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Final Report for AHDB Beef and Lamb Assessment of silage clamp losses and factors affecting them on beef farms across England
(AHDB Reference: 6110032017)

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Aims: The predominant aims of this project were to examine the variability in grass silage quality from a number of farms in England and to assess what factors were associated with differences in quality both within a clamp on a single farm and between clamps on different farms.

Materials and Methods

Twenty-one farms volunteered for the survey but upon visiting one farm was rejected as the grass silage clamp was very small, the silage within the clamp was approximately 18 months old and the clamp had been opened once and resealed and the top sheet had numerous holes visible from a standing position at the face. Therefore the report is based on the 20 remaining farms. Figure 1 shows a google map of the location of all the participating farms, with names and addresses in Appendix 1.

Figure 1 – Geographical location of the 20 farms

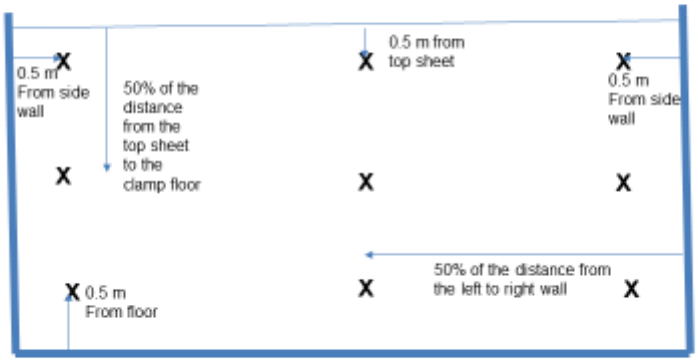
Assessment process

All farms were visited in January 2017. It was decided that the shorter the time frame between farm visits, the lower the climatic variables affecting the silage assessments on farm would be and January is a time when most farms are feeding a consistent quantity of silage on a daily basis.

On arrival at each farm one grass silage clamp was identified for the assessment. Each farm assessment was made by the same two personnel from Silage Solutions Ltd (namely D.R. and G.K Davies). The first assessment was height of grass in the clamp, clamp width and length. In addition ambient temperature in front of the clamp was measured as was the geographical

orientation of the clamp and the open face. From the clamp dimensions the sampling points in each clamp were then marked out as shown in Figure 2.

Figure 2 Sampling- Open clamp face sampling at points denoted with an X



At each sampling point a temperature measurement was made at three depths into the face, firstly at the surface using an Infrared Thermometer (Fluke 62 Max+) and at 12 and 50 cm depths perpendicularly into the face using probe thermometers. This assessment enabled a relative temperature assessment to be made in order to make an evaluation of the aerobic deterioration of the silage on the day of the visit.

In addition to this a handheld NIRs (Nirs4Farm, Aunir) silage quality nutritional assessment was made at each point by holding the NIRs scanner directly onto the open face (this assessment fell out-side the project agreement but selected results will be included as they provide useful data for the industry to be aware of).

Once the measurements that required the face to be undisturbed had been made a silage core sample was removed from each of the 9 points. Each cored sample was weighed upon removal from the corer and the depth of the hole in the clamp recorded, these measurements along with the dimensions of the corer radius enabled an assessment of clamp density to be made (weight of silage removed in the core sample divided by volume of the cored hole), the methodology is an accepted technique (Muck and Holmes 2000). If insufficient sample was removed in a single core from that point (due to the density of silage at that being low) then further core samples immediately adjacent to that core were taken in order to provide sufficient sample for analysis.

Each sample was mixed well and analysed by NIRs on farm analysis (NIRs4Farm) before leaving the farm. The samples were then individually vacuum packed and stored for subsequent analysis by laboratory NIRs analysis using the Forage Analysis Assurance group (FAA) prediction equations at the FAA Grass Silage Master Lab at Agriculture Food Biosciences Institute AFBI, Hillsborough, Northern Ireland. In addition analyses of pH, Lactic acid, Volatile Fatty acids, Ammonia-N, dry matter, Ash and total-N (Crude Protein) were

conducted using recognised wet chemical approaches, with all except pH, being conducted at the AFBI laboratory. The pH analysis was conducted by Silage Solutions Ltd. Additional sample of all samples have been retained at -20^{o}C for subsequent further analyses as required, for example the samples would provide an invaluable data resource for the assessment of the both within and between farm variability in grass silage mineral content.

In addition to these samples three other sample types were taken:

1. A sample of top 'waste' silage was collected on all farms. This sample was collected by walking across the top of the clamp and taking a core vertical down into the clamp of approximately 30 cm depth every 3-4th step and mixing all cores taken together. These samples were analysed by wet chemical procedures for Dry Matter and Ash and incidentally mineral content the latter of which also falls outside the remit of this project. These analyses were conducted at a commercial laboratory in England (NRM, Cawood, Yorkshire).
2. A sample was removed immediately behind the silage fed on the day of the visit and a second sample removed from the face from where tomorrow's silage would be removed from. These samples were used to examine the aerobic stability/spoilage of the sample by placing in Aerobic Stability Vessels at Silage Solutions Ltd and assessing the time taken for the temperature to rise by +2^{o}C above ambient (Ambient being 18-20^{o}C).
3. A random sample of silage that had not been further 'chopped' by the feed-out process to assess particle size of the silage using the Penn state separator methodology. Before this was carried out the silage was partially air dried in order to facilitate particle separation.

Each farm was also requested to fill in a questionnaire about their grass silage production and management processes.

Results

Farm Survey and Observation Facts

The data collected either during the visit or in the questionnaire completed by each farm is shown in Table 1 as a resume. It indicates that 9 out of the 20 farms had a single cut in the clamp whereas the remainder had more than one cut. Six used a biological additive five of which were homo-fermentative and one a mixed homo/hetero-fermentative inoculant and one used a chemical additive with the remaining 13 using no additive or not specified. Four farms used forage wagons as the method of harvesting whereas the remainder used so called precision chop forage harvesters. Side sheet was not used on a number of the farms for the silage at the point when it was sampled.

Table 1 Resume of farm operations

Farm	Contractor			Chopped /Wagon	Side Sheet	Thin Top Sheet	Top sheet number	Top Weight	Additive	How many cuts/clamp	Cutting date (s)	Wilting time (h)	Livestock
	Mowing	Foraging	Compacting										
1	F/C	F/C	N	W	Y	Y	2	MATTS/MESH		2		24	Dairy
2	F	F	N	PC	N	N	1		Ecosyl	3 W/C		24-48	B/S
3	C	C	C	PC	Y	Y	2	TYRES		3 W/C	10/6		Beef
4	F	F	N	PC	Y	N	1	MESH/G BAGS		2		24	Beef/Sheep
5	C	C	C	PC	Y	Y	1	Some G Bags		2	May		Dairy
6	C	C	C	PC	N	N	1	MESH Some G Bags on edge		1	4pm 27/5	24	Dairy
7	F	C	F	PC	N Q seal	N	1	MESH Heston bales touching	N	2 1 week difference		48	Beef
8	F	C	F	W	Y	Y	1	Tyres touching	N	1	3/6 10-7pm	24	Beef
9				PC	N	Y	1	Barrels/ straw bales		2			Dairy
10				PC	Y	Y	1	MESH/ G Bags	N	1			Youngstock dairy
11	F	F	F	PC	Y	N	1	Hessian Bales G bags on side	Ecosyl	2	23/5 PM	42	Beef
12	F	F	F	PC	2	Y	2	Tyres touching	Ecosyl	2	19/5 and 15/7 PM	24-48	Beef
13	F/C	F/C	F/C	PC	Silostop 2	Silostop	1	Silage matts touching	Biotal Axphast	1	15/5 PM	36	Beef
14	C	C	C	PC	Y	N	2	Tyres	Ecosyl Ecocorn	1 direct cut 3 days	15/7 direct cut over 3 days		Beef/Sheep
15	C	C	C	PC	Y	Y	2	Hessian bales	N	1	26/5 all day		Beef/Sheep
16	C	C	C	PC	Y	Y	2	MESH G Bags	Ecosyl	1	24/5 PM	24	Beef
17	F	F	F	W	Y	N	2	Tyres touching not many on ramp	N	1	24/5 PM	24	Beef
18	F	F	F	PC	N	Clingseal	2	Tyres almost touching	N	2	24/5 PM	24	Beef/Sheep
19	C	C	C	PC	N	Y	1	Straw bales /Matts	N	2	26/6 3PM	24	Beef/Sheep
20	F	F	F	W	N	N	1	G bags in front	Safesil	1	13/5 PM	24	Beef

Key F = carried out by farmer, C = carried out by contractor, F/C carried out by farmer who was also a local contractor.

W = Picked up using self loading wagon, PC = Picked up by Precision Chop Forage harvester,

Y = Yes did use one, N = No didn't use one. Blank = no information was available/provided. Date contains all information provided.

Clamp Dimensions

The mean, minimum, maximum and range of clamp dimensions, and mean silage densities are indicated in Table 2. These data enable an assessment to be made of the effect of silage clamp size on the relative portions of silage that is in the vulnerable zone that is 0.5 m either from the side wall or the top sheet of the clamp (see Table 3). Many farmers disregard this portion of the clamp as being the 'bits around the side' but by conducting these evaluations then it is clear to see that a significant proportion and on average 27% of the volume and 21% of the fresh weigh of all the silage is in these more vulnerable zones. Obviously the smaller sized clamps have a higher proportion and the larger clamps a smaller proportion in this zone.

The ideal size of clamp depends on a number of factors most importantly is probably feed-out rate, however if small numbers of stock are to be fed from a single clamp than occasionally a clamp can be too small to enable good compaction. It is stated here that the proportion of the clamp within a 0.5 m of the wall increases as the silage clamp width and height reduces, such a statement implies small clamps will have higher losses than large clamps. However this is not necessarily the case as small clamps have a higher feed-out rate and so can have reduced aerobic spoilage losses at feed-out. The crucial factor is management at filling and rapid feed-out and this is true irrespective of clamp size. The data are presented to highlight the importance of silage in this region to the overall quantity of silage, its effect on losses of both DM and quality and by knowing, management process can be put in place to reduce these losses.

Table 4 indicates the mean percentage dry matter (% DM), the total clamp fresh weight and the costs of producing the silage. These show not only the costs of producing the silage but also the cost of the silage in the vulnerable 0.5 m of the top sheet and wall silage. The average cost of producing the silage from the farms surveyed was £21,000 with a maximum cost of *circa* £58,000 The average value of the silage within the vulnerable zone was *ca.* £4,200 whereas the maximum cost was *ca*. £10,700. The data in this section is calculated by using the AHDB cost of £120 to produce one tonne DM of grass silage. This is then used alongside the measured values for clamp dimensions and therefore the proportion of silage in the vulnerable 0.5 m zone next to the walls and top.

Table 2 Indicating the mean, minimum, maximum and range of clamp dimensions and density across all 20 farms surveyed

	Clamp Width (m)	Height of Silage at wall (m)	Height of Silage in the middle (m)	Clamp length (m)	Area of silage exposed face[a] (m2)	Volume[b] (m3)	Average FM[c] Density kg/m^3	Difference in silage height at the wall and middle of the face (m)
Mean	12.80	2.51	2.96	29.15	31.76	935.20	613.11	0.46
Minimum	8.40	1.60	1.90	14.00	13.44	336.00	291.64	0.00
Maximum	20.50	3.40	5.50	45.00	47.60	1872.20	805.47	3.20
Range	12.10	1.80	3.60	31.00	34.16	1536.20	513.83	3.20

Notes [a] Assumes all clamps have an even silage height equal to that at the walls, so underestimating the clamps where there is a big difference in height of silage at the wall and centre. [b] Calculated using the assumptions made for [1]

[c] The minimum targets for density are 750 kg FM/m^3 or more precisely on a dry matter basis 220-250 kg DM/m^3.

Table 3 Indicating the mean, minimum, maximum and range from the 20 clamps surveyed of the contents by fresh matter weight (t) and percentages in the various portions of the clamp

	Quantity of silage in the first metre depth of face[a] (FM T)	% volume of silage within 0.5 m of wall or top[b]	Weight (t) of silage in first metre back from face that is within 0.5 m from top and side[c]	% of total weight of silage within 0.5 m of wall and top[d]
Mean	20.07	27.39	4.14	21.62
Minimum	8.77	22.12	1.34	15.30
Maximum	38.34	39.43	7.89	36.30
Range	29.57	17.32	6.55	21.01

Notes [a] Calculated from Table 1 above using the assumptions made in that table and using the mean within clamp density for that farm.

[b] The % volume in the outer portion of the clamp is calculated form the width and length dimensions

[c] Calculated from the previous 2 columns [d] Calculated from previous column multiplied by total measured length

Table 4 Indicating the mean, minimum, maximum and range from the 20 clamps surveyed of the % DM, total silage fresh weight/clamp, total cost of production using the £120/t DM figure from AHDB and the cost of producing the silage within 0.5 m of the wall or top sheet.

	Mean %DM	Weight (t FM) of silage in clamp	Cost of Producing that clamp of silage £	Cost(£) of producing the silage within 0.5 m of top or wall
Mean	30.21	585	21,034	4,288
Minimum	20.47	166	6,324	1,488.
Maximum	44.85	1,368	57,845	10,620
Range	24.38	1,2012	51,521	9,131

The costs of production within this table are calculated by using the dimensions as measured on the farms of the width, height and depth of the silage in the clamp on the day it was filled. The assumptions are that the clamp was filled in a regular quadrat shape and therefore this is likely to be an underestimate in most cases. The mean density across the clamp is then used to estimate the kg of fresh matter in the clamp and then by using the mean % DM the total tonnes of silage DM can be calculated. Finally the cost of production per tonne of silage DM from AHDB is used. Finally the cost of silage with 0.5 m of the wall is also calculated using the dimensions of the clamp and calculating the amount of silage with in this region and working through the calculations made for the cost of the whole clamp. There are many caveats on to the exact accuracy of this data as the density, in general is lower in these regions however it does serve to encourage farmers to think about this region more carefully because despite these caveats it does make up a significant proportion of the forage ensiled.

Silage density

The density of silage in a clamp is a key marker that affects many of the problems associated with storage Poor density leads to poorer preservation quality and secondary fermentation (not to be confused with aerobic spoilage). This is where products of the primary fermentation normally lactic acid, are converted to secondary fermentation products such as acetic and butyric acids by undesirable silage microorganisms, due to the presence of trapped oxygen at the beginning of the storage period. Poor density also increases the ingress of oxygen during the entire storage period if sealing is inadequate and finally it increases the risk of aerobic spoilage or deterioration at feed-out due to the ability of oxygen to penetrate further into the silage from the open clamp face. Also in terms of forage audit a standard book value is often used by farmers to assess silage stocks. Therefore the data collected during this survey is of great value.
Figure 1 shows the variation in density for all 20 farms (F1-F20). At each of the 9 sampling sites density was measured. The graph indicates the mean values of the three right hand side, three left hand side, three top and three vertically central samples. Farm 9 was the largest clamp in the study hence the central sample density is partly a result of the settling effect from the weight of silage above it.

Figure 1 Variation in Fresh Matter density across all farm clamps

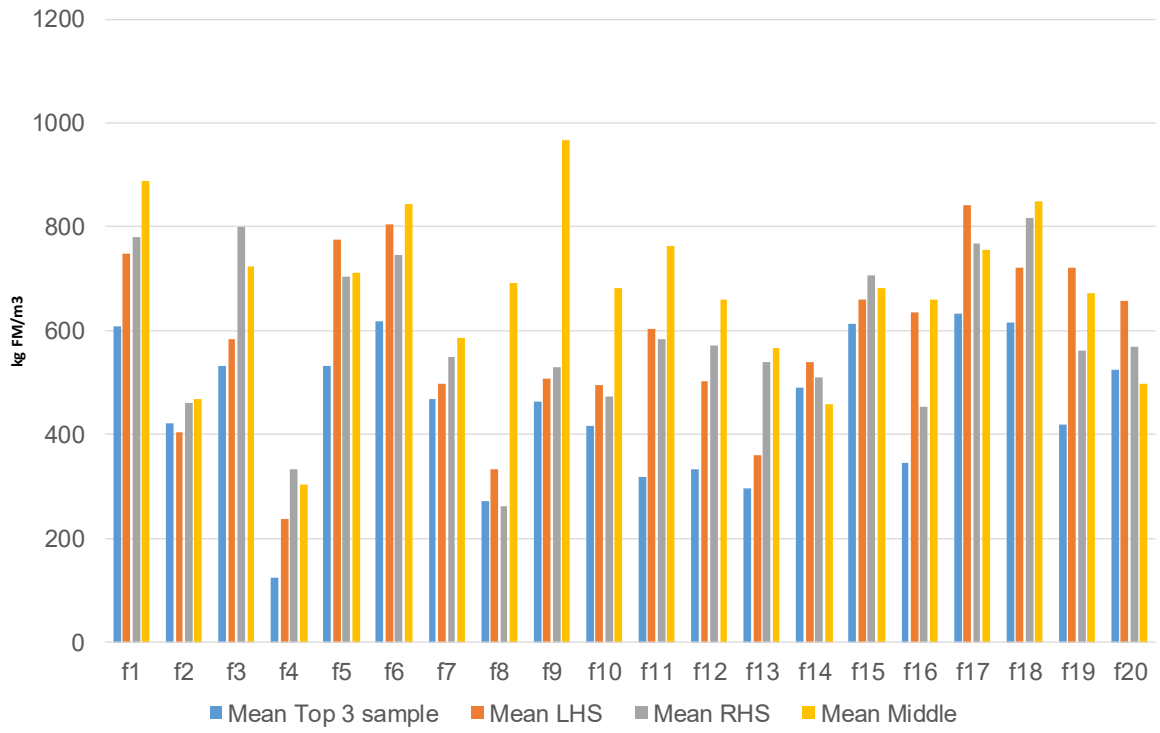


Figure 2 shows the comparative mean density of the left hand side to the right hand side three samples. The dataset is such that the value for the mean three right hand samples (top middle and bottom) is subtracted from the mean three left hand samples. The data indicates that on four of the 20 farms there is a big difference between density between the two sides (namely farms 3, 13, 16 and 19) and on a further three farms there was a difference that is probably more than just random sampling errors (namely farms 4, 18 and 20). Specifically considering farm 16, which was more dense on the left hand side than the right hand side, this farm had a sloping earth bank on the left hand side and a vertical wall on the right hand side, indicating that compaction of sloping walls can be greater than vertical walls due to the ability of the packing tractor to exert more weight on the forage beneath as the silo is being filled. These data suggest that on some farms at least the process of filling and compacting the clamp is affecting the density. Factors such as direction compacting tractor travels up and down the clamp, may have an effect. For example if consolidation occurs always with the tractor facing forward from front to back of the clamp then visibility of one clamp wall may be superior to the other and thus affecting closeness of the tractor wheel to the wall. Alternatively if the delivery trailers always tip the forage at one side of the clamp this may also affect the filling on the opposite sides of the clamp. Farm 16 had an earthen wall at a shallow angle on the left hand side and a more vertical soil wall on the right hand side. The left hand side had a much higher density than the right hand side due to the angle of the retaining clamp soil wall.

Figure 2 Difference between the mean left hand side density compared to the right hand side density

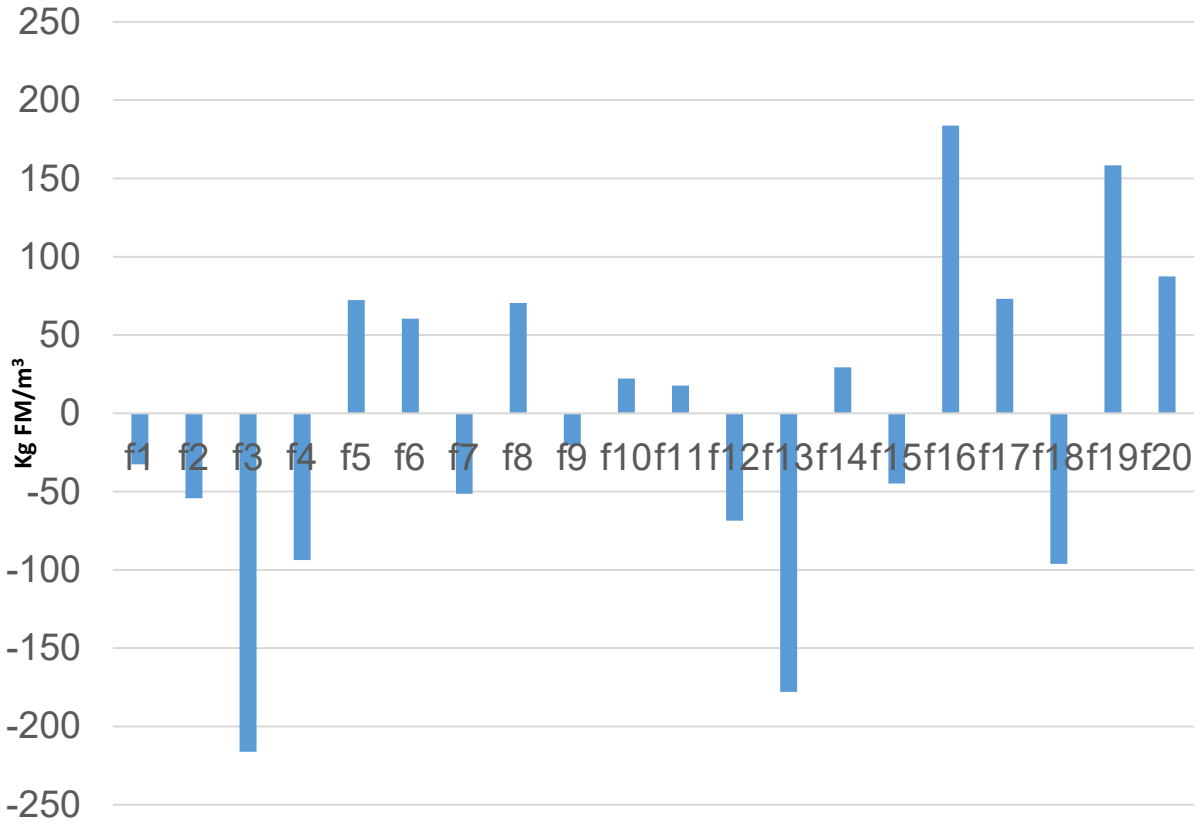
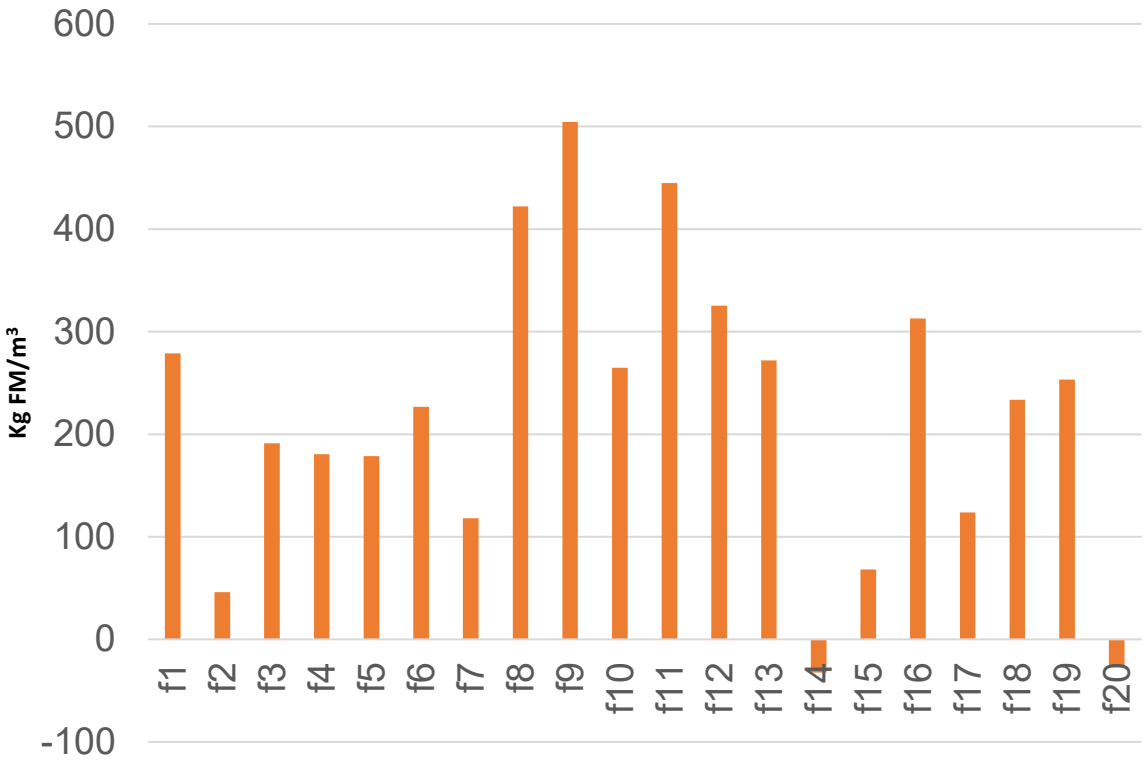


Figure 3 shows the comparative mean FM density of the vertical central samples to the top three samples. It should be as close as possible to zero (probably near 100) and it is driven by top weight not being the heavier weight. The data clearly shows big difference in density between the top and central samples. The exceptions are F2, F14, F15 and F20. Farms 2 and 14 had relatively poor density, throughout the clamp. Whereas F15 and F20 had relatively good density in the body of the clamp but due to their small height the impact of any settling derived consolidation would have been less than larger taller clamps. Farm 20 was a self-feed clamp which thus necessitates a lower overall height

Figure 3 Difference between mean top and mean centre FM density



Particle size distribution

The chop length of silage has been one of the key factors shown to influence silage density. However much of this work has been done in experimental trials on one given research farm. In order to assess the effect of particle size distribution on silage quality and density in this survey, the Penn State Separator method was employed to examine the particle size distribution. A sample was collected from each farm in such a way as to avoid further change in the chop length. On most farms this was achieved by taking a sample immediately beneath the previous days' block of silage that had been removed. The sample was air dried to approximately 60% DM. The sample was then placed on the Penn state separator (a series of four boxes on top of each other such that there is a gradation of pore

size largest to smallest). The proportion retained on each sieve was then calculated and the results are presented in Table 5. In addition the DM density (kg/m^3) are also indicated. This methodology only gives an estimate of particle size distribution as the particles residing on a given sieve can be significantly larger than the pore size of the sieve especially on the top sieve. A simple r^2 correlation between % on the top sieve and DM density gave a r^2 value of 0.0016 indicating no relationship between particle size distribution and density and thus showing that on farms whilst particle size maybe important what is far more important is the way the silage clamp is managed at filling to ensure good compaction density. Furthermore considering farms 1 and 2. Farm 1 used a forage wagon whereas farm 2 used a precision chop forage harvester. It is clear to see that farm 1 has a larger particle size distribution but four times better silage density.

In total across the 20 farms surveyed four farms used a forage wagon and looking at their mean particle size distribution and the % of forage retained on the top sieve it is clear that they had almost two times the percentage than the overall mean, indicating a larger chop length. However comparing their DM densities then three of the four farms had a higher density than the overall mean density. Finally comparing the best forage wagon silage it ranked second out of the 20 farms in terms of overall mean silage density and when compared to the best mean farm density it actually had less variation in density with the parts nearer the walls and top of the clamp having better density. Thus again indicating the importance of silage clamp management in obtaining the required density rather than one aspect which could be envisaged as being detrimental.

Table 5: the particle size distribution and the mean within farm DM density of silage.

Farm	% Top sieve	% second sieve	% Third Sieve	% fourth sieve	DM density kg/m3
1	76.	17	5	2	225
2	23.	43	21	13	86
3	31	52	11	7	244
4	50.	31	12	8	82
5	44	43	8	5.	154
6	44	48	5.	3	166
7	31	54	11	5	243
8	69	23	5.	2	147
9	32	53	8	6	258
10	27	55	11	7	124
11	29	59	8	3	164
12	34	59	6	0.2	161
13	30	60	7	3.	205
14	28	58	7	7.	141
15	32	65	0.2	3.	158
16	37	46	10	6.	220
17	78	18	4.	0	197
18	27	52	15	5	189
19	24	60	11	6	171
20	78	15	4	2	147
mean	41	46	8	5	174
min	23	15	0.2	0	82.
max	78	65	21	13	258
std	18.8	15.9	4.6	2.9	48.8

Silage temperatures

Table 6 shows the mean, minimum, maximum, standard deviation and range of temperatures measured at all sampling sites across all farms at each measurement depth namely surface, 12 cm and 50 cm depths. The data indicate that in general the silages were cool but that there were exceptions as can be seen by the maximum temperature in excess of 49^{o}C.

Table 6 Summary of all the silage temperatures

	Surface ^{o}C	12 cm ^{o}C	50 cm ^{o}C
mean	8.06	13.94	17.46
min	2.30	4.00	5.90
max	16.00	49.00	49.10
std	2.48	7.05	7.57
Range	13.70	45.00	43.20

Table 7 :the within farm minimum, maximum and range of temperatures measured across the 9 sampling points.

	Ambient	Surface ºC	12 cm ºC	50 cm ºC	12 cm minus surface	50 cm minus surface	50 minus 12
F1	5.50	5.36	8.68	11.31	3.32	5.96	2.63
F2	5.60	7.36	22.73	28.43	15.38	21.08	5.70
F3	5.80	6.46	9.61	14.22	3.16	7.77	4.61
F4	8.00	8.00	18.13	22.01	10.13	14.01	3.88
F5	9.20	11.71	21.22	24.99	9.51	13.28	3.77
F6	9.10	9.03	16.72	19.51	3.32	5.96	2.63
F7	10.10	9.66	12.99	14.59	3.33	4.93	1.60
F8	10.50	9.56	13.82	19.49	4.27	9.93	5.67
F9	7.90	6.18	12.54	16.98	6.37	10.80	4.43
F10	7.90	5.76	12.39	14.56	6.63	8.80	2.17
F11	10.40	10.69	15.19	18.40	4.50	7.71	3.21
F12	10.60	10.61	12.28	12.90	1.67	2.29	0.62
F13	6.00	6.26	8.76	11.16	2.50	4.90	2.40
F14	7.40	7.71	14.36	18.41	6.64	10.70	4.06
F15	5.80	5.41	13.41	15.89	8.00	10.48	2.48
F16	7.50	9.12	19.34	23.89	10.22	14.77	4.54
F17	8.50	9.52	10.92	15.46	1.40	5.93	4.53
F18	6.10	6.23	14.98	18.00	8.74	11.77	3.02
F19	6.60	8.24	13.04	18.97	4.80	10.72	5.92
F20	7.50	8.32	7.58	10.08	-0.74	1.76	2.50
Mean	7.80	8.06	13.94	17.46	5.66	9.18	3.52
Min	5.50	5.36	7.58	10.08	-0.74	1.76	0.62
Max	10.60	11.71	22.73	28.43	15.38	21.08	5.92
Range	5.10	6.36	15.16	18.36	16.12	19.32	5.30

Table 7 indicating the within farm minimum, maximum and range of temperatures measured across the nine sampling points. The relative temperatures at each sampling point have been calculated by subtracting the temperature nearest the surface from the temperature deeper in the clamp.

There is no correct answer to what should the temperature in a clamp be, this is because it depends on a number of factors such as the prevailing temperature on the day the crop was harvested and the position in the clamp. So a silage cut in early May is likely to have a core temperature in the 20s where as a second cut made in June may have a temperature of 37ºC if the weather was good and the silage clamp is outside reflecting the sun's rays. Then once the grass is compacted the heat will remain in the clamp and only very slowly dissipate such that the top and near the walls will cool whereas the central portion may maintain this temperature if it is well consolidated and sealed for six months or more. Therefore as a rule of thumb the temperature nearer the open face of the clamp should be cooler than the temperature deeper in the clamp. Thus in these tables if there is a negative number then this indicates a potential issue of aerobic deterioration as the sample nearer to the open face is warmer than that deeper in. The results shown in Table 7 suggest there is no problem with heating at feed-out and thus no problem of aerobic spoilage. The negative number does indicate that

in that particular instance the temperature of the silage nearer the surface was higher than deeper into the face. Whilst the table provides useful mean data two of the farms did have interesting results in certain regions of the clamp these results are shown in Table 8.

Table 8: Selected temperature results of sites

Farm No.	Sample site	Surface °C	12 cm °C	50 cm °C
F2	1	5.4	19.2	33.4
F2	2	4.3	9.2	25.5
F2	3	6.6	18.8	22.9
F2	4	10	36.1	31.7
F2	5	9.3	17.8	31.8
F2	6	4.5	8.7	24.8
F2	7	11	31.5	35.4
F2	8	8.7	33.1	26.8
F2	9	6.4	30.2	23.6
F4	1	8.5	20.2	39.4
F4	4	8.9	26.2	34.3
F4	7	8.2	25.6	27.4
F5	1	13.4	49	45.1
F11	7	10.8	19.1	29.8
F14	4	11.7	33.1	37.3
F16	1	12.2	32.1	30.1
F16	4	11	47.6	49.1
F16	5	9	18.9	35.6
F17	1	7.8	14.6	17.6
F17	2	5.9	9.8	15.5
F17	3	5.7	7.1	9.6
F17	4	8.3	5	6.9
F17	5	7.5	12.6	22.9
F17	6	8.6	15.1	21.2
F17	sun7	13.3	7.5	7.3
F17	sun8	13.6	13.6	19.6
F17	sun9	15	13	18.5
F18	7	10.9	27.4	23.1
F19	2	8.6	14.5	23.7
F19	7	9.8	23.6	29.1

Table 8 indicates selected temperature results of sites where the subtraction method of analysing temperatures for aerobic spoilage problems doesn't highlight the issue.

Table 8 above shows that 8 out of the 20 farms had some heating due to aerobic spoilage in certain points. Mainly in the top sections of the clamp. Here the deep thermometer can be relatively hot compared to the face sample, this is because the heating is occurring further back than the face and by the time the silage is at the face the heat has dissipated. Farm 16 sample point 1 and 4 show this most clearly. Farm 2 had a problem throughout the clamp face with some degree of heating in most/all

samples. Farm 17 had no problem with heating and aerobic spoilage but some of the data has been included to indicate what happens to the surface temperature measurement when the sun is shining on a portion of the clamp face (sample sites 7 – 9) but not the whole clamp face. This is an example of when thermal imaging cameras are used to assess aerobic spoilage that misinformation can be attained.

This data also indicates why the thermal imaging camera employed by many sales reps can also be misguided. It can both under and over predict aerobic spoilage. Figure 3a below is a thermal imaging camera of a grass silage clamp. The 'hotter' red colour does not indicate heat generated due to aerobic spoilage but indicates where this farm fed silage using a shear grab 1h previously. The region has therefore recently been exposed and represents the residual heat in the silage that is now exposed and on the surface and so is relatively warmer than the surrounding face silage which was exposed over the previous day or so and which has now had time to cool down.

Another example of this is where the sun has been shining on a portion of the clamp face and this has caused additional heating of the silage in a specific region, this rise in temperature can last for some time after the sun stops shining and the thermal imaging camera will still be able to detect the temperature differences.

Figure 3a: A thermal imaging camera's view of a silage clamp

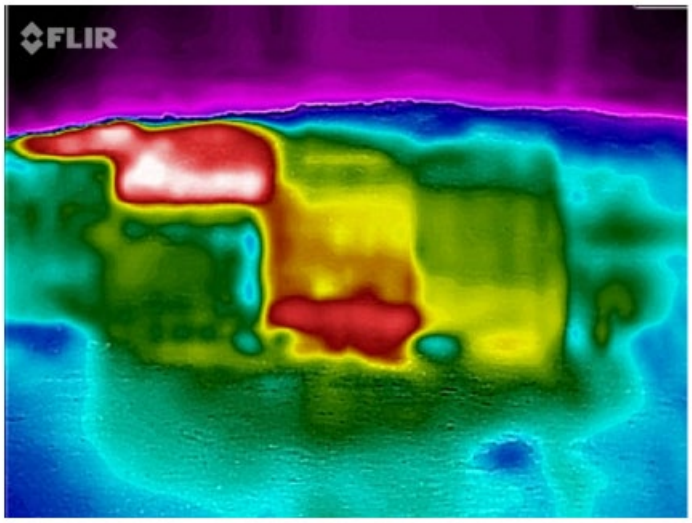


Figure 3a shows a thermal imaging cameras view of a silage clamp face the warmer temperature are in red with the colder temperatures in blue. There was no aerobic spoilage on this particular clamp face.

Top and side waste and associated losses

Table 8 below shows the quantity of top and side waste as determined by measuring the surface area of the waste from the open clamp face and sampling the waste and using a calculation based on the relative ash and organic matter content in the waste and the silage sampled from the top central point of the clamp (S4). This methodology enables an estimation of the kg of visible waste. Farm 3 had zero waste anywhere and so no sample of waste was taken. On all other farms measurements were made even if the silage on top/side looked of reasonable quality. Where samples are showing 0.00 waste this is because the waste sample had a lower ash content than the S4 sample from that silage clamp. This data only indicates losses associated with visibly wasted silage. The % DM losses in

weight enables the farmer to actually calculate that for every kg of waste there would have been even more weight of good quality silage and this is shown in the final column of the table.

Aerobic stability

Aerobic deterioration of silage is a big issue that can cause major DM losses and losses of nutritive value.

In an attempt to gauge this, two samples per farm were taken by hand. One sample was taken from a region of the clamp immediately behind the days feeding and a second sample was taken from the front of the following days feeding. This was an attempt to examine freshly exposed silage and longer exposed silage and how this may affect silage aerobic stability. Obviously on some occasions this was not possible, for example with self-feed clamps, also the silage fermentation quality between these two sample types may be variable as the on some farms one of the samples would be nearer to the wall or top of the clamp and will already have been potentially aerobically challenged. The samples were returned to SSL lab and there they were loosely packed into aerobic stability vessels with a temperature probe in the centre of each sample and the whole sample incubated at a constant temperature ranging between 18-20^{o} C. The temperature was monitored every 30 minutes and the time taken for the temperature to increase to 2^{o} C above the ambient was recorded. Measurement was stopped after 850 h (which is 35 d) some samples had not heated after this time, but in reality a period of 360h (15 d) is more than enough to indicate good aerobic stability. In fact too long aerobic stability s an indicator of poor fermentation quality as silages with high levels of butyric acid and ammonia-N are generally very stable. On average the data in Table 9 indicates that the aerobic stability on most farms was more than sufficient to be able to feed across the clamp face quickly enough not to have changes in quality during feed-out. However this data only represents two point samples from the clamp and it should be interpreted alongside the data on clamp temperatures measured across the 9 points shown in Table 8. In addition the month of January 2017 was relatively cold which has an obvious positive effect on aerobic stability as the yeasts that initiate most aerobic spoilage will not be able to proliferate very quickly and often the feed-out rate in January is also at its highest due to more animals being fed silage. However some farms had significant issues with aerobic spoilage most notable farm 2 which incidentally had one of the poorest mean silage density values. Farms 11, 12 and 14 had less aerobic stability on their recently exposed silage than five days and so one might expect losses occurring if their feed-out regime was taking five days to move one complete transit across the clamp face. Interestingly however the part of the clamp that had been exposed for longer had better aerobic stability on farms 11 and 12, bringing about more fundamental questions about aerobic stability and the silage clamp and the routine laboratory measurements to assess this process. However as eluded to early the silage fermentation quality may also have been poorer in these regions.

Table 9:The aerobic stability of two silage samples/farm as measured by the time taken (h) to increase to 2^{o} C above the ambient

Farm	Recently	Longer
1	850	577.5
2	23.5	61.5
3	226	90.5
4	850	267
5	850	66.5
6	157.5	67.25
7	372.5	803.25
8	850	396.75
9	360	425
10	850	71.5
11	96.5	116.25
12	76.25	850
13	850	850
14	67.5	65.75
15	220.75	850
16	377.25	178.25
17	850	850
18	850	850
19	227	203.25
20	850	850
Mean	492.7375	424.5125
Min	23.5	61.5
Max	850	850
Std	344.4099	343.034

Table 10:The losses associated with visible waste on top of the clamp

Farm	% Ash waste	% OM waste	%OM Losses In waste sample	% DM losses in waste sample	Equivalent weight of well-preserved silage for every 1 kg DM waste silage produced (kg)[1]
F1	19.60	80.40	63.41	45.65	1.84
F2	17.50	82.50	45.63	24.62	1.33
F3	NT	NT	NT	NT	NT
F4	12.50	87.50	37.39	47.91	1.92
F5	30.00	70.00	74.39	50.92	2.04
F6	15.30	84.70	32.21	17.07	1.21
F7	7.30	92.70	7.35	4.55	1.05
F8	7.50	92.50	0.00	0.00	1.00
F9	12.50	87.50	19.01	7.34	1.08
F10	9.80	90.20	23.76	21.80	1.28
F11	16.10	83.90	46.06	31.76	1.47
F12	8.40	91.60	0.00	0.00	1.00
F13	8.80	91.20	4.59	2.31	1.02
F14	5.80	94.20	0.00	0.00	1.00
F15	9.60	90.40	0.00	0.00	1.00
F16	13.80	86.20	38.98	34.10	1.52
F17	9.70	90.30	0.00	0.00	1.00
F18	14.20	85.80	22.26	19.66	1.24
F19	10.60	89.40	14.03	18.31	1.22
F20	8.40	91.60	0.00	0.00	1.00

[1] Visible waste is not the same as actual waste. During almost all fermentation in the silo there will be the production of some CO_2 and water, but the silage will be appear of good quality. Visible waste looks poor quality. Visible waste has undergone secondary fermentation (not aerobic spoilage) whereby the lactic acid has been converted initially to butyric acid, CO_2 and water. Thus the visible waste is the proportion remaining, however if this proportion of silage had remained in its original well preserved it would have weighed considerably more than the weight of the visibly wasted silage remaining. This column of data calculates the quantity of well-preserved silage for every kg of visible waste that would have been available for utilisation had the waste not been produced. OM = organic matter, DM = dry matter

The data presented in table 11 below uses data from table 10 to calculate the actual %DM losses of the waste using the equation

{1-(ash content of good silage x Organic Matter content of Waste)/(Ash content of Waste x Organic Matter content of Good silage)}x100.

The value from the equation 1 above is then used alongside the measurement on farm of the regions of waste, which enables a total volume of waste to be calculated and thus in the final calculation the actual weight and % DM losses in the first 1 metre of visible open face. This is then used to calculate total clamp waste assuming the same volume of waste occurs throughout the clamp. It also assumes that this level of waste is the same throughout the clamp and calculates the total weight lost and the value (using the AHDB figure of £120/tonne DM) in terms of costs of production of the waste. The data shows that there is a large degree of variability in the quantity of visible waste between the farms ranging from 0-36% DM losses and 0 to 68 tonnes of DM and when taking the highest weight lost

alongside the quantity of silage that would have been if visible losses had been zero that equates to 139t DM and at 21.97% DM which was the mean % DM content of the silage on that farm that represents 632t of fresh matter waste of silage or 63 loads of waste to be carted away if the trailer is a 10t trailer.

Table 11: The weight and % DM losses of visible waste.

Farm	Weight (kg DM) in the first 1 metre of open clamp face					Total Loss in whole clamp (kg DM)	Cost of production of losses (£)
	Total silage and waste	Shoulder waste	Top waste	% waste	Total waste		
F1	10,747	26.63	0.00	0.25	26.63	372.84	44.74
F2	4,006	7.53	794.01	20.01	801.54	13,225.39	1,587.05
F3	6,521	0.00	0.00	0.00	0.00	0.00	0.00
F4	2,703	0.00	0.00	0.00	0.00	0.00	0.00
F5	4,490	160.68	1,487.81	36.71	1,648.49	68,247.68	8,189.72
F6	7,312	0.00	1,152.99	15.77	1,152.99	34,013.33	4,081.60
F7	8,707	1.29	14.70	0.18	15.98	601.01	72.12
F8	4,397	0.00	0.00	0.00	0.00	0.00	0.00
F9	10,955	0.00	703.43	6.42	703.43	30,950.71	3,714.09
F10	3,250	11.40	522.63	16.43	534.04	14,739.44	1,768.73
F11	4,616	24.87	1,206.76	26.68	1,231.63	33,993.03	4,079.16
F12	3,609	0.00	0.00	0.00	0.00	0.00	0.00
F13	5,437	0.00	0.00	0.00	0.00	0.00	0.00
F14	3,604	0.00	0.00	0.00	0.00	0.00	0.00
F15	2,108	0.00	0.00	0.00	0.00	0.00	0.00
F16	9,268	0.00	779.52	8.41	779.52	21,436.87	2,572.42
F17	9,219	0.00	0.00	0.00	0.00	0.00	0.00
F18	6,967	20.03	0.00	0.29	20.03	454.68	54.56
F19	6,739	2.95	140.34	2.13	143.29	3,152.32	378.28
F20	3,511	0.00	0.00	0.00	0.00	0.00	0.00

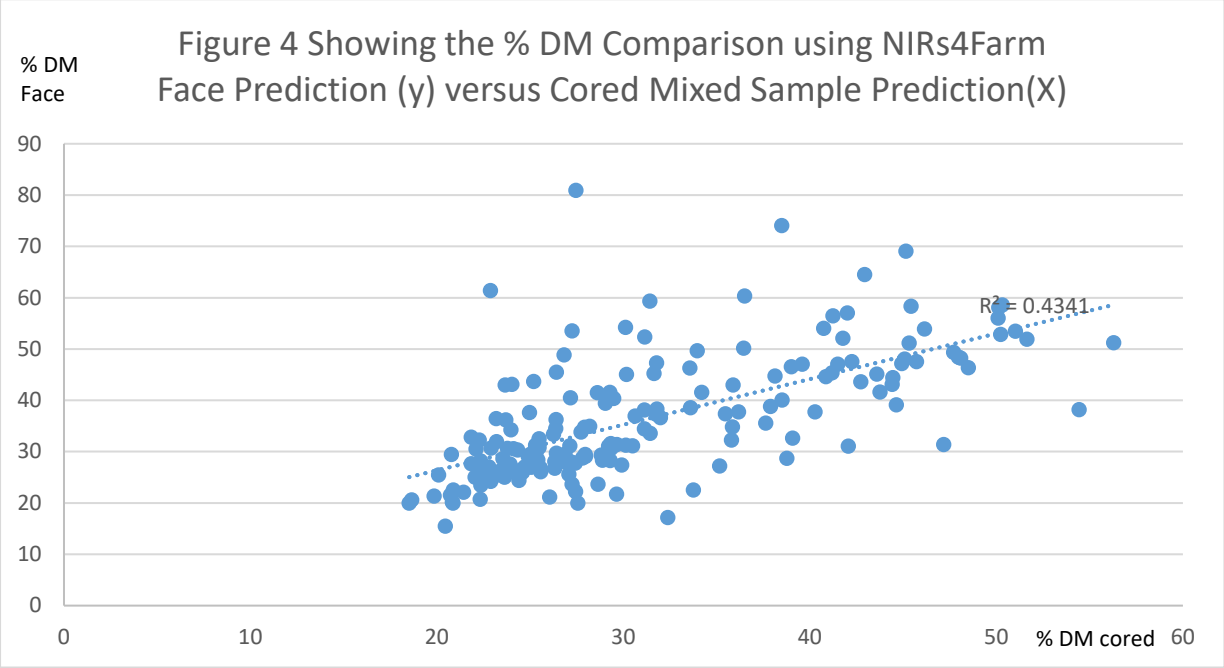
Regression analysis indicated that there was no relationship between the size of the clamp or silage density and the visible top or side waste.

Nutritional and silage fermentation analyses

Sample procurement was a very valuable additional part of this project and once the project funding had been agreed Silage Solutions Ltd made the decision to obtain as much data as possible from the samples. This went beyond what was agreed in the original contract proposal but has provided very useful information.

The first part involved the use of an on-farm hand held NIRs device. There are currently four commercial devices on the market from different suppliers and using different NIRs calibrations. Some of these devices claim to be able to produce a representative silage analysis from just placing on the open face of the clamp. Others suggest this can be done but say it is always better to take a well-mixed sample and analyse in a sampling bowl. The one used in this study was in the latter category (NIRs4Farm). However, for each sample an *in situ* face NIRs prediction was made alongside the exact same sample from a cored sample well mixed in a sampling bowl. The full results are in Appendix 2.

Figure 4 below shows the regression analyses of face versus cored for the 177 samples assessed, for the dry matter percentage.



The % DM analysis shown (Fig 4) and those in the appendix indicate that by taking the easy option of placing the NIRs analyser on the silage open face will give you an inaccurate prediction of the nutrient content. This is not surprising as the maximum depth Near Infra Red light will penetrate the sample is less than 0.5 cm and the face of any silage clamp will undergo some changes relative to the silage immediately behind it. Whilst on-farm NIRs devices are likely to increase in the coming years there still needs to be correct sample analysis and presentation to the analytical instrumentation being employed.

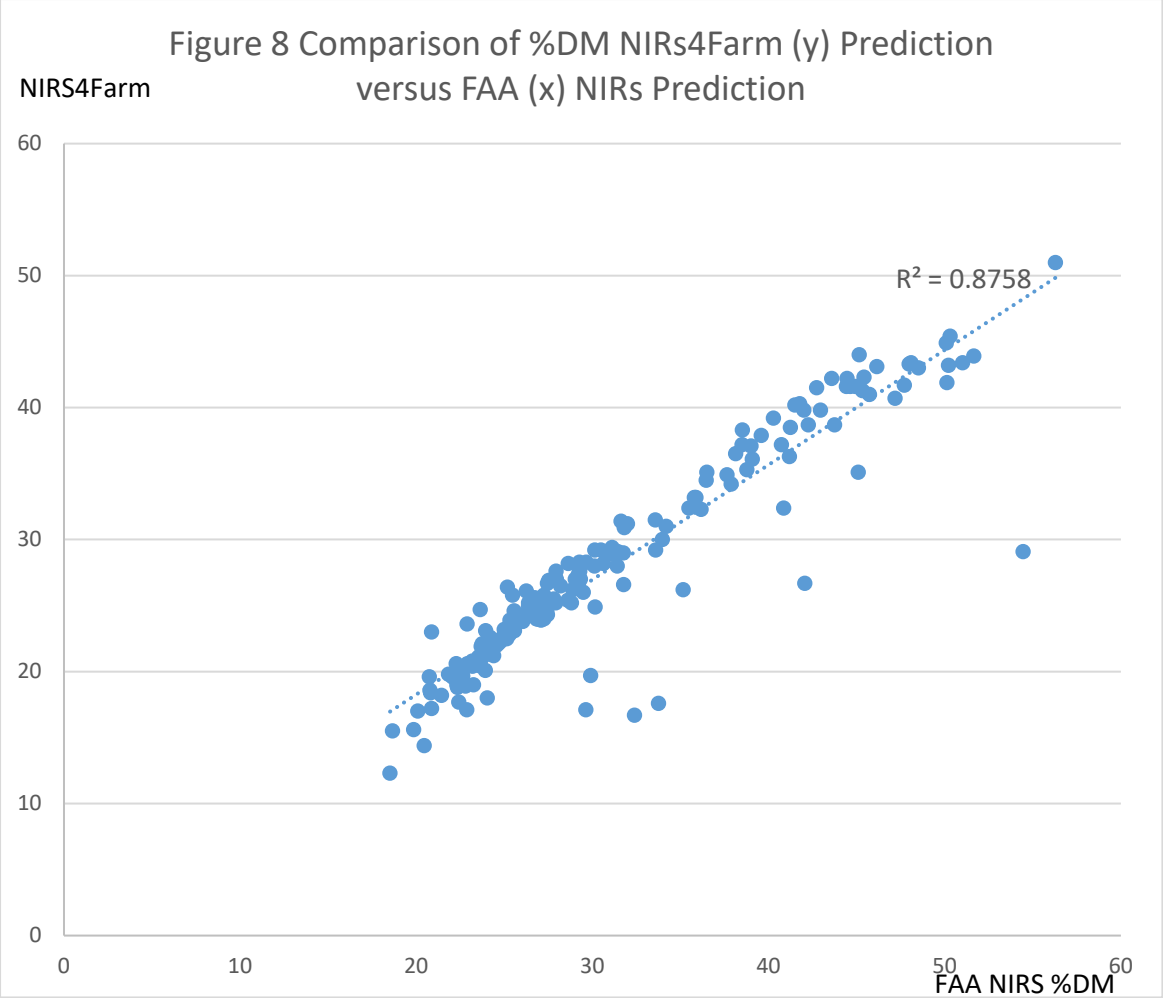


Figure 8 above shows the relationship between the on-farm NIRs prediction (conducted in the well mixed sample in a bowl) and the laboratory NIRs prediction for %DM. The prediction is quite good with just a few outliers. Other results vary on their degree of similarity to the laboratory NIRS predicted value and are shown in Appendix 2. It is worthy to note that both methodologies rely on predictions from a database and this result for DM suggests that providing the database is robust accurate prediction should be possible.

Laboratory NIRs compared to wet chemical analyses

The following section compares the laboratory NIRs results to the recognized wet chemical methodology.

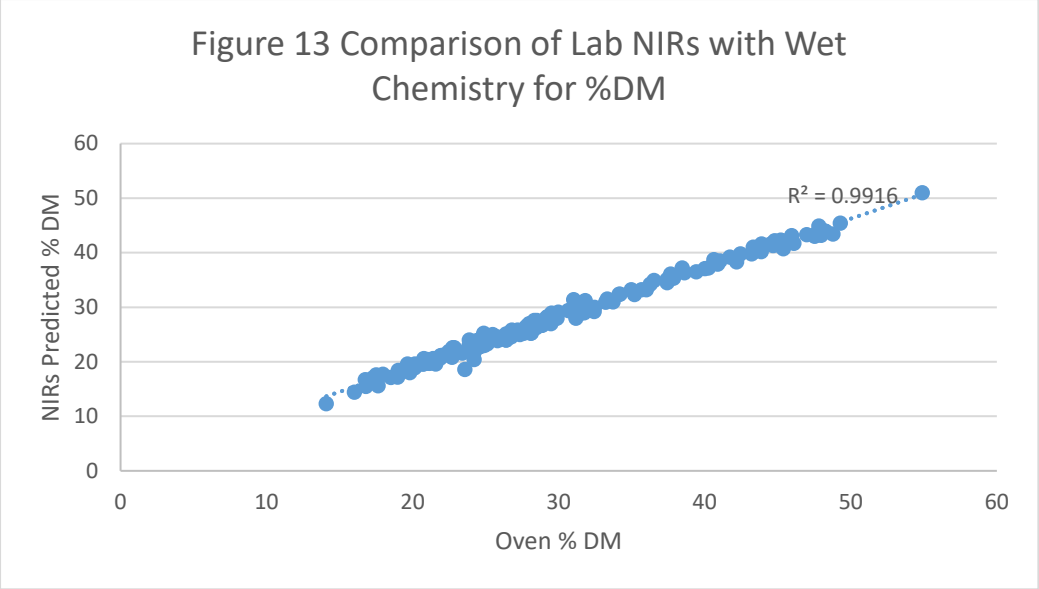


Figure 13 shows the relationship between Lab based NIRs predicted DM and Oven DM and the predicted values are in very good agreement with the traditional wet chemistry methodology over a wide range of parameters. This is an excellent correlation and appears to be strong over a wide range of % DM. Other analyte comparisons can be found in Appendix 2. None are as good as the prediction for % DM and some require further work on the database to improve the prediction for UK derived grass silages.

Within and between farm variability of key nutritional/silage quality parameters

The following section contains mean and range data for some of the key nutrients measured in standard silage analyses.

Table 12 shows the means/farm ie the 9 samples from each farm were averaged and the table represents the overall results of the 20 farms averaged values. The data indicates the mean % DM was 28.3 which is around the long term UK national average %DM. However the samples ranged from 19.4 to 41.6 % DM. With respect to % crude protein the mean was 12.76 with a range from 9.51 to 16.00, these data show a typical range in % crude protein concentrations compared to the national average figures, with possibly a lower maximum level. The D value had a mean of 67 (ME 10.72 MJ /kg DM) with a range from 56.17 to 75.0 (ME (from 9.0 to 11.9 MJ/kg DM) which is much more acceptable with dry cows requiring low D value silage but productive stock requiring a much higher plane of digestible energy nutrition.

Table 12 Lab NIRs Mean results of 9 samples/farm from the 20 farms (Intake and Milk yield are predicted values with 0 kg of concentrate supplementation)

	Dry Matter (%)	pH	Protein (% DM)	ME (MJ/kg DM)	D Value (% DM)	Oil (% DM)	Intake (kg DM per day)	Milk yield (kg)
Min	19.40	3.84	9.51	9.00	56.17	2.60	10.63	5.89
Max	41.61	4.61	16.00	11.92	75.00	4.02	15.11	19.33
Mean	28.30	4.17	12.76	10.72	67.06	3.25	13.06	13.75
Range	22.21	0.77	6.49	2.92	18.83	1.42	4.48	13.44

Possibly more important than the actual mean value/farm of the silage composition is the within clamp variability in silage quality across the clamp face, because this will lead to variability in the daily nutrient intake of the livestock being fed. In addition in the case where concentrates are being supplemented to the ration the relative proportions of forage to concentrates in the daily ration, which in some classes of stock can have effects on the health status of the heard with respect to production diseases such as sub-acute rumen acidosis, ketosis and laminitis.

The data in Table 13 shows that there is considerable within farm variability. The average variability in % DM across a single clamp face was 13.62 % units. With the most variable being 27.9% units and the least variable 4% units. For % crude protein the mean within farm variability was 4.6 % Units and for D value 11.0 % Units (ME 1.74 MJ/kg DM). This data shows considerable nutritive value variation on feed-out from the clamps and this variation is going to reduce the efficiency of livestock production and reduce the chances of maintaining a constant nutrient input and therefore a constant livestock production. The variability is likely to be less of a problem for the dry suckler cow than any other class of stock. This variability in production can be clearly seen from the predicted intake figures where the mean within clamp variation being equivalent to almost 3.3 kg DMI/cow/day depending on where in the clamp the silage originated with a maximum of 6.1 kg DMI/cow/day variation in intake. This has obvious knock on effects on potential production as can be seen from the predicted milk yield figures.

Table 13: Lab NIRs (AFBI) Mean results of the within farm ranges/farm from the 20 farms (Intake and Milk yield are predicted values with 0 kg of concentrate supplementation)

	Dry Matter (%)	pH	Crude Protein (% DM)	ME (MJ/kg DM)	D Value (% DM)	Oil (% DM)	Intake (kg DM per day)	Milk yield (kg)
Min	4.00	0.40	1.70	0.70	4.00	0.20	1.00	3.00
Max	27.90	1.60	11.30	3.60	23.00	2.20	6.10	17.00
Mean	13.62	1.03	4.60	1.74	11.00	0.75	3.29	9.45

Considering that seven farms had one cut of one crop of silage in the clamp and the other 13 had more than one cut this could alter the variability shown in table 11. Tables 14 and 15 show the mean and ranges in silage composition across clamps with a single cut of grass (Table 14) and more than 1 cut (table 15).

Tables 14: the lab NIRs (AFBI) mean results of the single cut/clamp farms

	Dry Matter (%)	pH	Protein (% DM)	ME (MJ/kg DM)	D Value (% DM)	Oil (% DM)	Intake (kg DM per day)	Milk yield (kg)
Min	19.40	3.84	9.51	9.43	58.67	2.60	10.63	5.89
Max	38.96	4.47	16.00	11.92	75.00	4.02	14.86	18.78
Mean	26.35	4.17	12.42	10.83	67.75	3.25	12.84	13.62
Range	19.56	0.62	6.49	2.49	16.33	1.42	4.22	12.89

Table 15 Shows the Lab NIRs (AFBI) Mean results of the more than one cut/clamp

	Dry Matter (%)	pH	Protein (% DM)	ME (MJ/kg DM)	D Value (% DM)	Oil (% DM)	Intake (kg DM per day)	Milk yield (kg)
Min	20.54	3.88	10.90	9.00	56.17	2.78	11.23	8.11
Max	41.61	4.61	14.71	11.50	72.00	3.72	15.11	19.33
Mean	29.34	4.17	12.94	10.66	66.69	3.25	13.17	13.82
Range	21.07	0.73	3.81	2.50	15.83	0.94	3.88	11.22

The data in tables 14 and 15 indicate that there is very little difference in the variability across all farms irrespective of whether there was a single or more than 1 cut of grass per clamp, which is not surprising.

Tables 16 and 17 show the within clamp variability in quality depending on whether there is a single cut (Table 16) or more than 1 cut (Table 17) of silage in each clamp assessed. The data indicates that the single cut per clamp has marginally less variability within clamp than the clamps that had more than 1 cut/clamp suggesting factors other than variation in harvesting conditions between different cuts cause the within clamp silage variation.

Table 16: the Lab NIRs mean results of the within farm ranges/farm from farms with one cut/clamp

	Dry Matter (%)	pH	Protein (% DM)	ME (MJ/kg DM)	D Value (% DM)	Oil (% DM)	Intake (kg DM per day)	Milk yield (kg)
Min	4.00	0.50	1.70	0.70	4.00	0.30	1.00	4.00
Max	14.80	1.60	10.50	1.70	10.00	2.20	6.10	13.00
Mean	10.20	1.11	4.34	1.24	7.86	0.70	2.61	7.14

Table 17 Shows the Lab NIRs mean results of the within farm ranges/farm from farms with more than 1 cut/clamp. (The data in this Table is for farms where more than 1 cut was in the clamp)

	Dry Matter (%)	pH	Protein (% DM)	ME (MJ/kg DM)	D Value (% DM)	Oil (% DM)	Intake (kg DM per day)	Milk yield (kg)
Min	6.10	0.40	1.70	1.00	6.00	0.20	1.40	3.00
Max	27.90	1.60	11.30	3.60	23.00	1.90	6.00	17.00
Mean	15.46	0.98	4.74	2.00	12.69	0.77	3.65	10.69

Similar variability data was determined using the on-farm NIRs, the only difference was the absolute values and thus this indicates that on-farm NIRs can be used to determine variability in silage quality within a single clamp.

The data showing predicted intake and milk performance, is shocking showing that between 1 and 6 kg of DM is the predicted variability in intake across a single clamp with the corresponding differences in milk yield being 3 to 17 kg/cow/day. Unfortunately no LWG predictions were available.

Tables 18 and 19 indicate wet chemistry results all conducted at AFBI with the exception of pH which was performed in house. NIRS predicted values for Lactic acid, Volatile Fatty acids and ammonia-N have for a long time been suspected of being relatively poor thus it was always intended to use wet chemistry to obtain values for these parameters.

The tables follow the same format as tables 12 and 13 with mean and ranges of the farm data and the mean ranges of the within farm data.

Table 18: Wet Chemistry mean results of 9 samples/farm from the 20 farms (179 samples)

	Lactic Acid	Acetic Acid	Propionic Acid	n-Butyric Acid	TVFA	NH3/N	Ethanol	Propanol	WSC	Ash	Lactic:Acetic
	g/Kg DM	g/Kg DM	g/Kg DM	g/Kg DM	g/kg DM	%TN	g/Kg DM	g/Kg DM	g/kg DM	g/kg DM	Ratio
Min	14.90	8.84	0.09	0.00	14.30	6.33	1.41	0.00	3.29	70.08	0.94
Max	150.68	39.06	8.56	25.94	70.73	26.06	24.15	8.46	139.51	120.03	10.78
Mean	62.20	21.27	2.47	6.35	30.36	10.08	7.74	1.97	33.64	88.47	3.92
Range	135.78	30.22	8.46	25.94	56.44	19.72	22.74	8.46	136.22	49.95	9.85

Table 19: Wet chemistry Mean results of the within farm ranges/farm from the 20 farms

	Lactic Acid	Acetic Acid	Propionic Acid	n-Butyric Acid	TVFA	NH3/N	Ethanol	Propanol	WSC	Ash	Lactic:Acetic
	g/Kg DM	g/Kg DM	g/Kg DM	g/Kg DM	g/kg DM	%TN	g/Kg DM	g/Kg DM	g/kg DM	g/kg DM	Ratio
min	34.37	12.32	0.44	0.00	11.98	1.30	2.54	0.00	1.37	9.51	1.41
Max	202.17	71.46	16.38	56.90	104.32	34.40	43.35	22.02	170.72	142.76	18.94
mean	121.98	31.79	6.11	22.66	49.24	11.20	12.37	6.30	64.64	43.48	8.30
range	167.80	59.14	15.94	56.90	92.34	33.10	40.81	22.02	169.35	133.25	17.54

Tables 18 and 19 above both show that there is a large degree of variability in silage preservation/fermentation quality. It is well known that these products have an effect on the intake of silage with increased levels of them associated with decreased levels of silage intake and ultimately performance. Thus when looking at the within farm ranges it is likely that these results explain a common problem on many farms prefaced by the comment 'Oh the cattle haven't eaten up today, I wonder why'. Variation in silage preservation quality across the clamp face during feed-out will affect daily intakes and this will have a knock on effect on rumen health and production response and even meat quality by affecting daily live weight gains and keeping livestock on a consistent growth pattern.

In addition the fermentation profiles will have an impact on storage losses as the higher relative proportions of acetic and butyric acids and ammonia are also associated with the production of CO_2 and water which represent DM losses. Typical 'average' biochemical equations are indicated below. There are a number of assumptions in the equations developed below such as the pathways of formation of the end products and the specific microbial groups involved but it does enable an estimation of 'invisible' fermentation losses to be assessed. It also highlights some of the issues to farmers of these undesirable fermentation end-products in the silage.

1g DM Acetate $\longrightarrow$ 0.3 g H_2O + 0.7 g CO_2

1g DM Butyrate $\longrightarrow$ 0.4 g H_2O + 1.0 g CO_2

1g DM Ammonia-N $\longrightarrow$ 2.6 g CO_2

The formulae above have been used to estimate the 'invisible' losses on the farms surveyed at each individual sample point. Tables 20 and 21 indicate the calculated losses on a g/kg DM basis, also indicated are the DM density data and the fermentation losses on a kg DM/m^3 basis. These are included as an approximation of losses. As with the previous data Table 21 indicates the average data from each individual farm to show the mean and range across all farms, whereas Table 21 shows the within each individual farm in order to indicate the range of variability seen within farms.

Table 20: Showing the Mean fermentation losses results of 9 samples/farm from the 20 farms

	Fermentation losses g/kg DM	DM density kg DM/m3	Fermentation loss kg/m3	Financial loss (£/T DM)
Min	16.86	30.45	0.84	2.02
Max	84.60	257.64	13.61	10.15
Mean	35.38	171.30	5.66	4.25
Range	67.74	227.19	12.77	8.13

Table 21: Showing Mean fermentation losses of the within farm ranges/farm from the 20 farms

	Fermentation losses g/kg DM	DM density kg DM/m3	Fermentation loss kg/m3	Financial loss (£/T DM)
min	12.27	100.10	2.98	1.47
Max	122.56	456.55	24.90	14.71
mean	56.94	201.60	9.62	6.83
range	110.29	356.46	21.91	13.31

The percentage fermentation/storage losses estimated by this methodology between farms range from 1.7% DM to 8.5% DM with a mean of 3.5% DM (Table 20). Putting the economics to these figures and using the AHDB cost of £120/T DM to make silage then the range of losses gives values ranging from £1.40 to £11.04/t DM with a mean of £4.34/T DM. This is obviously a significant cost difference between the best and the worst farms. However behind this are the within farm ranges with % DM losses (Table 21) ranging from 1.2 to 12.3 %DM and a mean of 5.7% DM, indicating a large degree of variability in the losses depending on where in the silage clamp the silage originates. These within clamp losses show economic losses ranging from £1.45 to £16.84/t DM with a mean of £7.25/t DM. This shows the effect that silage clamp management can have on both the % DM losses and also the economic cost of silage production. More importantly it shows that within each farm if they paid attention to detail across the whole clamp they have potential to reduce the losses in the weak parts to the same as the good parts to reduce their losses and therefore cost of production. By doing this they could benchmark their own performance internally and could evaluate the cost/benefit of undertaking certain decisions during the ensilaging cycle on farm.

Key points

- Using the AHDB cost of production figures it is clear that silage is a significant annual investment on many farms with an average cost of production in the clamp assessed of £21k with much greater cost of production on some farms, given alongside this many of the farms had more than one clamp of silage.
- The average figure of 26% of the silage volume being within 0.5 m of the side wall or top sheet of the clamp also highlights the importance of attention to detail of these regions of the silage within the clamp.
- Visible peripheral waste as exemplified by rank un-feedable silage was variable with some farms having zero and others considerable quantities. On those farms with the waste this represents a considerable economic loss with 7 out of the 20 farms losing in excess of £1500 as a result of this lone with the worst farm it representing over £8000 worth of loss. However, 9 out of the 20 farms had no discernible visible silage waste. The biggest factors known to affect this are the quality of the compaction, side and top sheeting and the top weight applied subsequently.
- Variation of silage nutritive and preservation quality both between farms but possibly more importantly within a single silage clamp is generally very large and is likely to be having an impact on animal performance and health.
- Variation in silage density both between farms and within a single silage clamp is on average very large and this is likely to be one of the factors affecting the variability in silage quality.
- Across the farms particle distribution had no discernible effect on silage density.
- Aerobic stability was not a problem on most farms during the visit in January 2017. However, the visits coincided with a cold month and high feed-out rate and given the poor

density in some regions of most of the clamps visited I would expect increasing problems and DM losses during periods of elevated ambient temperatures and/or slower feed-out rates.

- The wide range of farm operations employed during silage harvesting make it difficult to draw any firm conclusions on the methods employed to reduce silage variability and silage losses.
- Fermentation quality also ranged greatly both between and within farms and these factors indicate also protein quality and silage fermentation losses. The lowest fermentation losses within the silo being 1.7% are very good however the highest of 8.5% does have a significant economic impact. The average of 3.5% is within the values quoted. However these figures represent the mean across the clamp whereas the within clamp assessments do show a higher average variability in losses of 5.7% being above the generally quoted figure and a maximum of 12.2% being considerable. Again indicating a significant economic cost of losses in weak regions within the clamp.
- The use of on farm portable NIRS devices to predict silage quality is likely to increase over the coming years. As an aside during this study it was clearly demonstrated that these devices could not simply be placed on the silage clamp face and expect a good prediction of silage quality as the NIR light does not penetrate deep enough into the silage to enable an a relevant sample to be assessed.
- The use of NIRS for many of the silage analytes was also assessed as a side issue within this project and clearly showed by comparing back to standard chemical analyses that it is important that the database used for the prediction models is updated on a regular basis to take into account, climatic, geographical and developmental variations in silage quality year on year.

Conclusions

Many farms do not pay enough attention to detail when managing their silage and there is not sufficient focus at every step of the process on what the nutritional requirements of the animal/s to which the silage is intended to be fed. This is has to be the focus and is important no matter how much silage is being produced. The best practice guidelines need to be implemented on all silage clamp management and the key points highlighted from this survey are:-

1. Compaction density of the whole clamp. Even layers no more than 15 cm (6 inch) deep and adequate rolling layer by layer.
2. Good side and top sheeting with sufficient overlap between the two to ensure a good seal.
3. Sufficient weight around the edge of the clamp, preferably sand bags touching including down the ramp and along the front.
4. Sufficient top weight, again ideally mats touching.

If these points are followed then the clamp storage quality should be enhanced, DM losses between cutting and feeding reduced and thus it will also have a knock on effect at reducing the nutritional quality losses during storage. Clamp filling management is one single factor that should be under the control of all farmers even if being done by a contractor. It is the biggest single factor affecting silage quality as it drives in silo losses and feed-out losses caused by heating of silage and aerobic spoilage. It is also the one factor that should be conducted to the highest standard irrespective of stock type being fed the silage and it has a significant impact on DM losses, cost of silage in the whole feeding system and climate change gaseous emissions (on many levels).

Important but more difficult for farmers to manage is the crop quality at harvest to meet the requirements of the animals being fed. This should be an important target for farmers. This is more challenging due to the vagaries of the weather and the arrival of the contractor. Two key targets exist here:-

1. Within this target fertiliser and farm waste application rates particular nitrogen and sulphur need to be reassessed in light not only of RB209 but also meeting the yield and crude protein requirements of the silage for the respective stock being fed.
2. Crop maturity at harvest needs closer monitoring and the linkage between stage of maturity and digestibility/metabolisable energy (ME) content re-established in the farming community and the relationship that exists between this and DM yield. There needs to a reassessment of silage quality on the two important protein and energy parameters and the initiation of concepts such as yield of protein and energy per hectare and even yield of meat and milk based on standard ME equivalents. This will re-focus the farmers mind away from green mass yield of silage.
3. Alongside these methodologies to reduce variability in silage nutritive quality across the clamp need to be employed.

Finally farmers need to be provided with both the training and the tools to assess their silage on their farms. This would in the first instance require training of the trainers. In the UK the current trainers are either silage additive sales reps or feed reps and it is my belief and as a gross generalisation that neither of these groups have the skill set required to adequately inform farmers of the real factors affecting silage quality as in general they are trying to make a sale of a product.

The first step would be for every farm to possess instruments to assess aerobic spoilage namely two probe thermometers, one with a 10-15 cm long probe and a second with a 40-50 cm long probe. By using these probes as comparators a good assessment of the problems of aerobic spoilage can be made. The long probe should have a higher temperature than the short probe, with the short probe being closer to the ambient temperature of the day. In addition every farm should have the tools required to assess density. This requires a steel tube with one sharp edge with a diameter between 5 and 6 cm and approximately 1 m in length, a tape measure and a balance. By measuring density and temperature the farmer will begin to understand the relationship between aerobic spoilage, silage preservation quality and silage density.

These steps should be backed up by training courses that enable farmers to make assessments of visual and sensory silage quality on farm.

By assessing their own silage quality farmers will begin to make the link between the effects of various management decisions they make and the silage feeding value, for example since conducting this survey, I was presenting at an AHDB farm event and showed at the clamp the variation in density on the silage clamp between the left and the right hand side. The farmer acknowledged that the intake of the poorer density right hand silage was often lower than the higher density left hand side silage. This is matched to the fermentation quality as more undesirable end-products such as acetate and ammonia are produced in lower density silage, due to the greater influence of air on the initial preservation process.

Examining all the data and considering all aspects I would suggest that if this were a silage competition Farm 1 would be the winner. This farm has the lowest variability in the on-farm parameters measured and whilst this farm did have some peripheral visible waste it was small in quantity and I suspect did not move back in the clamp with feeding time. In addition this farm payed very close attention to detail of all management practices with good sealing, high density and low variability in density across the clamp face. Also the management of the top of the clamp was ideal

with sufficient top weight to enable consolidation and density of the top region of the clamp to be maintained. This farm would be ideal for a case study.

Appendices Not for Publication

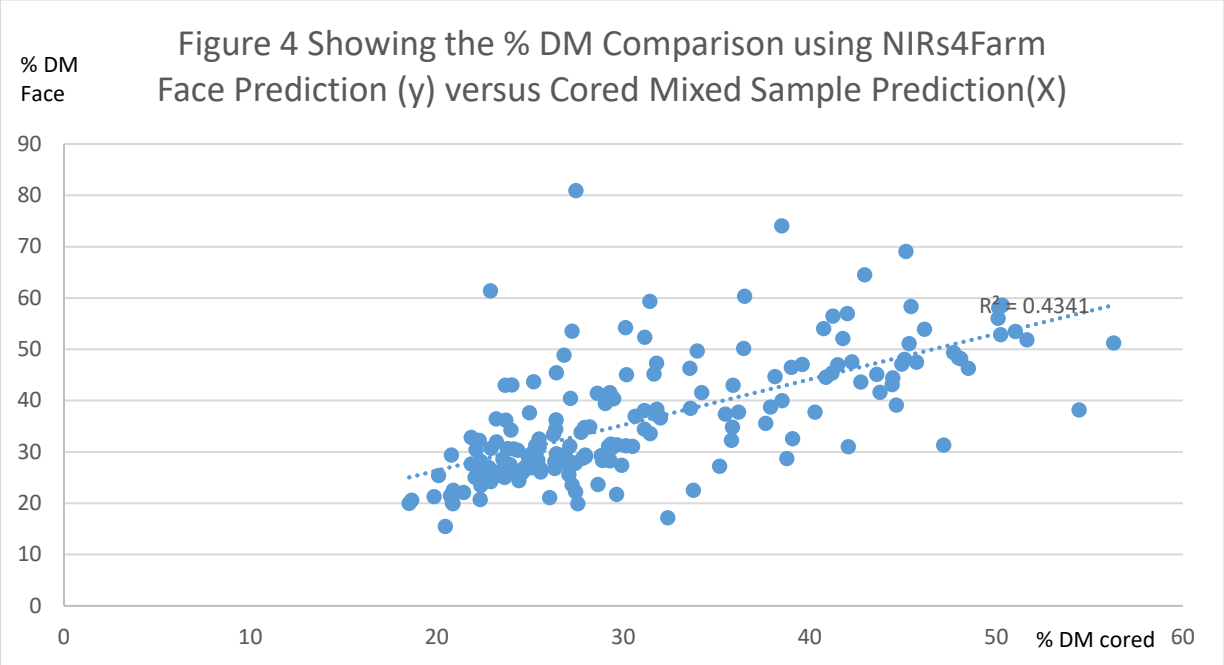
Appendix 1

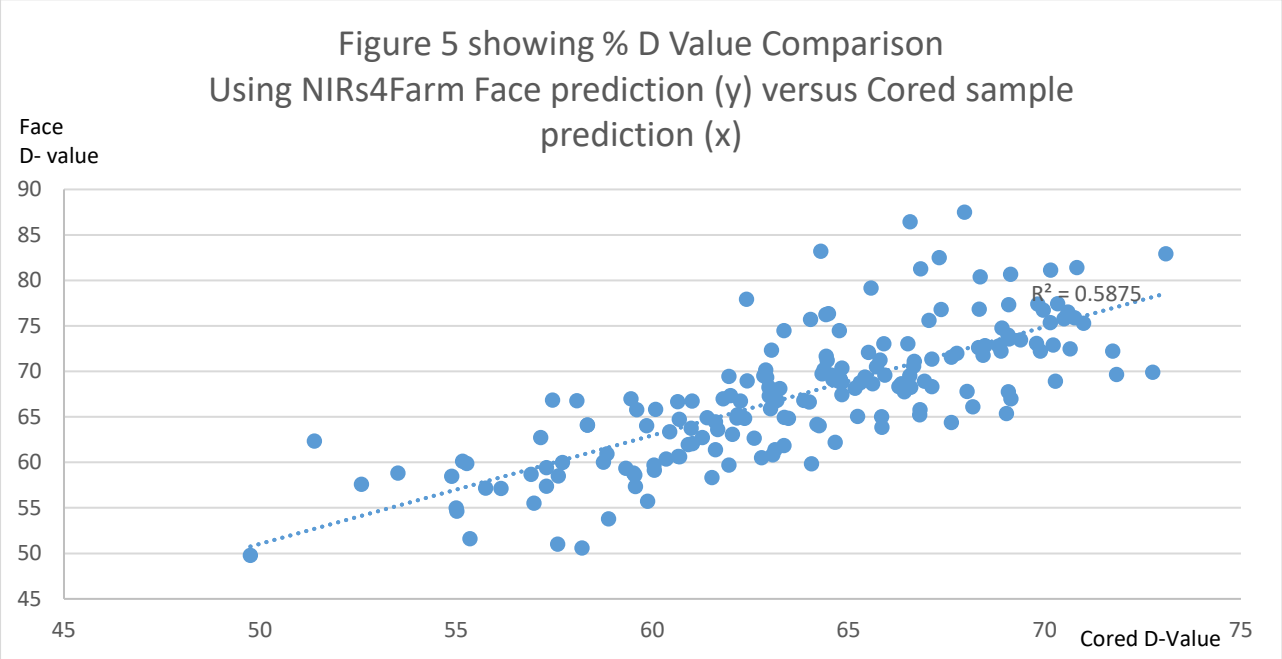
Future Work

1. **Re-evaluation of the commonly prescribed 'W' method for obtaining a representative sample from a silage clamp face for analysis. I would suggest an intensive 1-2 week study on 2-3 farms examining the 'W' versus other methodologies to compare with the silage composition as fed. This should be done in conjunction with silage density measurements**
2. **Considerable work is required in the area of NIRS calibrations and the accuracy of the NIRS predictions. This is a great cause for concern for key nutrients such as crude protein and predictors of energy. I would suggest that the use of NIRS as it currently stands for the prediction of fermentation parameters of Lactic acid, VFA, Ethanol, and ammonia-N is pointless. Many farmers use these parameters to assess the value or otherwise of their additive purchases. I would propose an alternative rapid methodology that warrants further investigation.**
3. **A real assessment of losses and their impact on silage nutritive value and variability across a single clamp face at feed-out could be conducted at the time of harvest on 3 farms. Whereby every load of grass entering the clamp is sampled and analysed and at feed-out a large number of samples are also taken on a regular basis to assess total losses from the point of ensiling to the point of feed-out. With such an approach it may be able to ascertain markers for losses which could then be used in all silage analyses in the future to give an estimation of ensiling losses.**
4. **The development of a simple mobile application to assist the farmer during filling the clamp and compacting it could be developed to ensure the optimum layer depth is maintained. This could be done very easily using simple maths and GPS systems.**
5. **The samples obtained should be analysed for minerals to assess the variability in silage mineral content across and within farm clamps.**
6. **The impact of the weaker points of the silage clamp namely those parts closer to the wall and top sheet on animal health should be investigated. This should involve a twin target. Firstly how these points affect diet formulation where a complete mixed ration is being fed and how the nutrient variability affects forage:concentrate ratio in the ration. This will have a knock on effect on production diseases such as acidosis, laminitis and fertility. Secondly the influence these parts of the silage clamp have on infectious diseases and disease agents, in particular *Listeria* sp, *Bacillus licheniformis* and microbial toxins such as Clostridial toxins and mycotoxins.**

Appendix 2 NIRS and Wet Chemistry Comparisons

The following four figures show the regression analyses of face versus cored for the 177 samples assessed, for the analytes Dry matter, Digestibility, Crude Protein and pH.





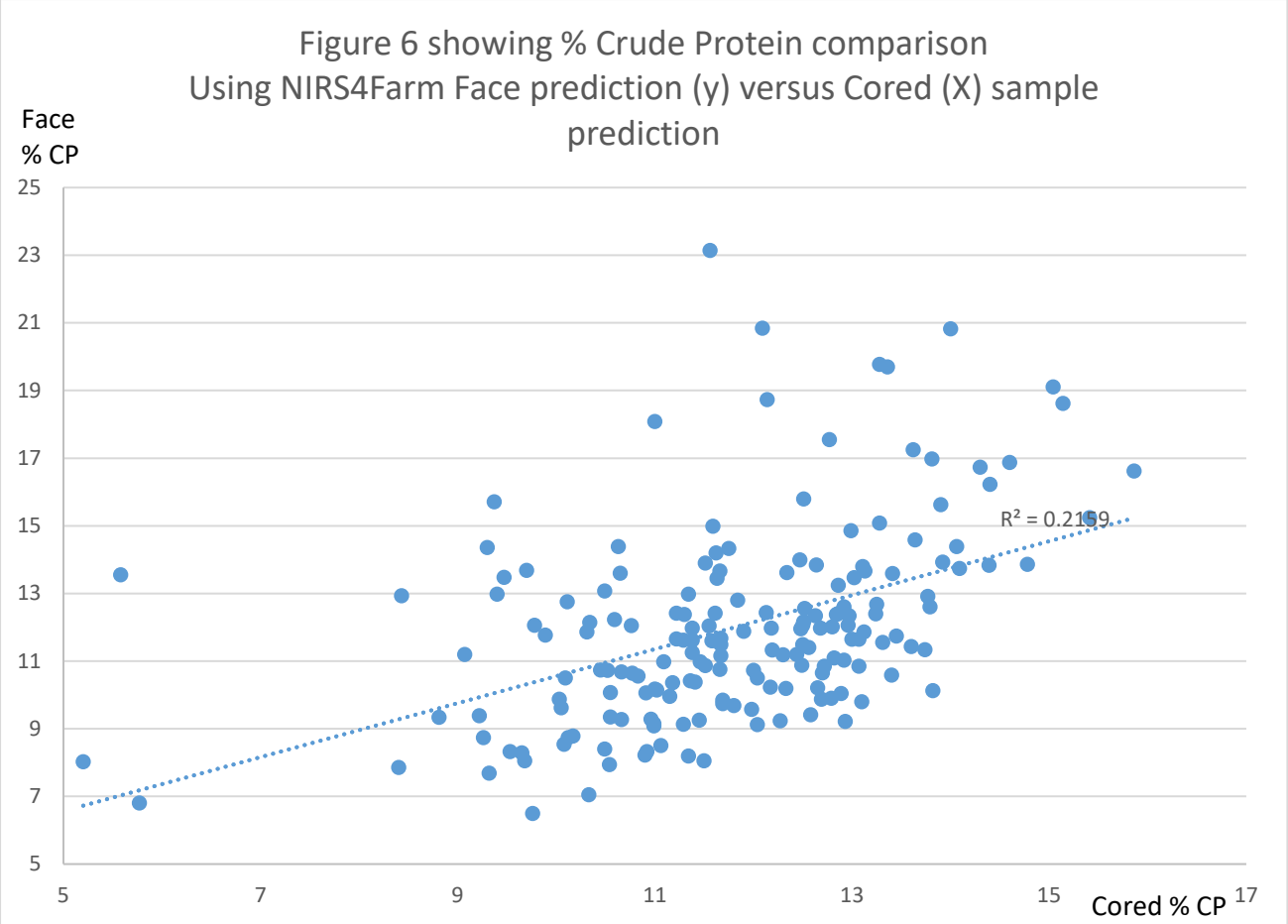
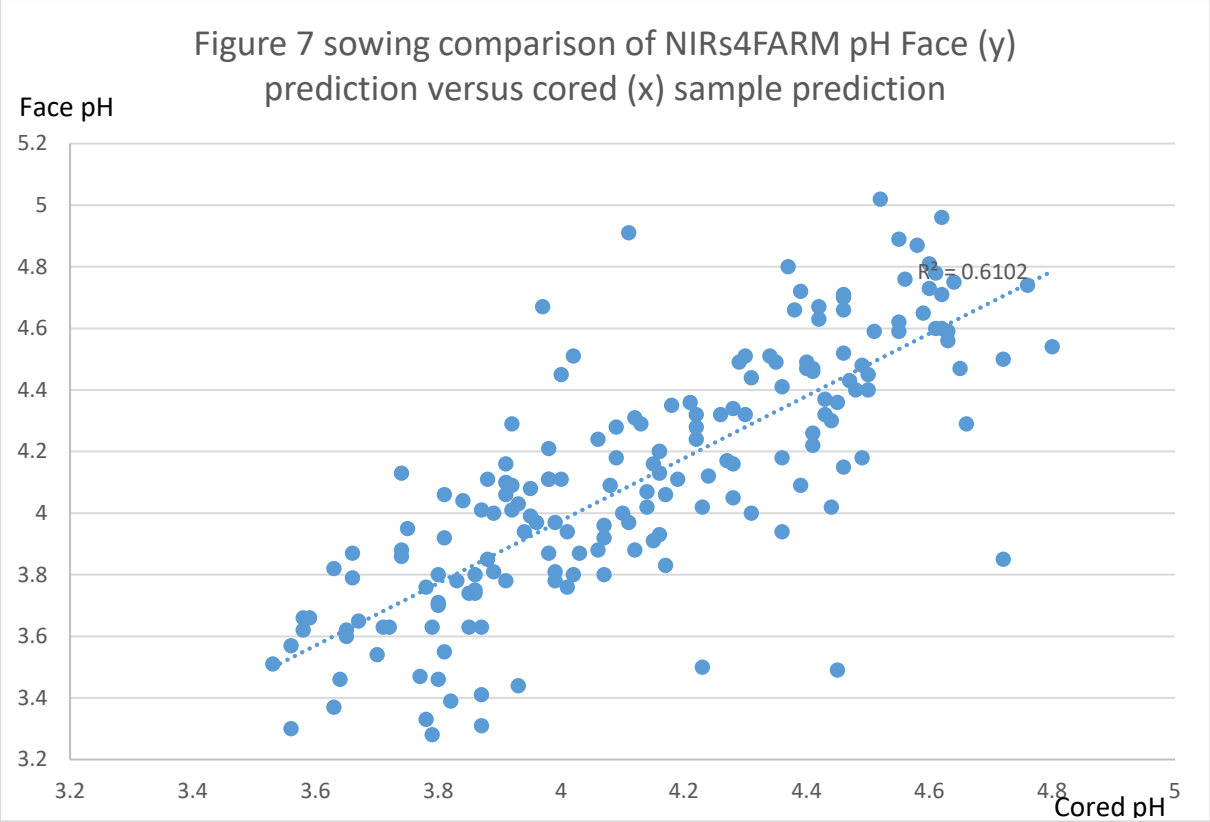


Figure 6 showing % Crude Protein comparison
Using NIRS4Farm Face prediction (y) versus Cored (X) sample prediction
Face % CP
25
23
21
19
17
15
13
11
9
7
5
5
7
9
11
13
15
17
Cored % CP
R² = 0.2159



All the analyses shown (Fig 4-7) indicate that by taking the easy option of placing the NIRs analyser on the silage open face will give you an inaccurate prediction of the nutrient content. This is not surprising as the maximum depth Near Infra Red light will penetrate the sample is less than 0.5 cm and the face of any silage clamp will undergo some changes relative to the silage immediately behind it. Whilst on-farm NIRs devices are likely to increase in the coming years there still needs to be correct sample analysis and presentation to the analytical instrumentation being employed.

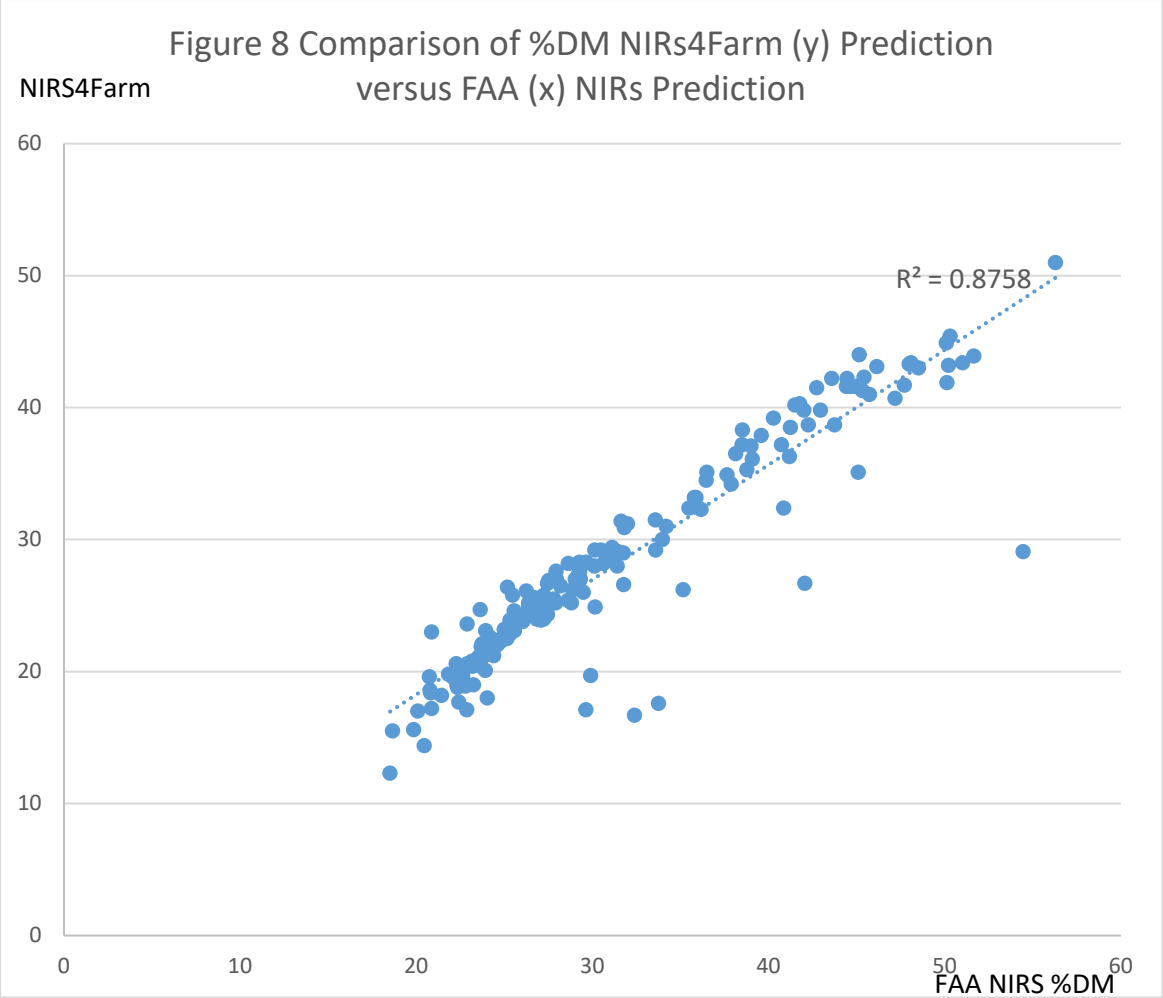
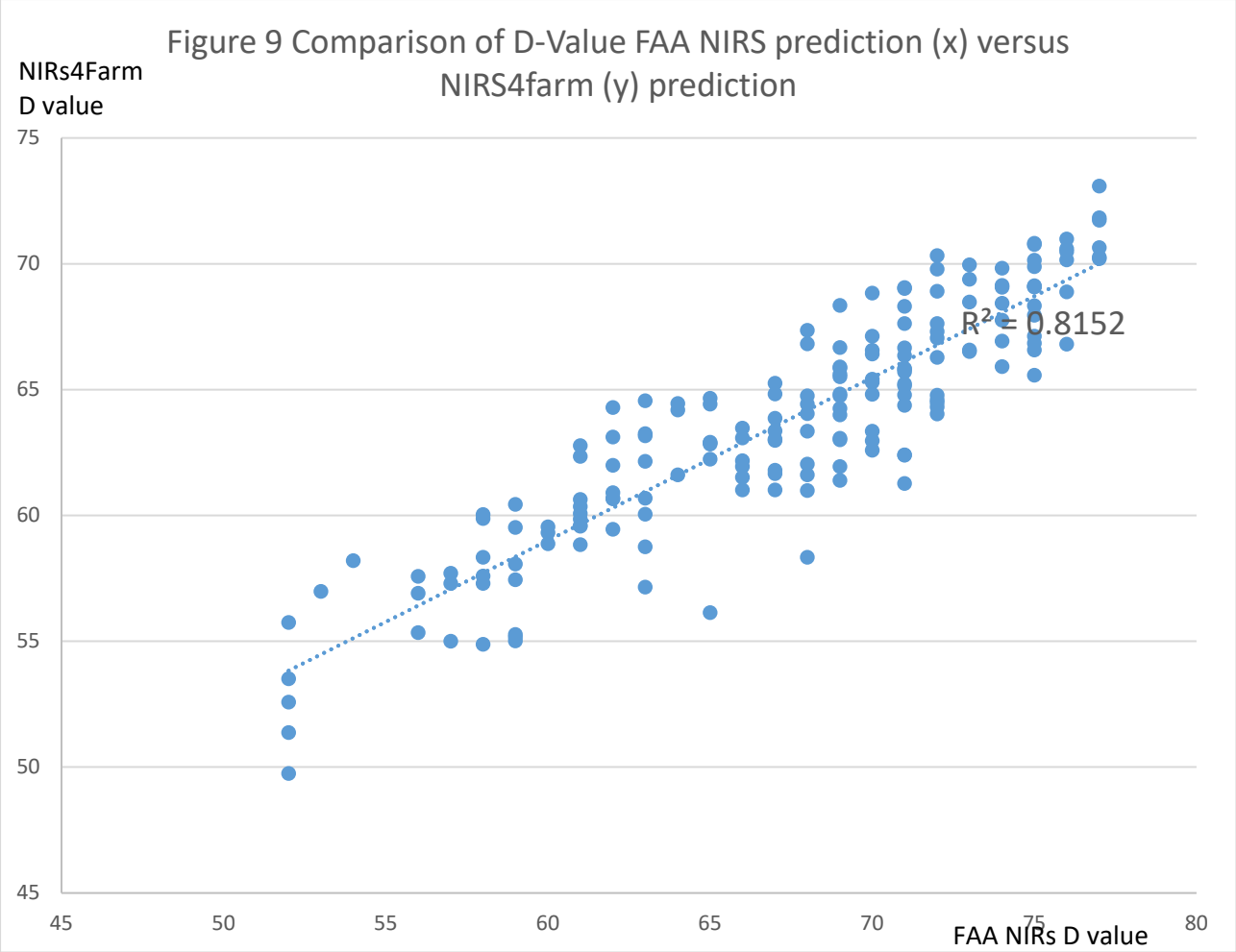
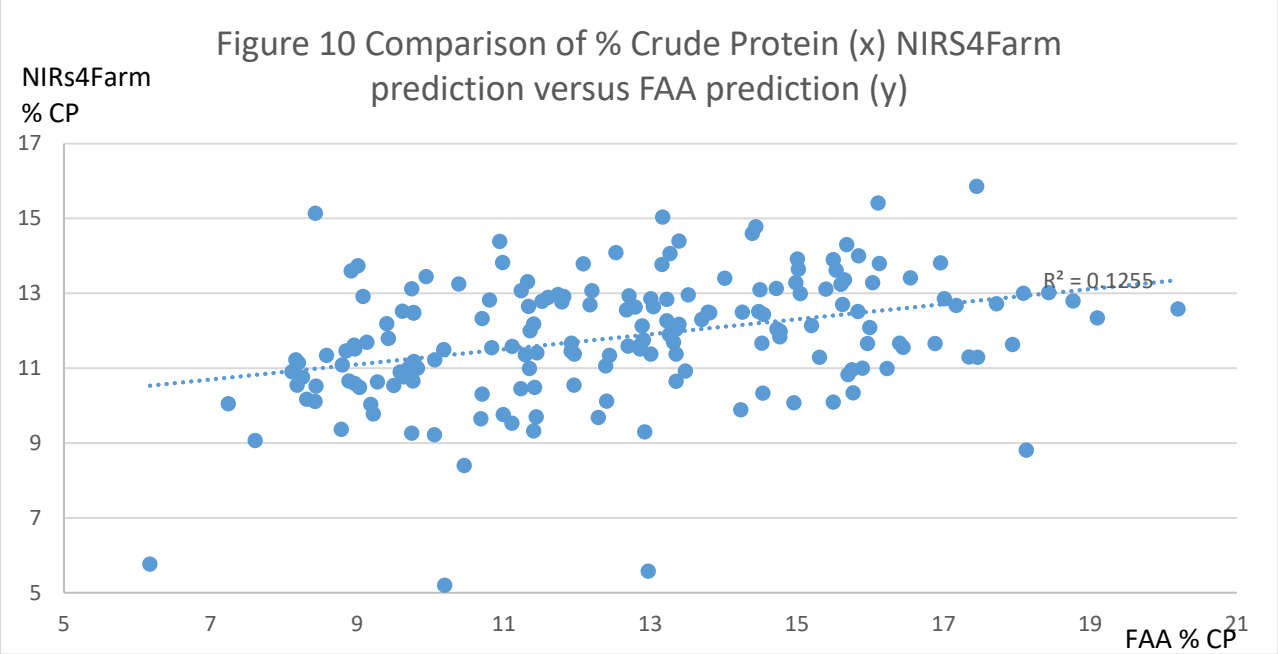


Figure 8 above shows the relationship between the on-farm NIRs prediction (in a mixing bowl?) and the laboratory NIRs prediction for %DM. The prediction is quite good with just a few outliers.



The Figure above shows the same comparitive data for on farm and lab based NIRs for % D value. Whilst the r^2 value is good at 0.82 closer inspection of the values show that there are differences in the predicted values for the two methods in a number of situations and there is a skew away from the angle of 45^o which would indicate a perfectly corresponding prediction for all samples.



The data for protein shows a very poor correlation between the two NIRs prediction equations for crude protein and really there is no relationship between the two methodologies.

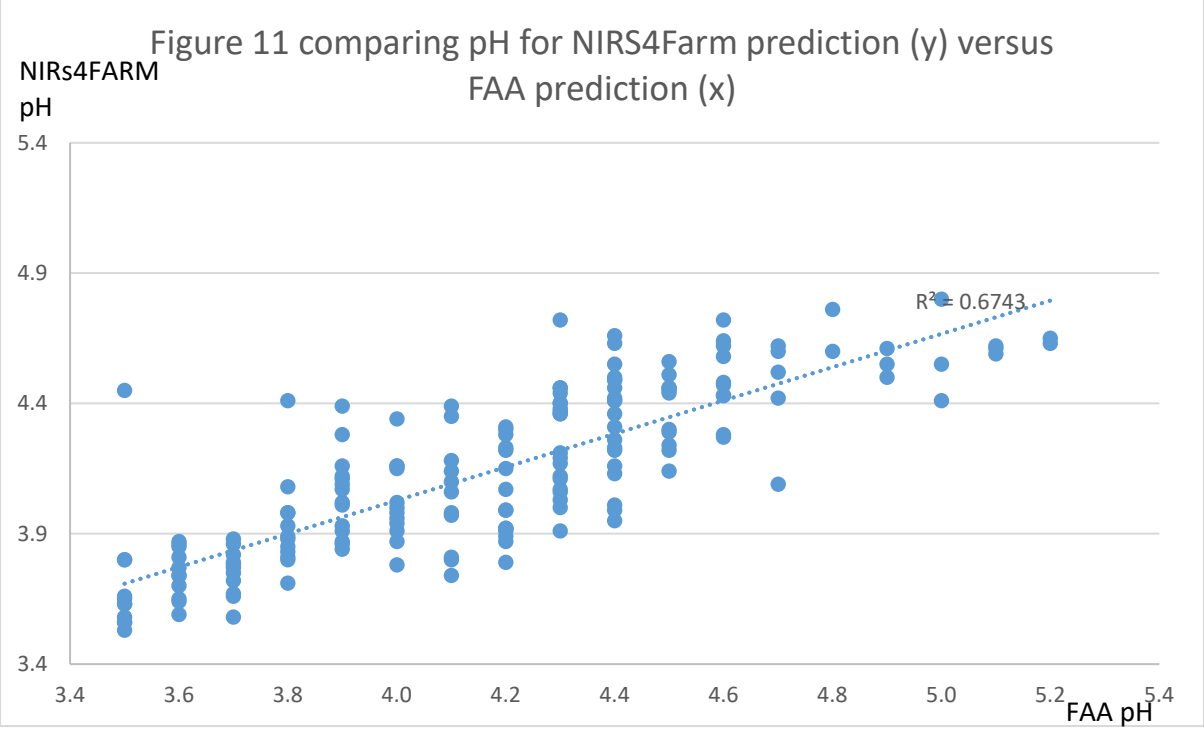
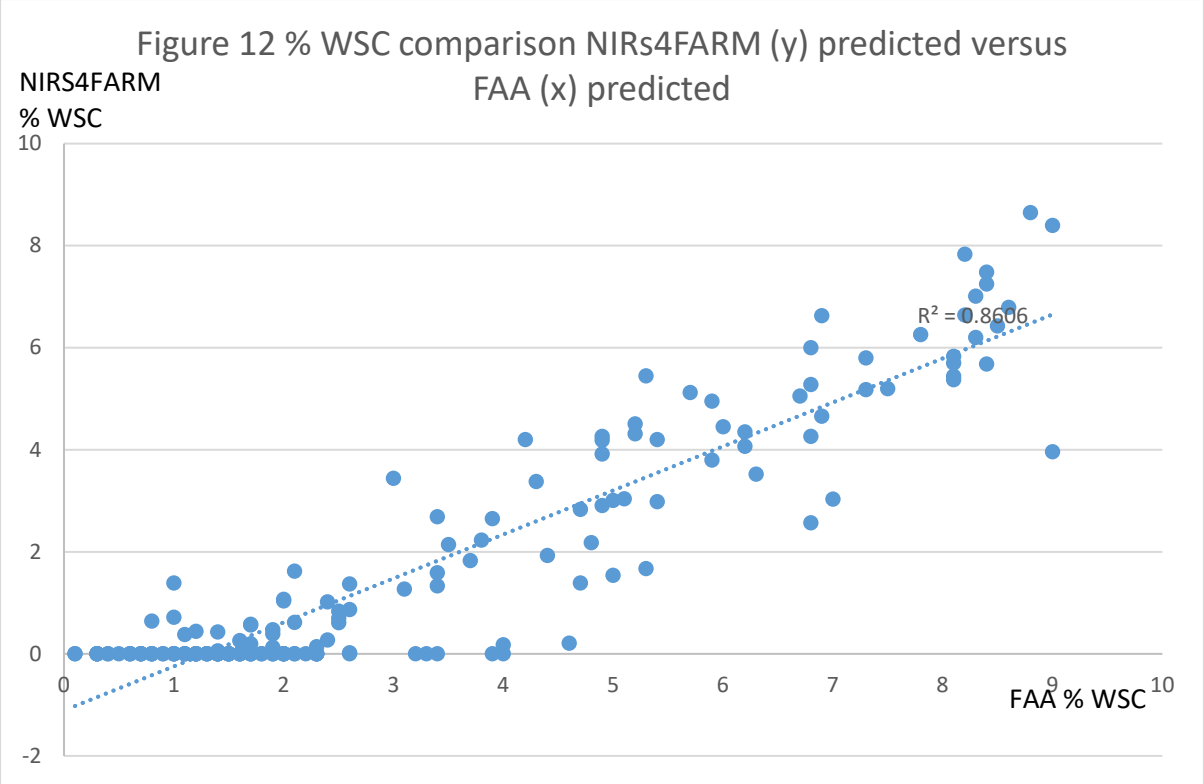


Figure 11 showing the relationship between the two NIRs methodologies for pH, the r^2 value of 0.67 indicates a relatively weak relationship between the two predictions, to explain a little more looking at the value for pH of 4.4 on the x axis predicted by the Lab NIRs then the On farm NIRs gives values for those samples ranging approximately between 3.95 and 4.66.



The final comparison graph shown for the two NIRs predictions is that for water soluble carbohydrate the r^2 value is very good but in this case is very misleading in terms of the absolute value that is reported to the end-user as the on-farm prediction is consistently under-predicting by 2-3% units.

Laboratory NIRs compared to wet chemical analyses

The following section compares the laboratory NIRs results to the recognized wet chemical methodology.

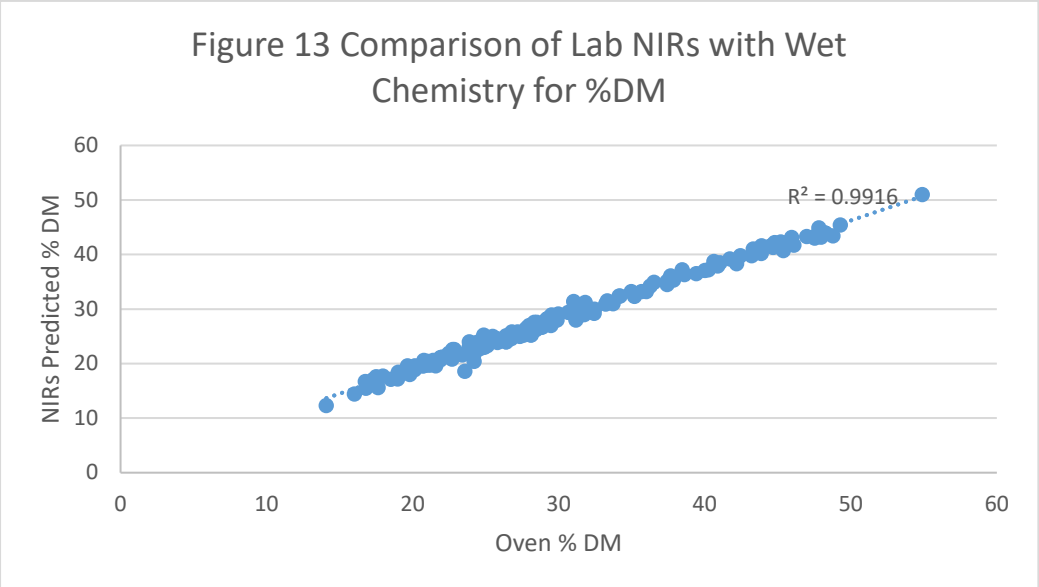
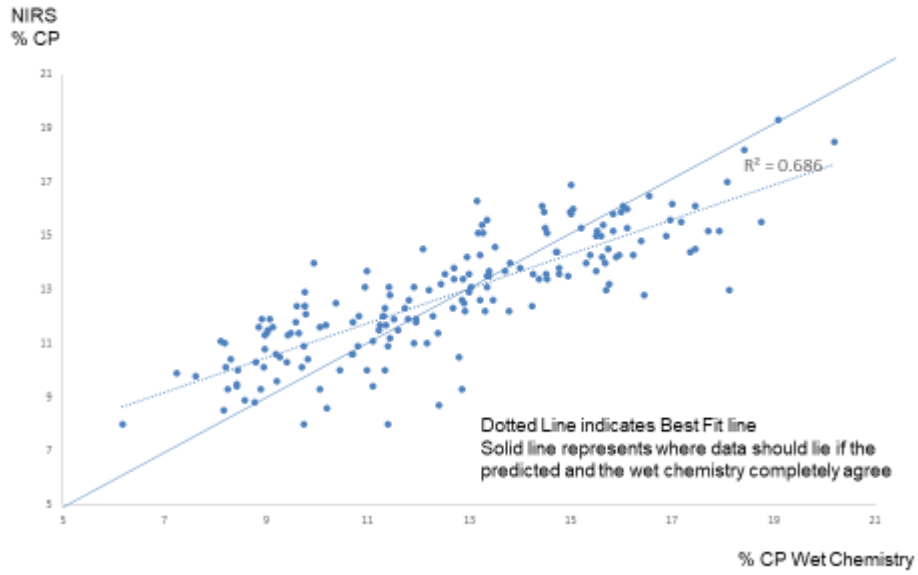


Figure 13 shows the relationship between Lab based NIRs predicted DM and Oven DM and the predicted values are in very good agreement with the traditional wet chemistry methodology over a wide range of parameters.

D-value is not included in these comparisons because all the methods employed use a prediction to obtain the D-value. The only way to determine the D value precisely is in a feeding trial where the whole tract digestibility is measured by feeding a known weight of silage to a ruminant and collecting all the faeces over the feeding period and then calculating the D-value from the difference between silage weight fed and faeces weight collected. This was not possible in this project. However, given that so many of the other predictions were poor when related back to the underlying chemically determined analysis it does bring into question the accuracy of the current NIRS predicted D values for English grass silages.

Figure 14 Comparison of Lab NIRs Prediction and wet chemistry for % Crude Protein



The data in figure 14 show the comparison between Lab NIRs predicted % CP and Wet chemistry based on a total nitrogen analysis multiplied by 6.25 which is the agreed global standard for the average nitrogen content of forage proteins. The data shows a relative poor prediction for such an important nutrient that is used in all rationing programmes and considering that the ammonia-N and the a, b, and c protein fractions are based on a proportion of the total crude protein then these analyses will also have a lower accuracy of prediction and thus the accuracy of rations based on them, ie the proportion may be correct but the absolute g/kg DM will not be. The dotted line indicates the best fit regression line, whereas the solid line indicates the line where all values should fall if the prediction back to wet chemistry was 100% accurate. The data indicates that the low Crude protein silages are being over predicted by NIRs whereas the high crude protein silages are being under predicted by the NIRs prediction. The inaccurate prediction is as a consequence of the database that is used for the original calibration and this can be compared with the report produced by Cedar on the red clover Dairy Co funded project where one of their conclusions was that there were inaccuracies in the prediction of Crude protein concentrations of silages even when there were very low levels of clover in the silage being analysed.

Figures 15 and 16 show the comparisons between % WSC content analysed by Wet chemistry compared to Lab NIRs. Figure 15 shows the comparison graph for samples with 5% WSC of lower, this indicates an r^2 of 0.529 is poor, but at this low level of WSC it is more difficult to be so precise using NIRs and at this level NIRs is generally over predicting the %WSC but the individual values are relatively close on the predicted compared to the chemical derived value. Figure 16 shows the entire dataset and indicates that whilst the r^2 value is better (0.72) than the previous figure, that overall there is an under-prediction of the %WSC by the NIRS methodology. This is a reflection on the age and sample database from which the Lab NIRs prediction is based on, which were generally low in % DM, with grass cultivars that are in general not so widely used and possibly with silage additives that were not so effective.

Figure 15 Comparison of % WSC for samples analysed by wet chemistry with ca. 5% WSC or less compared to LAB NIRs Prediction (n=135)

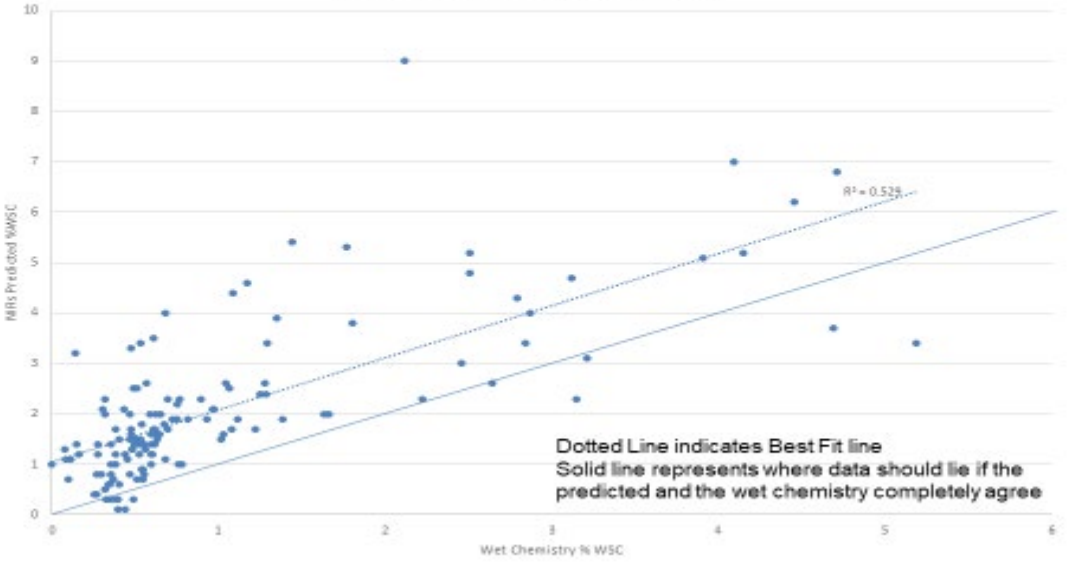


Figure 16 Comaprison of the %WSC Wet chemistry versus Lab NIRs Predicted

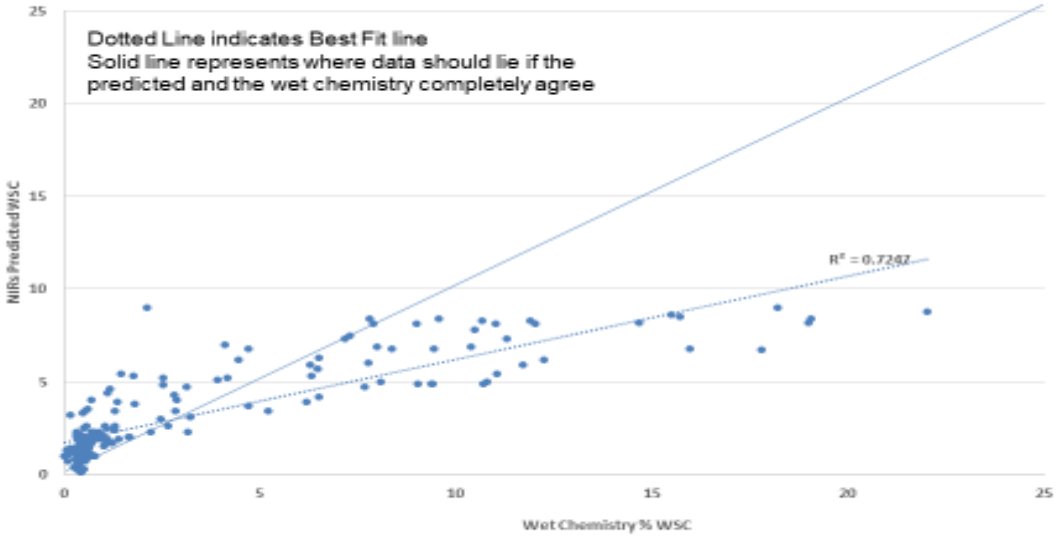
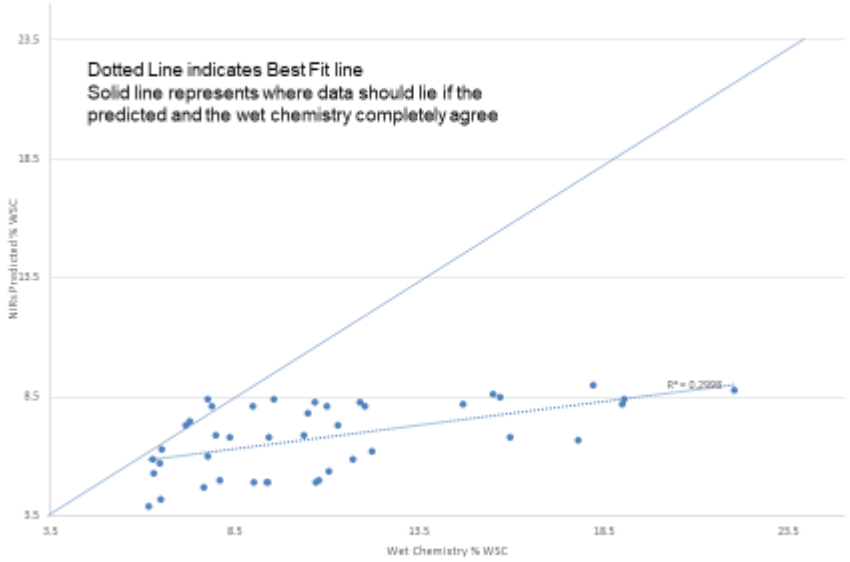


Figure 17 Comparison of % WSC for samples Higher than 5% on Wet chemistry (n=41)



For completeness sake graph 17 shows the relationship between the two analytical methods for samples higher than 5% WSC by wet chemistry.

Figure 18 Comparison of Wet chemistry and Lab NIRs Lactic Acid Concentration (g/kg DM)

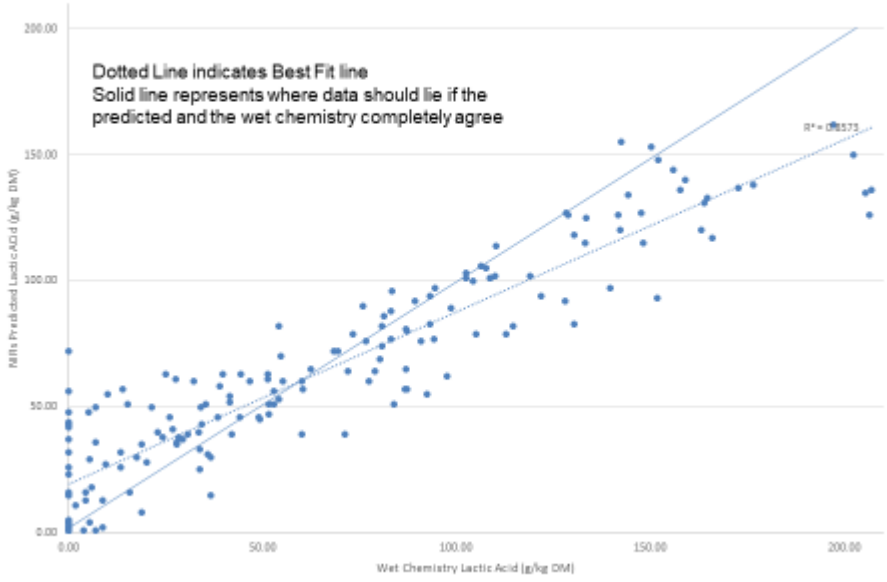


Figure 19 Comparison of Wet chemitry and Lab Nirs prediction of VFA concentrations (g/kg DM)

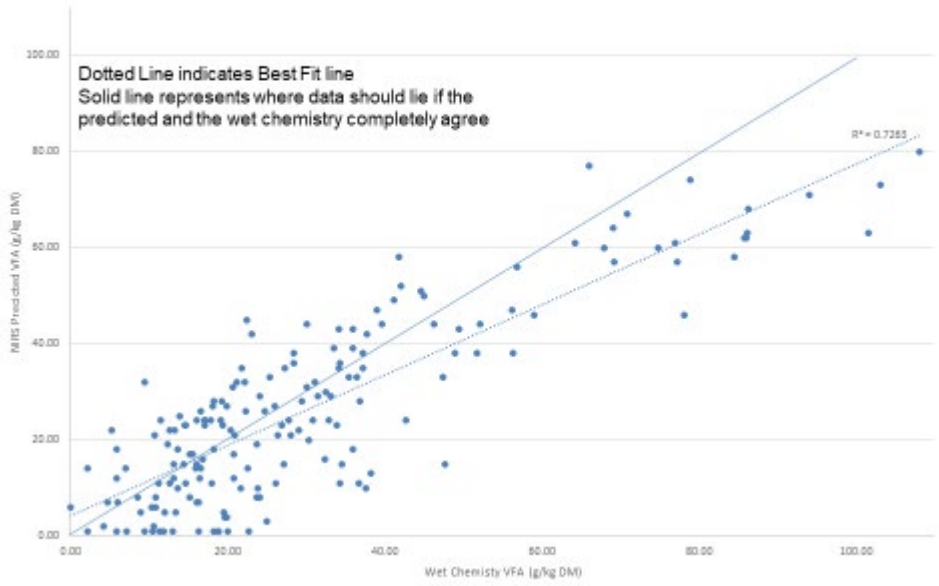
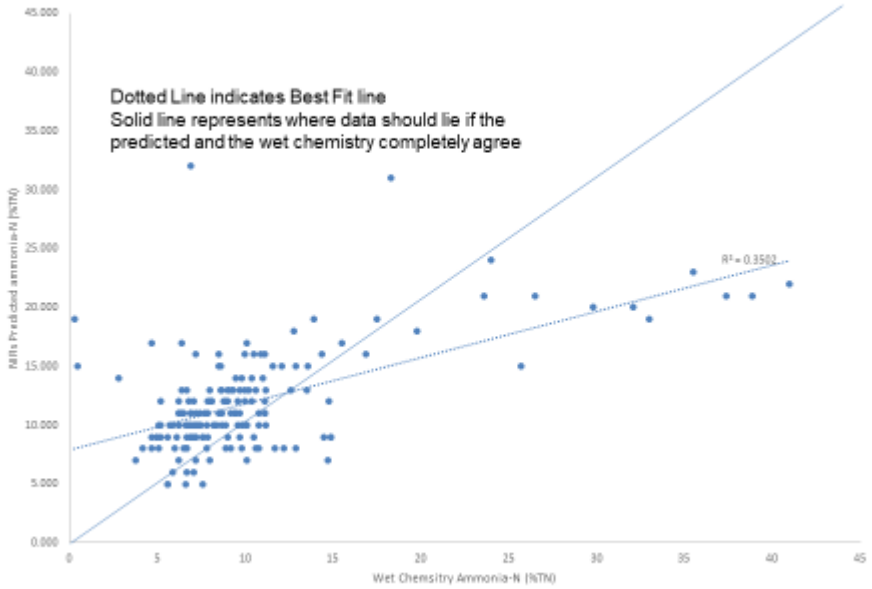


Figure 20 Comparison of Wet chemistry Versus Lab NIRs for Ammonia N (% TN)



Figures 18, 19 and 20 show the comparisons of Wet Chemistry to lab NIRs prediction for Lactic acid (g/kg DM), Volatile Fatty Acids (g/kg DM) and Ammonia-N (% TN) respectively. These are the main markers for the estimation of silage quality along with WSC concentration. The r^2 values are relatively good for lactic acid and VFA but poor for ammonia-N. However the values when compared on an absolute value comparison the data indicates that for both Lactic Acid and often Ammonia-N that the NIRs prediction is over predicting values for silages with lower concentrations and under predicting for silages with a higher concentration. However for the VFAs the opposite is true with over prediction of silage with low concentrations and under predicting for silages with a higher concentration. This alongside the results for the WSC concentrations has very important implications for the farmer and the management choices they are making. The reason being it is

indicating much smaller differences in fermentation quality between what could actually be quite different. Factors that affect the fermentation quality are compaction, sheeting properly and additive use. So these results are not informing farmers properly of the choices they should be making and they are probably being used to support the sale of products to farmers that should not be used, all on the basis of poor fermentation quality predictors by NIRs.