc. A maximum of 0.3 % butyric acid in DMc is tolerated as a limit value for good silage. The butyric acid formation is not due to use of the PistenBully.

The unwelcome clostridia activity is linked to anaerobic conditions. Therefore, the levels of ammonia and butyric acid increased from the edge to the silo middle. Acetic acid was found at first sampling and predominantly in the upper layers. Thus, the delayed covering with tarpaulin had a negative effect.

The ethanol content was very low at a mean 0.55 % in DMc. It was not affected by the use of the PistenBully.

Following page:
Table 8: Feed value and fermentation quality in the green rye silage, arranged by sampling date.

Date	Position	Location	DMC	CP	CF	CA	Energy MJ/kg DM		pH	$NH_3N:N_t$	Lactic	Acetic	Butyric	Propion.	Ethanol	Sugar
			%	% in DMc			ME	NEL		%	% i. DMc					
07.08.09	Edge 1	30 cm from the top	23.4	10.1	39.9	8.4	8.8	5.1	5.5	23.1	0.3	4.4	1.6	0.3	0.6	0.2
	Edge 1	100 cm from the top	24.2	11.7	39.0	7.7	9.4	5.5	4.9	13.4	3.7	4.2	0.6	0.3	1.1	0.3
	Edge 1	50 cm from bottom	18.6	11.7	39.1	8.6	9.0	5.3	5.4	22.0	1.0	2.4	2.7	0.9	0.3	0.2
	Edge 2	30 cm from the top	21.3	7.1	42.6	7.9	8.0	4.5	5.5	40.6	0.0	6.6	3.5	0.7	0.5	0.2
	Edge 2	100 cm from the top	27.1	11.5	37.4	8,0	9.5	5.6	4.9	11.5	4.2	5.5	0.0	0.1	0.6	1.7
	Edge 2	50 cm from bottom	20.7	13.0	37.3	8.9	9.4	5.5	5.5	15.8	1.4	4.0	1.9	0.3	1.0	0.2
	Silo middle	30 cm from the top	23.7	11.0	38.1	8.3	9.0	5.3	5.0	15.2	2.3	8.0	0.4	0.1	0.7	0.1
	Silo middle	100 cm from the top	21.8	13.4	33.1	8.5	9.5	5.6	5.2	12.7	2.2	10.2	0.0	0.2	1.0	0.2
	Silo middle	50 cm from bottom	21.9	9.6	41.4	7.7	8.7	5.0	4.7	9.6	5.2	6.0	0.1	0.4	1.3	0.0
07.08.09	**n=9**	**Mean**	**22.5**	**11.0**	**38.6**	**8.2**	**9.0**	**5.3**	**5,2**	**18,2**	**2.2**	**5.7**	**1.2**	**0.4**	**0.8**	**0.3**
		Min	**18.6**	**7.1**	**33.1**	**7.7**	**8.0**	**4.5**	**4,7**	**9,6**	**0.0**	**2.4**	**0.0**	**0.1**	**0.3**	**0.0**
		Max	**27.1**	**13.4**	**42.6**	**8.9**	**9.5**	**5.6**	**5,5**	**40,6**	**5.2**	**10.2**	**3.5**	**0.9**	**1.3**	**1.7**
31.08.09	Edge 1	30 cm from the top	24.6	9.8	40.6	7.0	8.8	5.1	5.3	24.6	0.2	8.3	0.3	0.4	0.5	0.1
	Edge 1	100 cm from the top	14.8	7.2	44.3	6.1	8.3	4.8	4.7	9.2	0.0	1.1	0.4	0.5	0.0	0.0
	Edge 1	50 cm from bottom	13.9	6.4	45.8	3.9	8.1	4.6	4.4	8.4	0.0	1.4	0.1	0.6	0.0	0.0
	Edge 2	30 cm from the top	26.0	9.7	40.5	7.7	8.8	5.1	5.0	19.6	1.8	3.7	0.4	0.3	0.5	0.1
	Edge 2	100 cm from the top	19.2	9.8	37.1	8.7	8.7	5.1	5.4	28.2	0.1	3.9	2.8	1.4	0.5	0.0
	Edge 2	50 cm from bottom	14.9	6.0	46.5	4.9	8.1	4.6	4.7	16.7	0.0	2.4	0.7	1.0	0.1	0.0
	Silo middle	30 cm from the top	22.6	8.1	43.7	7.2	8.5	4.9	5.5	35.4	0.0	5.4	3.2	0.7	0.8	0.0
	Silo middle	100 cm from the top	26.3	11.2	41.1	8.1	9.5	5.6	5.1	19.1	1.7	5.1	0.4	0.4	0.6	0.1
	Silo middle	50 cm from bottom	17.7	7.5	43.2	8.2	8.4	4.8	5.5	43.5	0.0	6.4	3.5	1.8	0.7	0.1
31.08.09	**n=9**	**Mean**	**20.0**	**8.4**	**42.5**	**6.9**	**8.6**	**5.0**	**5.1**	**22.7**	**0.4**	**4.2**	**1.3**	**0.8**	**0.4**	**0.0**
		Min	**13.9**	**6.0**	**37.1**	**3.9**	**8.1**	**4.6**	**4.4**	**8.4**	**0.0**	**1.1**	**0.1**	**0.3**	**0.0**	**0.0**
		Max	**26.3**	**11.2**	**46.5**	**8.7**	**9.5**	**5.6**	**5.5**	**43.5**	**1.8**	**8.3**	**3.5**	**1.8**	**0.8**	**0.1**
28.09.09	Edge 1	30 cm from the top	21.9	9.5	40.4	6.6	8.9	5.1	5.2	19.0	0.5	4.0	1.1	0.7	0.3	0.6
	Edge 1	100 cm from the top	14.3	5.2	50.7	2.0	8.4	4.8	4.9	4.6	0.0	0.1	0.2	0.2	0.1	0.0
	Edge 1	50 cm from bottom	14.0	7.5	45.9	5.7	9.1	5.3	4.5	4.2	0.3	0.6	0.1	0.1	0.1	0.0
	Edge 2	30 cm from the top	26.6	10.9	38.9	7.5	9.0	5.2	5.1	15.6	0.9	4.7	0.2	0.5	0.7	0.2
	Edge 2	100 cm from the top	17.9	6.0	45.3	5.7	8.4	4.8	5.4	39.9	0.0	2.9	2.1	1.3	0.4	0.1
	Edge 2	50 cm from bottom	14.5	5.5	45.4	2.8	8.8	5.1	4.5	11.4	0.0	1.4	0.2	1.9	0.1	0.0
	Silo middle	30 cm from the top	20.3	7.2	39.4	8.8	8.2	4.7	5.6	47.6	0.0	4.6	3.4	1.2	0.9	0.1
	Silo middle	100 cm from the top	20.1	8.5	38.5	8.9	8.7	5.1	5.8	44.2	0.0	3.7	3.8	0.5	0.8	0.2
	Silo middle	50 cm from bottom	18.2	7.8	39.1	8.4	8.7	5.0	5.2	40.7	0.0	5.6	2.1	2.2	0.5	0.2
28.09.09	**n=9**	**Mean**	**18.6**	**7.6**	**42.6**	**6.3**	**8.7**	**5.0**	**5.1**	**25.3**	**0.2**	**3.0**	**1.5**	**1.0**	**0.4**	**0.2**
		Min	**14.0**	**5.2**	**38.5**	**2.0**	**8.2**	**4.7**	**4.5**	**4.2**	**0.0**	**0.1**	**0.1**	**0.1**	**0.1**	**0.0**
		Max	**26.6**	**10.9**	**50.7**	**8.9**	**9.1**	**5.3**	**5.8**	**47.6**	**0.9**	**5.6**	**3.8**	**2.2**	**0.9**	**0.6**

Table 9: Feed value and fermentation quality of the green silage, means values of all samples

		DMC	CP	CF	CA	Energy MJ/kg DM		pH	$NH_3N:N_t$	Lactic	Acetic	Butyric	Propion.	Ethanol	Sugar
		%	% in DMc			ME	NEL		%	% in DMc					
n=27	Mean	20.4	9.0	41.3	7.1	8.8	5.1	5.1	22.1	1.0	4.3	1.3	0.7	0.5	0.2
	Min	13.9	5.2	33.1	2.0	8.0	4.5	4.4	4.2	0.0	0.1	0.0	0.1	0.0	0.0
	Max	27.1	13.4	50.7	8.9	9.5	5.6	5.8	47.6	5.2	10.2	3.8	2.2	1.3	1.7

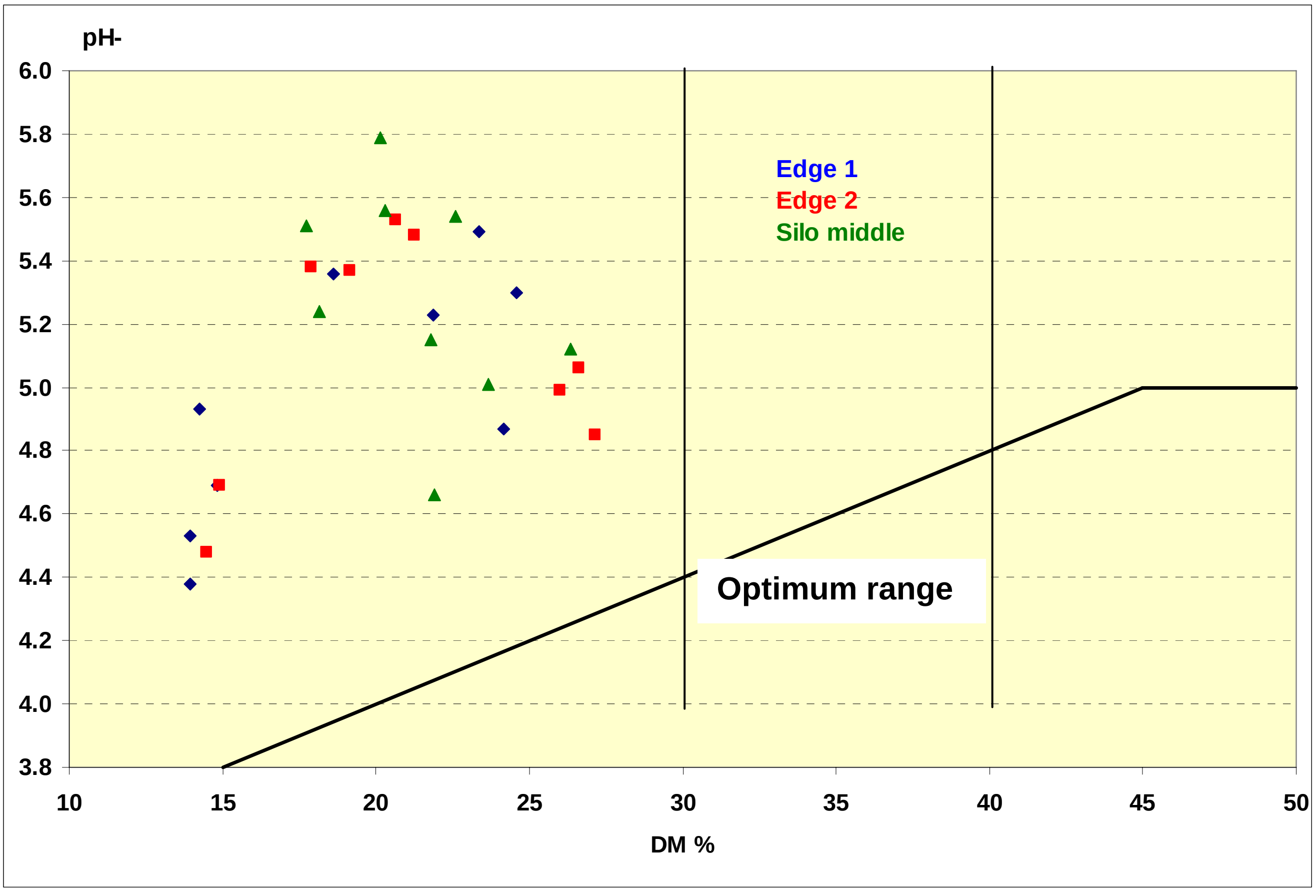

Figure 14: Grading the fermentation quality of the silage by DM content and pH value. The ideal is silage that is beneath the "critical pH value" (black line) and between 30 and 40 % DM.

4. Evaluating the results

4.1 Unloading

Almost 116 tonnes of fresh mass per hour were delivered on the first day. The harvested crop was high in crude fibre, but was not unwieldy due to the cut length of around 25 mm (theoretical cut length) and the mean DM content of 17.6 %. The PistenBully performed well with spreading the loads in the stage up to 230 t FM/h, when the harvested crop was loaded over the dumping edge at the start and, accordingly, spreading effort was limited. During the later course of the first day, the PistenBully spread the feed easily along a length of up to 50 metres. In stages with a high output, however, there was little time to roll the feed. The results were unfavourable when a tipped load was pushed head on. This mainly led to skidding, especially when concrete or asphalt was beneath the drive chains. In terms of power and time expenditure, it was better to "cut" the load laterally and, thus, to reduce it.

A mean of 78 t FM per hour were delivered on the second day. The PistenBully performed well in terms of both spreading and rolling. The feed was sufficiently compacted to allow full tippers to drive across the silo. The uppermost layer was scattered in the silo in the event of fast turning movements or fast bends; otherwise a very even and smooth surface was produced. In total, 2,150 tonnes of fresh mass were unloaded in around 2,700 m³. The achieved **compaction** of almost 800 kg FM/m³ and 140 kg DM/m³ was almost in the target range of 860 kg FM/m³ and 150 kg DM/m³.

There were no **technical problems** during unloading. Neither the tracks, engine nor cooler became dirty or blocked. The PistenBully was very agile and was able to spread the feed well up to the side walls and into the corners.

It was possible to drive very safely along the wall with the blade, thanks to the distance rolls on the blade. However, when rolling, a distance of at least 40 to 50 cm between wall and vehicle remained even when the **blade** was retracted. In future, it would be a good idea to construct a blade that did not exceed the track width when retracted. This disadvantage was neutralised as the silo filled up, because the blade was skewed and then pushed across the silo wall laterally. Therefore, it was possible to roll directly along the silo from a fill height of around 2 metres.

4.2 Silage

Higher **DM levels** with a mean 20.4 % DM were found in the tested silage than in the initial unloading (mean 17.8 %). On the one hand, this is due to the fermentation liquid outflow, which occurs in silage with less than 30 % DM and, on the other, to the fact that the samples were taken at least 50 cm above the silo floor, overlooking damper sections in the lowest level of the silo. The displacement of the moisture from the top (23.4 % DM) downward (17.2 % DM) is clearly noticeable in the tested samples and it should be noted that more heavily wilted harvested crop was unloaded in the uppermost layers.

Overall, the PistenBully had no effect on the DM content of the silage, even if the DM content increased from the edge (18.8 % DM) to the silo middle (21.4 % DM). These differences are mainly due to the heterogeneity of the harvested crop (spread of 12.9-29.9 % DM at unloading). The DM content right at the edge may have been slightly affected by rainwater penetration.

The PistenBully did affect silage **compaction** in the silo. Around 119 kg DM/m³ was achieved in the weighed mean of all samples. Thus, the green rye silage was an average 20.5 % beneath the target of 150 kg DM/m³. The gap to the desired compaction decreased from -29 % right by the edge to 26 % (one metre from the wall) to the silo middle (-21 %), but overall the compaction was not ideal. The evaluation from Table 9 shows that only around 55 % of all silage was characterised as well compacted, a further 25 % as moderately and 20 % of the silo as less well.

Consequently, the question arises of how overall compaction could be improved. The high output on the first day needs to be addressed first. The PistenBully performed well and spread a mean 116 tonnes of fresh mass per hour but, despite this, there was insufficient time to perform the additional rolling processes in addition to spreading. At peak times, a tipper was unloaded around every 3 minutes and around every 5 minutes in the middle of the day. A load was delivered around every 7 to 8 minutes on the following day. This meant the PistenBully had more time for the rolling work. As a result, the question arises of whether an additional rolling vehicle ought to be used for high outputs of over 100 tonnes of fresh mass per hour, or when two choppers are working in parallel. At the same time, more ballast on the PistenBully would be beneficial and the design permits this. As the blade was wider than the tracks in the test and, therefore, could not be rolled parallel to the wall, altering the blade could enable closer rolling to the wall and, thus, the less compacted edge section could be smaller.

All tippers were weighed on delivery and the volume of the filled silo was taken from the fill level (Figures 8 and 9) of the individual sections (5 metres each). A mean compaction of 140 kg DM/m³ resulted from the overall tonnage of 2,151 tonnes of fresh mass and the overall volume of 2,700 m³ and the individual DM content of each tipper load (mean value 17.6 % DM). This density was only achieved in one instance (silo middle, lower layer) when sampling the grass silage. Several things may be responsible for this. It should be noted that sampling with boring stock only produces a relatively small (45 mm x 450 mm) and, above all, point-like sample. Small quantitative displacements in the boring stock can clearly affect calculations on a cubic metre of silage. Three borings were used per measuring point in an attempt to counter this. However, it remains possible that the type of sampling has affected the overall result. Unfortunately, there is no precise evidence on the accuracy of this type of sampling. Nevertheless, starting with a fluctuation range of 5 to 10 %, and this tends to vary downward for grass silage due to unavoidable material deviations in the pipe (deviations in the feed), the calculated densities are within the range of the calculated overall compaction. DM loss may be a further reason for the variations, which occur due to the fermentation liquid and the fermentation process. Fermentation liquid occurs up to a DM content of 30 %. The unavoidable fermentation losses amount to at least 7.5 % in ideal conditions and may also be higher than 10 % in practice.

If the effects of the PistenBully on the different zones in the silo are taken into account, however, then the comparison of the densities with one another is significant in any case. Accordingly, the edge sections are less well compacted than the samples from the silo middle.

The increase in compaction from the top downward is observed in every silo in a similar manner. The reasons for this are, on the one hand, the more frequent traversing of the lower layers and the increase in dry mass content of the parts unloaded later. This can be countered by extended rerolling (up to an hour after the last tipper). The PistenBully in this test had around half an hour for this each day.

There were only isolated incidents of visible **mould formation** and **decay** in the grass silage in the section right by the edge in the uppermost layer. No mould was detected in the deeper layers. Thus, the silage was airtight and use of the PistenBully had no negative effect.

The **temperature** of silage should not exceed 20 °C except for sections exposed to direct sunlight (silo face) and directly beneath the heated tarpaulin (in summer). The silage in this test was a mean 26.2 °C. There is a connection between the achieved density and the measured temperature. For example, the highest temperature (38.4 °C) was measured in the area of the lowest compaction (88 kg DM/m³). Temperatures of over 25 °C were detected in 60 % of all measurements (n=81). Over 90 % of all values were over 20 °C, although the green rye silage was very damp and there were areas of high butyric acid content. Dry silage tends to heat up more than damp silage because of the harder compactibility. Butyric acid also inhibits the growth of yeast. Thus, mean compaction of 119 kg DM/m³ is seen as critical with regard to reheating. The fact that the silo was not immediately covered with tarpaulin after all the rye was unloaded has certainly also had an unfavourable effect. The firm continued to unload grass silage on the silo side on the following day, where manure was also stored. Therefore, the silo was only sealed 2 days after completion of the green rye harvest. The yeast was probably able to proliferate in this time. High fungal content leads to diminished aerobic stability on removal, particularly if the removal rate is too low. The rate in summer should be at least 2.0 to 2.5 metres per week. The rate was around 2.9 metres per week in the period between the first and second sampling dates. A mean fill level of 2 metres was recorded during this period. The mean fill level was 2.5 metres in the period between the second and third sampling dates and, consequently, the rate was only around 2.1 metres per week. As a result, the low density, the delayed covering and a low rate (particularly from the second date) have all contributed to heating the silage.

Use of the PistenBully had a negative effect on the **nutritional value** of the silage. The fluctuations within the 27 samples reflect the range of the loads on unloading (Table 1) and are not due to use of the PistenBully. However, on average the silage did contain less crude protein and energy, but more crude fibre, than the harvested crop. According to this, the easy-to-digest substances and the energy content declined during storage. This decline is due to the poor fermentation quality of the green rye silage. All silage had high pH values (Figure 14) and, as a result, butyric acid and some high ammonia content. At the same time, the residual sugar content was at a very low level (almost zero). The unsatisfactory fermentation is predominantly due to the low sugar content in the damp harvested crop (Table 1). At least 8-9 % sugar in the dry substance (2-3 % in FM) is required for optimum fermentation. The harvested crop had a low mean sugar content of 4.9 % in DM due to the well advanced physiological maturation of the green rye, which lacked granulation at the time of harvesting. Thus, the amount of substrate hindered good fermentation. There was also a high resistance to acidification. The buffer capacity was 6.3 grams lactic acid per 100 g DM and, thus, the ratio of sugar and buffer capacity was 0.8. The ratio should be over 2 to 3 for good fermentation. Because of the low DM content, the fermentability coefficient was only 25.9, which also indicates poor ensilability. The scarce amount of substrate initially led to low lactic acid fermentation. However, the lactic acid that formed was changed into acetic, propionic and, above all, butyric acid as fermentation progressed. The butyric acid content increased from a mean 1.2 % in DMc to 1.3 % in DMc to 1.45 % in DMc. A maximum of 0.3 % butyric acid in DMc is tolerated as a limit value for good silage. These effects are not due to use of the PistenBully, however. The unwelcome clostridia activity is in fact linked to anaerobic conditions. Therefore, the levels of ammonia and butyric acid increased from the edge to the silo middle. Ammonia in silage indicates protein breakdown also by clostridia. This is why the level of NH_3 nitrogen in the total nitrogen should not exceed 10 %. The ammonia content in the tested silage increased from date to date. It achieved a mean 22.1 % (spread 4.2 – 47.6 %). Therefore, the crude protein content also decreased. Silage of this kind would no longer be suitable for use in dairy cattle fodder.

The unsatisfactory fermentation quality of the silage with predominantly too much butyric acid and ammonia is not due to use of the PistenBully, but rather to the poor fermentation characteristics of the harvested crop.

5. Summary

On 17th May 2009 in Pfullendorf, green rye at the growth stage “end of heading” to the “beginning of bloom” was mowed in swaths using a self-propelled chopper (Krone BIG M400). Harvesting followed on 19th and 20th May 2009 with the chaff cutter. The finely cut harvested crop was distributed and compacted in a bunker silo using a PistenBully 300. The harvesting process was documented by weighing the 220 tippers (2,151 t FM and 378 t DM), sampling all loads to determine DM content and evaluating the spreading and rolling work in the silo completely over time. The feed value and suitability for silaging of 19 samples were also tested.

After a fermentation and storage period of 2.5 months (75 days), the silage was removed for feeding in a biogas plant. The silage was sampled three times during the removal period (7th, 31st August, 28th September 2009) and tested with regard to compaction, fermentation quality and temperature. Three core samples were removed at three positions (edge 1, edge 2, middle of the silo) and layers (0.30 m, 1.00 m from the top; 0.50 m from the bottom) on each occasion and the temperature in the bore holes was measured at three depths (15 cm, 50 cm, 150 cm).

The results of unloading can be summarised as follows:

1. The harvested crop (n=220) had a mean dry mass content of 17.6 %. The completely tested samples (n=19) had 19.9 % DM, 11.9 % crude protein, 37.2 % crude fibre and 4.9 % sugar in the dry mass. The S/BC ratio was 0.8, the fermentability coefficient was 25.9. Accordingly, the green rye was well matured physiologically and hard to silage, but not unwieldy thanks to the short cut length of 25 mm.

2. A mean of almost 116 tonnes of fresh mass per hour were delivered on the first day and a mean 78 tonnes per hour on the second day. This corresponds to 18.6 and 16.3 tonnes of dry mass per hour. The peak output: 230 t FM were harvested from fields next to the site in one hour on the first day.

3. The PistenBully performed well with spreading the green rye, when the harvested crop was loaded over the dumping edge at the start and, accordingly, the distribution effort was limited. During the later course of the first day, the PistenBully spread the feed easily along a length of up to 50 metres. The feed was sufficiently compacted to allow full tippers to drive across the silo.

4. The results were unfavourable when a tipped load was pushed head on. This mainly led to skidding, especially when concrete or asphalt was beneath the drive chains. In terms of power and time expenditure, it was better to “cut” the load laterally and, thus, to reduce it.

5. The uppermost layer was scattered in the silo in the event of fast turning movements or fast bends; otherwise a very even and smooth surface was produced.

6. In total, 2,150 tonnes of fresh mass were unloaded in around 2,700 m³. The achieved compaction of almost 800 kg FM/m³ and 140 kg DM/m³ almost met the target figures of 860 kg FM/m³ and 150 kg DM/m³.

7. There were no technical problems during unloading. Neither the tracks, engine nor cooler became dirty or blocked. The PistenBully was very agile and was able to spread the feed well up to the side walls and into the corners. A distance of at least 40 to 50 cm between wall and vehicle remained when the blade was retracted. In future, it would be a good idea to construct a blade that did not exceed the track width when retracted.

8. Diesel consumption on the first day was recorded as 14.8 litres per hour and 0.13 litres per tonne of harvested crop or 1.25 litres per tonne of dry mass.

The results of silage sampling can be summarised as follows:

1. The 27 silage samples had a mean 20.4 % DM (13.9 - 27.1 %) in the dry mass, 9.0 % crude protein, 41.3 % crude fibre, 7.1 % crude ash and 5.1 MJ NEL.

2. The DM content in the silo decreased from the top downward with a mean 23.4 % DM to 20.6 % DM, to 17.2 % DM. This effect is due to the fact that more heavily wilted green rye was introduced when filling continued in the afternoon and fermentation

juice also moves downward in the silage.

3. Slightly lower DM content with a mean 18.8 % DM was detected in edge section 1, i.e. right next to the silo wall, than the 20.9 % in edge section 2 (1 metre from the wall) and the 21.4 % DM in the middle of the silo. These differences are mainly due to the heterogeneity of the harvested crop and not to use of the PistenBully.

4. The grass silage spread by the PistenBully had a mean compaction of 119.2 kg DM/m³. Thus, it was around 20.5 % beneath the target of 150 kg DM/m³.

5. The average, weighed compaction of 119.2 kg DM/m³ differed from the mean compaction of 140 kg DM/m³ recorded on unloading. Causes of this are the unavoidable DM losses through fermentation liquid (up to 30 % DM) and the fermentation process itself (at least 7.5 %). Possible variations may also be due to the point-like and small samples using sample borer, where quantitative displacements in the boring stock can clearly affect calculations.

6. There was a large range of compaction within the silo from 88.2 to 144.8 kg DM/m³ and effects were clear between the layers and positions. These effects are also due to use of the PistenBully. Around 55 % of all the grass silage was well (120 - 150 kg DM/m³), a further 25 % moderately (100 - 120 kg DM/m³) and around 20 % was less well (under 100 kg DM/m³) compacted.

7. The lowest compaction was measured at the silo wall with a mean 107 kg DM/m³. The compaction was around 29 % lower than the target of 150 kg DM/m³. The mean density around a metre from the silo wall was 111 kg DM/m³ and, thus, around 26 % beneath the target. The best mean compaction of 119 kg DM/m³ was measured in the middle of the silo. The compaction there was only around 21 % lower than the target of 150 kg DM/m³.

8. Edge effects were also noted with other techniques. The closer the rolling vehicle was able to work along the wall, the smaller these effects were. The fact that the PistenBully was not able to drive along directly and parallel to the silo wall because of the overhanging blade had a negative effect at the silo wall. The edge zone was regularly compacted though by reversing along the wall. However, this was insufficient to achieve optimum compaction right at the wall.

9. The compaction increased from the top downward in the silo from 100 kg DM/m³ to 114.5 kg DM/m³ with a mean 122 kg DM/m³. Effects of this kind are observed frequently regardless of the rolling technique.

10. Mould formation and decay only occurred in isolated incidents and right at the edge of the uppermost layer. No mould was detected in the deeper layers. Thus, use of the PistenBully had no negative effect.

11. Temperatures in the silo with a mean 26.2 °C were too high. Temperatures of over 25 °C were detected in 60 % of all measurements. Over 90 % of all values were over 20 °C, although the green rye silage was very damp and there were areas of high butyric acid content.

12. There was a connection between the achieved density and the measured temperature. For example, the highest temperature (38.4 °C) was measured in the area of the

lowest compaction (88 kg DM/m³). The fact that the silo was only covered with tarpaulin 2 days after completion of the green rye spreading has also had an unfavourable effect.

13. The delayed covering has probably led to an increase in yeast and, consequently, to lower aerobic stability. The rate in the period between the 1st and 2nd sampling dates was around 2.9 metres and around 2.1 metres per week in the period between the 2nd and 3rd dates. This indicates that the low density, the delayed covering and a low rate have contributed to heating the silage.

14. The use of the PistenBully had no negative effect on the feed value of the silage. The fluctuations within the samples reflect the range of the loads on unloading. However, the silage had less crude protein and energy, but more crude fibre on average than the harvested crop. According to this, the easy-to-digest substances and the energy content declined during storage. This decline is due to the poor fermentation quality of the green rye silage.

15. All the silage had too high pH values with a mean 5.1 and, as a result, butyric acid (mean 1.3 % in DMc) and some very high ammonia content. The unsatisfactory fermentation is predominantly due to poor silage capacity (S/BC = 0.8; FC = 25.9) due to the low sugar content in the damp harvested crop.

16. The scarce amount of substrate initially led to low lactic acid fermentation. However, the lactic acid that formed was changed into acetic, propionic and, above all, butyric acid as fermentation progressed. The butyric acid content increased from a mean 1.2 % in DMc to 1.3 % in DMc to 1.45 % in DMc and exceeded the limit value for good silage of 0.3 % in DMc.

17. The levels of ammonia and butyric acid increased from the edge to the silo middle. Ammonia in silage indicates protein breakdown by clostridia and should not exceed 10 %. The ammonia content in the tested silage increased from date to date. It achieved a mean 22.1 % (spread 4.2 – 47.6 %). Therefore, the crude protein content also decreased.

18. The poor fermentation quality of the green rye silage with predominantly too much butyric acid and ammonia is not due to use of the PistenBully, but rather to the poor fermentation characteristics of the harvested crop. Silage of this kind would no longer be suitable for dairy cattle feed.

It can be derived from these results that use of the snow groomer (PistenBully 300) is suitable in green rye silaging to spread and compact high harvest volumes up to around 100 tonnes of fresh mass per hour. Spreading is still guaranteed with higher outputs (100 – 150 t FM/h), but use of an additional rolling vehicle is recommended. The unsatisfactory fermentation quality of the silage is due to the poor ensilability (low sugar content) of the harvested crop and not to use of the PistenBully.

6. Responsible for the results

Dr Hansjörg Nußbaum
Landwirtschaftliches Zentrum für Rinderhaltung,
Grünlandwirtschaft, Milchwirtschaft, Wild und Fischerei
Baden-Württemberg(LAZBW)
Fachbereich Grünlandwirtschaft und Futterbau
Atzenberger Weg 99
88326 Aulendorf

Tel.: +49 (0)752 594 2352
E-mail: hansjoerg.nussbaum@lazbw.bwl.de

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