Development of a maize forage sampling system to accurately determine dry matter percentage

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Abstract

Field sampling, sub-sampling and laboratory methodology for maize forage DM % determination, from both trucks and finished stacks, were investigated in the 2001-02 and 2002-03 seasons. A number of sampling and sub-sampling techniques were tested. A target 95 percentile confidence interval of ±1.0 % from the true mean DM % appears to be a realistic target for maize forage assessment when samples are collected from completed stacks and sub-sampled in the field. For stack sampling, testing showed that to be 95 % confident of estimating the true DM % to within 1.0 % for 95 % of stacks sampled, seven individual auger-cores (samples) need to be taken equidistantly along the formed stack, with each sample submitted for DM % testing individually. To reduce the number of samples submitted to the laboratory, the use of a riffle-box proved the most accurate and unbiased sub-sampling technique. To get the same level of accuracy, 10 auger-core samples must be collected and combined through the riffle-box, from which 1-2 sub-samples then need laboratory testing. Determining forage DM % by sampling from trucks proved more difficult. A minimum of 52 trucks per paddock (source) need to have one composite sample (sample made up of at least four hand-scoop samples combined per truck) tested individually to be 95 % confident of estimating the true DM % to within 1.0 % for 95 % of paddocks sampled. Sub-sampling of truck samples was not conducted.

Additional key words: silage, fair-trading, auger-corer, riffle-box, quartering, stack, truck, wet weight.

Introduction

New Zealand has seen a significant increase in maize silage production over the past five years. Much of this increase has been on arable farms where crops are grown under contract for the dairy industry. An area of concern for maize growers and end-users pertains to the 'fair trading' of this forage. Of major interest to the industry is the development of a standard practice (methodology) for the collecting and assessing of maize forage samples. This will help determine the true value of the forage for both trading and feed budgeting purposes and alleviate disputes among growers, contractors, traders and end-users.

Chopped maize forage is non-homogeneous containing both cob and stover and is generally traded on a kilograms of dry matter (kgDM) basis (FAR, 2002). The ratio of cob:stover and the dry matter (DM) of each will vary between and within paddocks and between hybrids in the same paddock (Daynard and Hunter, 1975). It is essential that any sampling system ensures that the sample provided for analysis is representative of the bulk quantity (stack or truckload) as a whole. Any change in the ratio of cob:stover in a sample can greatly affect the final DM and quality parameters of that sample (Deinum and Struik, 1980; Cherney *et al.*, 1996). Current maize forage sampling practices vary among contractors, with most taking 1-3 random hand grab samples per stack or source for % DM analysis. It is unknown exactly how much maize forage is traded on a weight basis, nor is there any published information on the current levels of accuracy of current sampling and testing systems used in New Zealand. A study that had two people sub-sample the same chopped maize plants found a 20 g/kg (2 %) difference in DM content of samples from the two individuals (Deinum and Struik, 1980). When DM % assessment is incorrect, either the seller or the buyer loses financially. The monetary impact of DM accuracy is illustrated in Table 1.

Table 1: Examples of differences in gross return per hectare ($/ha) for both growers and dairy end-users, for different estimated DM %s. The true DM% is assumed to be 35 % and the wet weight is 57.14 t/Ha[1].

Sample DM %	Variance from True DM (%)	Calculated DM Yield (t DM/ha)	Return or Cost in $/ha (@ 16c/kgDM)	Difference in value of forage to dairy end-user ($/ha[2] purchased)
35%	0%	20	$3200	$7200
34% or 36%	±1%	20±0.6	$3200±$91	$7200±$205
30% or 40%	±5%	20±2.9	$3200±$457	$7200±$1028

[1]Estimated wet weight per hectare for an average forage crop at correct forage harvest maturity.
[2]Calculated assuming 100 gMS/kgDM consumed, with a production payout of $3.60/kgMS (36 c/kgDM).

There are three key issues which need to be considered in developing 'best practice' recommendations for maize forage DM determination: (a) accurate determination of bulk weight of each truck load that make up a forage stack (wet weight determination), (b) accurate sampling and sub-sampling of formed stacks or truck loads to obtain a representative sample for laboratory submission, and (c) standardised and accurate laboratory sub-sampling and testing procedures to accurately measure DM % (FAR, 2002).

Trading forages on a weight basis is not common internationally and there are no current commercial best practice recommendations available. Unlike homogenous grain samples and other forages, stover and cob particle sizes and weights differ greatly from one another, producing a non-uniform substrate with poor mixing and flowability properties (Bilanski *et al.*, 1986). Most small plot trials take whole plants as individual samples, with no sub-sampling. Wolkowski *et al.* (1988) found that a sample size of 10-15 whole plants per plot minimized the coefficient of deviation of maize dry matter yields. This size sample is unrealistic under commercial conditions without sub-sampling. This paper summarises the research conducted by the Forage Trading and Development Group (FTDG), whose members include growers, contractors, end-users and industry representatives, over both the 2001-02 and 2002-03 maize silage seasons. It specifically summarises findings pertaining to accurate sampling and sub-sampling in the field, of maize truckloads and forage stacks (pre-ensiling) made mostly from one source (typically one paddock per stack). Laboratory procedures are reported by Hill and Ballinger (2004) in these proceedings.

Materials & Methods

The type of sampling technique, position of sampling and the number of samples taken per site varied across sites. The general procedure for sampling at each site (stack or truck) was:

1. Remove the top 15-20 cm of forage from proposed sampling position and

then use one or several of the sampling techniques to obtain samples approximately 1000 g in size at each sampling position.
2. Number and record bags identifying test site, sampling technique used, source (truck or stack) and sampling position.
3. Some samples were bulked together and then replicated sub-samples taken by various techniques.
4. Final DM % test samples placed in airtight zip-lock bags and placed in cool location until end of site sampling. Fresh weight of samples submitted to the laboratory was approximately 1000 g.
5. Samples then either sent directly to Hill Laboratories for testing or frozen if unable to be dispatched on overnight courier to the testing laboratory within 12 hrs of collection.

Sampling Techniques

In 2001-02, three sampling techniques were trialed: (i) 'hand-scoop' (HS) using two hands in a cupped fashion, (ii) 'handheld plastic scoop' (PS) using a generic scoop, and (iii) electric 'auger corer' (AC) 1.5 m long x 50 mm diameter, made up of a stainless steel outer tube revolving at 120 rpm and an inner auger revolving at a higher speed. Several HS and PS collections from each sampling position were required to make a 1000 g final sample, while each AC collection yielded 1000 g/sample. Six maize forage stacks and their truckloads were sampled as described in the following two sections. No sub-sampling techniques were evaluated.

In 2002-03 there were two objectives which arose from the 2001-02 work: (a) verify the number of AC samples needed per stack using a larger number of stacks, and (b) evaluate various sub-sampling techniques to reduce the number of samples submitted to the laboratory for DM % testing. In 2002-03, only the AC technique was used to collect initial samples and only stacks were tested. A large number of initial samples were taken to provide the stack's true DM % estimate (referred to as 'Gold Standard') for sub-sampling results to be compared to. Following initial sampling, four sub-sampling techniques were evaluated. These were: (i) AC taken from samples layered in a tube, (ii) six-compartment riffle-box, (iii) quartering, and (iv) barrel mixing.

Truck Sampling

Truck sampling was only conducted in 2001-02. Sample collection took place from either the top of trucks as they went over a weighbridge or immediately after the load was dumped at the stack, as soon as possible after harvesting. Initial truck sampling at Site 1 was intensive to identify both within and between truck variability and also variability among sampling techniques. This stack was made up of 11 truckloads, totaling 125.6t wet weight. The systematic sampling system (Fig. 1) by truckload for Site 1 was:

- Truck No. 1,2,3,5,6,8,9 – HS samples taken at each of nine positions (n=63)
- Truck No. 4,7,10 – HS, PS and AC samples taken at each of nine positions (n=81)
- Truck No. 11 – HS samples taken at 3 separate depths at each of 13 positions (n=39)

The remaining five sites had fewer samples collected per truck (refer to Table 2).

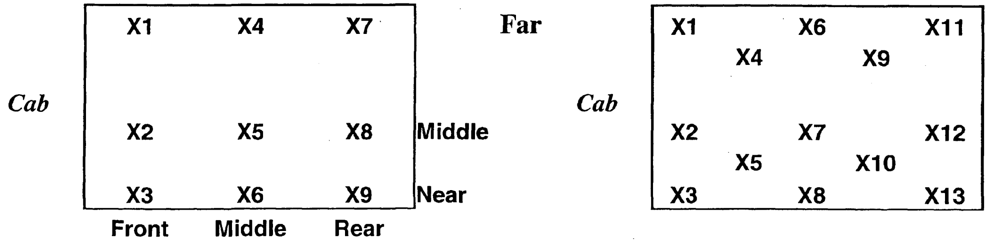

Figure 1: Each truckload had either 9 or 13 sampling positions (X) located as follows (birds-eye view):

Table 2: Summary of truck sampling by site and sampling technique for 2001-02 trials.

Site ID	No. trucks sampled	No. HS samples individually tested	No. PS samples individually tested	No. AC samples individually tested	No. composite[+] sub-samples individually tested
1	11	129	27	27	0
2	13	36	0	4	39
3	15	0	0	0	45
4	13	0	0	0	39
5[^]	22	0	0	0	66
6[#]	21	0	0	0	69
No.samples /technique	-	165	27	31	258

[+] 4-9 HS samples taken per truck, then combined in a bucket and three 'composite' sub-samples extracted by HS and submitted for DM % testing.
[^] Stack made from maize harvested from two sources, one source delivered by truck the other by tractor.
[#] Built over three different days.

Stack Sampling

Stacks were sampled once they were completely compacted but before the cover was applied. Initial stack sampling at Site 1 (2001-02) was again intensive, to identify both within stack variability and variability among sampling techniques. As with the truck sampling, this stack was made up of 11 truckloads, totaling 125.6t wet weight and was approximately 16 m long x 8 m wide. Sampling positions are presented in Figure 2. Subsequent stacks had 12 sampling positions approximately 1m either side of the centre line taken equidistantly along the length of the stack with both AC and HS sampling techniques, making a total of 48 samples per stack. Stack sampling techniques are listed in Table 3. When more than one sample was taken at a particular sampling position, it was taken at least 0.2 m from where any other sample has been taken.

Table 3: Summary of stack sampling by site and sampling technique for 2001-02 trials.

Site ID	No. HS/stack individually tested	No. PS/stack individually tested	No. AC/stack individually tested
1	30	30	30
2	24	0	24
3	24	0	24
4	24	0	24
5	24	0	24
6	11	0	0
No. samples/technique	137	30	126

In 2002-03, a further 14 stacks had a number of samples collected by the AC technique only, in a single line equidistantly along the spine of the finished stack. Eleven stacks had 2-5 sets (replicates) of AC samples taken at each of 14 sampling positions (28-70 samples per stack), which could then be used for sub-sampling evaluation. Replicates were either sent directly to the laboratory for testing (to provide a gold standard for each stack), or further reduced in size by sub-sampling and then tested. Sub-sampling techniques and numbers of sub-samples tested are listed in Table 4.

Table 4: Summary of sample numbers sent for %DM testing by sub-sampling technique.

Sub-sampling technique	No. stacks tested	No. sub-samples % DM tested per stack	Total No. sub-samples % DM tested
AC tube	8	2	16
Riffle-box	3	4	12
Quartering	3	6	18
Barrel	5	14	70

Results & Discussion

Truck Sampling

Site 1 (2001-02)

DM %s from 39 individual HS samples taken at three different depths from 13 positions (truck 11, Fig. 1) were subjected to an analysis of variance with factors of depth and position, with the depth by position interaction being used for the error term. There was no significant effect of depth, with main effect means being 34.9 %, 33.9 % and 34.4 % for bottom, middle and top of this truckload respectively with a 5 % level least significant difference (LSD) of 1.1 % DM. There were also no significant positional effects, including no sideways or lengthways trends.

DM %s from 90 individual HS samples collected from nine different positions from the top of the truckloads (trucks 1-10, Fig. 1) were analysed by analysis of variance as a 3 x 3 factorial with truck used as a block factor. The overall range in DM % was 9.1 % across all samples, while the maximum range within a truck was 6.3 % (Table 5). There was a highly significant difference in DM % among trucks (Table 5). There was no significant effect of sampling position on DM % (Table 6). The data suggests that as long as several samples are collected per truck, the actual position of sample collection is not critical.

Table 5: Variation in % DM between and within truckloads 1-10 collected at Site 1. Trucks were sampled in sequential order of harvesting – HS sampling technique only.

Truck No.	1	2	3	4	5	6	7	8	9	10	LSD (5 %)
Mean DM %	33.6	33.8	32.3	34.4	33.8	35.0	36.0	35.5	35.5	35.0	1.4
DM % Range within truck	2.9	5.9	6.3	4.0	2.6	3.7	2.9	3.3	3.0	4.3	-

Table 6: Positional effect of sample collection on DM % from trucks – HS sampling technique only.

Lengthways position	DM %	Sideways position	DM %
Front	34.1	Near	34.4
Middle	34.9	Middle	34.7
Rear	34.4	Far	34.3
LSD (5 %)	0.8	LSD (5 %)	0.8

DM %s from 81 samples from three trucks (No. 4,7,10) obtained using HS, PS and AC sampling techniques at nine positions (Fig. 1) from the top of the truckloads were analysed by split plot analysis of variance with truck used as a block factor, the nine positions (3 sideways x 3 lengthways) treated as a main plot factor, and the three sampling techniques as a subplot factor. Positional and technique effects were not significant (Table 7). The lack of positional effects confirms the result from truck 11. The easiest technique to use is HS, which makes it the technique of choice.

Table 7: Main effects of sampling technique and sampling position (from the top of truckloads) on DM %.

Sampling technique	DM %	Lengthways position	DM %	Sideways position	DM %
HS	35.1	Front	34.6	Near	34.6
PS	34.9	Mid	35.1	Mid	35.0
AC	34.5	Rear	34.9	Far	35.0
LSD (5 %)	0.6	LSD (5 %)	0.9	LSD (5 %)	0.9

Sites 2-6 (2001-02)

Samples were taken from either four or nine positions in each of 83 trucks, combined in a bucket, and three sub-samples (composite samples) taken by HS (in order 1,2,3). The resulting 249 DM %s were analysed by analysis of variance with trucks treated as the block factor. There was no significant difference in DM % among the three 'composite' sub-samples sent for analysis, means being 36.6 %, 36.5 % and 36.7 %DM respectively with an LSD(5 %) of 0.3 %DM. For each site, the mean DM %, its range, and the pooled standard deviation (sd) within buckets are given in Table 8.

Table 8: Summary of all 'composite' truck samples from trial sites 2-6 (2001-02).

Site ID	No. trucks sampled	Estimated mean DM %	Sd of truck DM % within site	Sd within buckets
2	12	36.0	1.77	0.39
3	15	33.8	1.09	0.40
4	13	38.1	3.68	0.81
5 (tractor)	11	37.5	2.74	0.51
5 (truck)	11	34.1	2.32	0.69
6 (day 1)	5	33.1	2.55	0.55
6 (day 2)	7	39.3	1.81	1.52
6 (day 3)	9	41.5	1.00	1.46
Pooled Sd.			2.30	0.85

At Site 2, HS samples were taken at nine positions (3 sideways x 3 lengthways) from each of four trucks. The 36 DM %s were analysed by analysis of variance treating trucks as a block factor. No significant positional effect was demonstrated, but there was a significant truck effect (Table 9). This confirmed findings detailed previously.

Table 9: Effect of position and truck on DM % for truck No. 4, 8, 12 & 13 at Site 2.

Truck No.	DM %	Lengthways position	DM %	Sideways position	DM %
4	35.2	Front	36.4	Near	35.7
8	37.4	Middle	35.3	Middle	35.9
12	33.9	Rear	35.8	Far	36.0
13	37.0				
LSD (5 %)	1.5	LSD (5 %)	1.3	LSD (5 %)	1.3

To determine how many 'composite' truck samples are required to accurately estimate the actual forage DM % for a paddock (source) being harvested, M±D was calculated, where M is the estimated forage DM % and D is the half width of the 95 % confidence interval (CI) for the mean DM %. The estimation of D was made on the basis of a variance components analysis involving data from 83 trucks in the eight groups listed in Table 8 and a total of 249 samples. D was estimated as: $2 * \sqrt{[(5.045+0.733/s)/t]}$, where t is the number of trucks sampled within a group, s is the number of composite samples taken from each bucket/truck and 2 is an approximation to the *t*-value for large degrees of freedom (d.f.). For D to be as low as 1.0 % (ie. M±1.0 %DM paddock estimate), it would be necessary to sample 23 trucks (ie. all trucks in most cases), with one composite sample taken per truck. There was little advantage in testing more than one composite sample per truck. This calculation applies only to a paddock (source) with an average sd (from truck to truck), however. To make it applicable to 95 % of paddocks (individual sources), the mean and sd of the sds in Table 8 were used to calculate a 95 percentile of truck sds (assuming a normal distribution for the sds), yielding 3.59 % DM. This means that for D to be less than 1.0 % DM for 95 % of paddocks, there needs to be 52 trucks sampled per paddock (source) and all samples analysed. This is clearly impractical and reflects the high variations that can occur between trucks.

Stack Sampling

Site 1 (2001-02)

For the initial stack (Site 1), the method of analysis was analysis of variance with a split plot design as each sampling technique (HS, PS, AC) was used at each position. Main plot treatments were a 4 (sideways) x 6 (lengthways) factorial. Sampling positions 1,2,3,28,29 and 30 (Fig. 2) were omitted from analysis as stack height was less than length of AC at these points. There was no significant difference in overall stack DM % between sampling techniques, with HS, PS and AC techniques averaging 35.1 %, 35.1 % and 35.3 % respectively with an LSD(5 %) of 0.3 %. As PS sampling was more difficult than HS, it was decided to only use the latter and AC sampling in future testing for this season.

		A	B	C	D	E	F	
Row 1		X4	X8	X12	X16	X20	X24	X28
Row 2	X1	X5	X9	X13	X17	X21	X24	X29
Row 3	X2	X6	X10	X14	X18	X22	X26	X30
Row 4	X3	X7	X11	X15	X19	X23	X27	

Front of Stack — End of Stack

Figure 2: Sample collection positions (X) for Site 1 stack, with stack divided into sideways (Rows 1-4) and length ways sections (A-F), plus two 'ends'.

The stack at Site 1 was divided lengthwise (Sections A-F) and width ways (Rows 1-4) as illustrated in Fig.2. There was no significant difference in DM % across the stack from one side to the other (Table 10). Along the length of the stack, the first end (Section A) had a significantly lower DM % than the centre (Section D) of the stack (Table 10). This was reflected in a 5 % significant quadratic trend along this stack.

Table 10: Comparison of stack DM % along length of stack (Sections A-F) and from side to side (Rows 1-4). Results are for all three sampling techniques combined.

Lengthways	DM %	Sideways	DM %
A	34.9	Row 1	35.2
B	35.0	Row 2	35.1
C	35.4	Row 3	35.3
D	35.4	Row 4	35.0
E	35.2	LSD (5 %)	0.4
F	35.1		
LSD (5 %)	0.5		

Sites 2-5 (2001-02)

A comparison between HS and AC was made at each of 24 positions (12 lengthways x 2 sides) in 4 stacks. The 192 DM %s were analysed by analysis of variance for a split plot design, with stacks treated as blocks, positions as mainplot treatment and sampling technique as subplot treatment. There was a significant difference between sampling techniques at all but one site. The trend of results was inconsistent however (Table 11). Sideways and lengthwise trends were again measured. There was no significant sideways effect, but there was a 5 % significant linear trend, which showed DM % increased on average about 0.5 % from the front to the end of the stack (data not shown).

Table 11: Comparisons of HS and AC sampling techniques over a series of stacks. comparison to relevant mean truck sampling also shown.

Sampling technique	Site 2	Site 3	Site 4	Site 5	Mean
HS DM % (mean)	35.9	33.3	35.7	35.7	35.1
AC DM % (mean)	35.1	34.3	36.6	36.3	35.6
LSD (5 %)	0.7	0.7	0.7	0.7	0.4
HS DM % sd	1.33	1.39	1.20	1.96	1.49
AC DM % sd	0.65	0.91	1.00	1.06	0.92
Truck DM % (mean)	36.0	33.8	38.1	35.8	-

To determine how many HS or AC samples to take from a formed 'single source' stack, to accurately estimate the actual forage DM % for the paddock being harvested, M±D was calculated, where M is the estimated forage DM % and D is the half width of the 95 % CI for the mean DM %. Here D was calculated as $D = 2 * sd/\sqrt{n}$, where n is the number of samples per stack and sd is the standard deviation of all sample DM % values within each stack, pooled over the 4 stacks. The pooled sd for HS was 1.49 and for AC it was 0.92. To obtain a 95 % confidence interval of M±1.0 % for a stack with 'average' variability, a total of nine HS samples or four AC samples need to be DM % tested. Note that the accuracy would be less than ±1.0 % for half the stacks sampled. Therefore a greater number of samples should be taken. To allow calculation of a 95 % CI of M±1.0 %D M for 95 % of stacks, the mean and sd of the sds given in Table 11 were calculated for each technique, and a 95 percentile of sds calculated (assuming they follow a normal distribution). This 95 percentile of sds was 2.02 for HS and 1.20 for AC. This calculation led to estimates of $n = (2 \times sd/ D)^2$ of 17 HS samples and six AC samples. These samples should be taken down the central spine of the stack after the stack is completely compacted but before the cover is placed on. Samples should be taken at equal distances apart down the full length of the stack. The AC proved to be less variable than surface HS samples in all four stacks examined (Table 11).

Sites 1-11 (2002-03)

For sampling stacks with an AC, the pooled estimate of the standard deviation (sd) is 0.81 %, based upon 2002-03 data from stacks at 11 new sites (Table 12). This estimate includes laboratory variation, variation due to the AC itself and variation along the spine of the stack that cannot be accounted for by the fitting of a smooth (quadratic) curve. If the latter variation is not accounted for, the sd is 0.98 %, as compared to the 2001-02 estimate of 0.92 %. This shows that results were similar between the two years. There was no correlation between stack mean DM % and sd ($r^2 = 0.35$) or the length of the stack tested ($r^2 = 0.18$).

Table 12: Summary of AC stack sample variations and sample numbers required to provide a 95 % confidence interval of ±1.0 % and ±0.5 for the different stacks tested.

Site ID	Stack mean DM % (M)	Stack sd (about a quadratic curve)	Sample size required to be M±1.0 %	Sample size required to be M±0.5 %
1	35.3	0.46	1	3
2	33.9	1.12	6	24
3	32.5	0.85	3	12
4	36.1	0.71	2	8
5	33.6	0.40	1	3
6	33.7	0.54	1	5
7	37.9	1.10	5	19
9	34.4	1.32	7	28
11	33.5	0.91	3	13
13	41.3	0.77	2	9
14	42.0	0.80	3	10
Mean	-	0.81	-	-

The sds within each stack are given in Table 12. If modeled using a normal distribution, then the 95 percentile of stack sds is 1.31. Hence if $(2 \times 1.31 / 1)^2 = 7$ samples are taken with the AC down the central spine of the stack, and each sample is analysed for DM %, then you would be within 1.0 % of the true stack's DM % for at least 95 % of stacks. This estimate is very similar to the figure of six AC samples from the 2001-02 work.

Sub-sampling Evaluation (2002-03)

To reduce the number of samples sent for DM % testing (and therefore cost), AC or HS samples could be recombined and only 1-2 sub-samples sent in for testing. Four techniques of combining the AC samples into a single or few samples were trialed. Three criteria are important for such combined samples: (i) the method should ideally be unbiased (sample DM % should equal the 'true' stack DM %), (ii) any bias should be consistent between stacks (enabling a correction to be made), i.e., low sd of bias, and (iii) the combined samples should have low variability for each stack, i.e., low sd within stacks. Here the 'gold standard' was calculated as the average of 14 AC samples taken down the spine of the stack, and 'bias' was calculated by comparisons with this gold standard. Results, given in Table 13, suggest that the riffle-box is the most promising method of in-field sub-sampling. The next best is the auger-tube sub-sampling method. Full results for only these two sub-sampling techniques are reported.

Table 13: Summary of sub-sampling suitability for in field use in maize forage sampling.

Technique	Mean bias in DM %	sd of bias	sd within stack	Overall bias	Overall sd bias	Overall sd within stack
Auger tube	0.83	0.64	0.43	Poor	Medium	Good
Quartering	0.41	0.34	0.65	Medium	Good	Poor
Riffle-box	0.08	0.31	0.34	Good	Good	Good
Barrel	1.07	1.05	0.74	Poor	Poor	Poor

To calculate D for the whole process for a stack sampled using AC sampling and riffle-box sub-sampling, the following calculations were done. From work done in 2002-03, the 95 percentile of the variance of the stack DM % estimate (M) was estimated to be $(1.31 * 1.31 - 0.3 * 0.3)/n + (0.34 * 0.34)/k$, where 1.31 is the 95 percentile of the AC sds within stacks (Table 12), 0.34 is the riffle-box sd (Table 13), n is the number of AC samples taken down the spine of the stack, and k is the number of riffle-box samples sent to the laboratory. The estimated laboratory sd (0.3 %) was subtracted from the first variance estimate to avoid double counting (since it is included in both 1.31 and 0.34). To get the standard error of the stack estimate, the square root of the variance is taken. This figure is then multiplied by 2 to get D, the half-width of the 95 % CI. The bias of the riffle-box is then removed by subtracting 0.08 % (Table 13). The resultant matrix of AC sampling and riffle-box sub-sampling options for 95 % of stacks tested is shown in Table 14. For example, if 10 AC samples are taken, put through the riffle-box and two sub-samples sent to the lab, the resultant 95 % CI is estimated to be (M-0.08)±0.94 %, where M is the mean DM % returned by the laboratory.

Table 14: Estimated maximum 95 % CI half-widths (D) for 95 % of stacks, for varying values of n and k when a riffle-box is used for in-field sub-sampling.

No. riffle-box samples (k)	No. AC samples along the spine of the stack (n)					
	1	2	5	10	14	20
1	2.64	1.93	1.33	1.05	0.96	0.89
2	2.60	1.87	1.24	0.94	0.83	0.75
3	2.58	1.85	1.21	0.90	0.79	0.69
4	2.57	1.84	1.19	0.88	0.76	0.66
5	2.57	1.83	1.18	0.86	0.75	0.65
6	2.57	1.82	1.17	0.85	0.74	0.63

For end-users who do not have a riffle-box, the AC could be reused in auger-tube sub-sampling (Table 15). For example, when 10 AC samples are layered in a tube and two auger-tube sub-sample are collected and submitted for DM % testing, the resultant 95 % CI is estimated to be (M-0.83) ±1.01 % (for 95 % of stacks), where the average bias of 0.83 % (Table 13) is subtracted. With the results to date, this technique appears inferior to the riffle-box since its average bias is greater, and the bias has greater variability from stack to stack, than with the riffle-box sub-sampling. Auger-tube sub-sampling is also physically difficult and unsafe to conduct.

Table 15: Estimated maximum 95% CI half-widths (D) for 95 % of stacks, for varying values of n and k when the Auger-tube technique is used for in-field sub-sampling.

No. Auger-tube samples (k)	No. AC samples along the spine of the stack (n)					
	1	2	5	10	14	20
1	2.69	2.00	1.43	1.18	1.10	1.03
2	2.62	1.90	1.29	1.01	0.91	0.83

Conclusions

Truck sampling consistently demonstrated that there was no positional effect of sampling location. There was also no significant difference in the DM% determination among HS, PS and AC sampling techniques when testing trucks. However, there were significant differences among trucks. 'Composite' 1000g HS samples (combination of at least four samples per truck) are suggested as a simple sampling technique for trucks, though this requires further work involving comparisons with other single-sample techniques. Because of the large variations in DM % from truck to truck, composite samples would need to be taken from at least 52 trucks per paddock and all tested for DM % individually to provide a 95 % CI of ±1.0 % DM for 95 % of paddocks (individual sources) tested when truck sampling is used. The number of samples sent to the laboratory could be reduced by sub-sampling. Sub-sampling of truck samples was not carried out in this trial, but would be an area for future studies to evaluate.

Stack sampling consistently demonstrated no sideways variation in DM %, but a significant trend (sometimes linear, sometimes quadratic) along the length of a stack was common. Therefore sampling should be conducted down the central spine of the finished stack over the entire length. To consistently obtain an estimate of the true stack DM ±1.0 % (maximum) for 95 % of stacks tested, a range of AC sampling and/or either riffle-box (preferably) or auger-tube sub-sampling regimes can be used. This level of accuracy can be achieved by either (a) taking seven AC samples per stack and sending all seven samples for laboratory analysis, or (b) taking 10 AC samples, mixing and dividing in the field via either a riffle-box or auger-tube system, to provide 1-2 sub-samples for laboratory analysis. Initial trialing suggests that 2-3 times as many HS samples would be required when stack sampling, to obtain the same level of accuracy as with the AC sampling technique. HS sampling is probably easier, but no further sub-sampling has been evaluated at this stage, so all samples would have to be sent to the laboratory for testing. Again, this is another area that future studies could target.

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