HGCA

PROJECT REPORT No. 79

AN ASSESSMENT OF PRACTICAL METHODS FOR COLLECTING SAMPLES FROM LORRY-LOADS OF GRAIN

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AN ASSESSMENT OF PRACTICAL METHODS FOR COLLECTING SAMPLES FROM LORRY-LOADS OF GRAIN

by

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SUMMARY

The collection and examination of samples is a fundamental component in determining quality of bulk grain. Currently, there is only one, well documented approach to sampling grain: British Standard 5410, which is identical to International Standard 950. However, there is no scientific basis for these Standards.

Grain is an extremely variable commodity so that there is a high probability of quality assessments being influenced by sampling errors. These potential errors are likely to have maximum commercial impact when lorry-loads of grain are sampled at time of sale. Therefore, the influence of sampling methods, sample position and methods of loading lorries, were investigated.

Loads of English feed wheat, all taken from the same batch, were sampled manually with a compartmented spear, automatically with a SAMPLEX C90 vacuum probe and manually at the tailgate during tipping. The lorries were loaded either from an overhead bin or with a front loader bucket. Samples were collected from 8 points with the manual spear or 5 points with the automatic probe, and assessed for moisture content, fine material and hectolitre weight. Assessments were made on individual samples and on a composite made by mixing individual samples. Only a single tail-gate sample was collected but this was made up of four scoops taken at intervals as the grain tipped.

In general, there was little difference in the results for hecto-litre weight and moisture content produced by the three methods of collecting samples. Manual sampling gave average values that were 0.5 kg/Hltr higher than the automatic sampler, and tailgate samples were 1.6 kg/Hltr higher. There was no significant difference for moisture content. However, with fine material, the differences were more pronounced and tailgate samples gave values 3 - 5% higher than the automatic sampler, which in turn was about 1.4% higher than the manual sampler. The method of loading appeared to have little influence on the results. There was very little correlation between sampling position and any of the parameters measured.

This work demonstrated the inadvisability of basing quality assessments on a single sample. The difference in the numbers of individual samples collected with the automatic probe and manual spear did not exert a large influence on the mean value obtained or on the size of the standard deviation around the mean.

More work is needed to confirm these conclusions over a wider range of circumstances. Such work should also have the objective of defining simple, standard sampling procedures with broad, practical application.

1. INTRODUCTION

Virtually all determinations of grain quality must start with the collection of a sample. As a result, the method of collection, point of collection and sample size, can influence the perception of grain quality derived from subsequent assessments.

HGCA Project Report No.34, "An assessment of methods of sampling bulk grain" concluded that almost no research had been conducted on this important topic. This project also indicated that wide variations in quality can occur even within relatively small bulks of grain and that variations in estimates of grain quality could occur because of differences in sampling. Recommendations were made for more detailed research on sampling procedures, the effects of different equipment and the impact of sampling on quality management.

In the UK, the majority of quality-related, commercial decisions are taken as grain is delivered by lorry to the purchaser. The only nationally recognised sampling method in the U.K. appears to be British Standard, BS 4510, which is identical to the International Standard, IS 950. This method provides clear guidance for some aspects of lorry sampling but there are no research data to validate the recommendations and, in many respects, they may not be applicable to modern practices, at either farm or commercial store level. For example, the method makes only limited suggestions as to the equipment that should be used to collect samples and is time consuming. As result, the method is often interpreted very loosely, giving rise to wide variations in methodology across the industry. The International Standards Organisation has called for a review of IS 950 but it is essential that any changes are based on research data rather than unsubstantiated interpretations of commercial practices.

The aim of this project is to carry out a preliminary investigation of some lorry sampling techniques currently used in the U.K. The results will provide data on which to base advice to the industry and to the British Standards Institute, as to the best approach to the collection of samples from lorries. Three systems were used to collect samples: manual spear, automatic suction probe and scoops collected from the tail-gate, as the lorry tipped. All systems are currently used commercially but there is a considerable variation within each method and this may have a profound influence on the results obtained. For example, suction probes may be of a simple type, where both air and grain are sucked out of the load and up the probe, or a complex type, where there is a separate air supply. This project was not able to assess if such variations in equipment were likely to influence the results of quality assessments.

2. OBJECTIVES

i) To examine the effectiveness of IS 950 as a method of sampling grain in lorries in terms of producing representative samples for the determination of grain quality.

ii) To examine the influence of the number of sub-samples and positions from which these sub-samples are taken, on the level of error of determination.

iii) To assess the effects of two methods of filling lorries and of three methods of collecting samples on the sampling results.

iv) To make an assessment of the differences between three methods of collecting samples in terms of measuring moisture content, hectolitre weight and fine material.

3. MATERIALS AND METHODS

A) Materials

i) Grain: A single batch of English feed wheat from the 1992 harvest was used for all assessments. This grain came from several producers but was considered to be largely of the same quality.

ii) Handling equipment: Lorries were loaded in one of two ways; either using a front-loader bucket or from the spout of an overhead loading bin. The same operator loaded all lorries.

In general, a lorry was loaded from the overhead bin, sampled and then tipped onto the ground. The grain was then reloaded using a front loader. However, on some occasions, it was not possible to use the same lorry for both forms of loading. Also, operational constraints prevented the lorry being reloaded with precisely the same grain.

iii) Sampling equipment: Two types of equipment were used: firstly, a 2-metre, compartmented spear with 6 ports that could be opened and closed by the operator, was used to collect the manual samples. The ports opened sequentially (lower ports first) into an undivided central tube so that, although the ports collected grain from different depths, when the spear was emptied, a single, composite sample was produced. The total capacity of the spear was about 500g of wheat but, in practice, only about 300 - 350g was collected. In order to provide sufficient grain for the assessments, the spear was inserted twice at each point and the two lots combined. Even so, the total amount of grain was less than 1kg suggested by IS 950. All samples were collected by the same operator.

Secondly, a SAMPLEX, C90 automatic suction probe was used to collect the "automatic" samples. The probe was mounted on a gantry and moved over the load to be sampled by electric motors. The probe was double skinned and air was fed down between the inner and outer skins and the grain was drawn up the centre. Grain fell into a port situated on the side at the bottom of probe but little air is sucked in from the bulk of grain. The grain sample is collected in a cyclone in the laboratory. Once again, using the standard speed of operation programmed into the sampler, the weight of grain collected per sample was less than the 1 kg recommended in the IS method. The same operator collected most of the samples but a few were collected by a second operator.

After manual and automatic samples had been collected, the lorry-loads were transported about 40 miles to the premises of a customer. A sample was then collected from the tail-gate of each lorry when it tipped. This sample was collected with a scoop and 4 scoopfuls were combined to give a sample. The same operator collected all the samples.

iv) Assessment equipment: the samples were divided as necessary with a sample divider to give a working sample for assessment. The samples were weighed on a standard laboratory balance, reading to 0.01g. The moisture content and bushel weight of the samples were measured using a Dickey John capacitance analyser. The fine material was measured by sieving a 100g sub-sample for 100 shakes over a standard 2 mm slotted sieve. Two operators carried out all the assessments and the calibrations of the equipment were not changed during the trial.

B. Methods

Lorries were loaded either from an overhead hopper bin with 3 spouts or with a 1-tonne bucket on a front-loader. All lorries were 38 tonne gross, standard grain transporters and a total of eight loads were sampled.

Each load was first sampled with the manual sampler at eight points, as specified in the IS method. The spear was inserted fully or until it reach the bottom of the lorry and the ports were then opened. When the sample had been collected, the ports were closed before the spear was withdrawn. Two sets of samples (eg 4 insertions of the spear) were collected on each occasion; one set was kept as individual samples and the other was combined to form a composite sample.

The loads were then sampled from five points, using the automatic sampler. Fewer sample points were used because, in practice, it is often difficult for an automatic sampler to reach the furthest corners of the lorry. Once again, two sets of samples were collected, with one set being kept separate and the other bulked to give a composite sample.

When the lorries reached their destination, a single sample was collected from the tail-gate of each lorry as the load was tipped. This was made up of 4 scoops of grain taken at intervals during tipping.

After collection, the samples were stored in sealed plastic bags and assessed as soon as possible. Each sample was weighed, divided as necessary using a laboratory divider, and assessed for hectolitre weight, moisture content and fine material. All assessments were completed within 48 hrs of the samples being collected.

In addition, an assessment was carried out on the repeatability of the results produced by the Dickey John instrument. A single sample of about 1 kg of wheat from the same batch was thoroughly mixed. An aliquot of about 200g was scooped from the sample, poured into the analyser and assessed for moisture and hectolitre weight. After measurement, the grain was mixed back into the 1kg sample and the process was repeated a further 9 times. This process took about 10 minutes.

C) Assessment of data

A simple, computerised spread sheet was used to hold the results and to generate maximums, minimums, means and standard deviations. More detailed statistical analysis was also applied.. This was done using a commercial statistical package (SAS 6.08) to perform a simple split plot analysis of variance. Further analysis, using other facilities within the programme, were performed to confirm the significance of the various comparisons that were made.

Given the Standard Deviations for the various quality parameters, there are various statistical approaches to allow the calculation of the numbers of samples needed to achieve certain levels of error. In this report, the method described by SNEDECOR, G. W. and COCHRAN, W. (Statistical Methods, Iowa State University Press, Des Moines, Iowa, 1967) was used. This is based on the formula:

$$\text{No. of samples required} = 4(\text{Standard Error}/\text{Acceptable error})^2$$

4. RESULTS

During the period when the samples were collected the weather was cold (5°C), dry and overcast. All samples were collected on the same day. However, it proved impossible to ensure that the manual spear filled evenly. Some of the ports became partly or completely blocked with chaff and straw on occasions, so that most of the grain must have flowed into the spear via the ports that were not blocked. This must have affected the make-up of the sample. This difficulty in filling the spear must have been responsible for the variation in the weight of sample. Similar difficulties probably also affected the automatic probe, as the weights of individual samples varied, despite a controlled sampling period. The manual collection of samples took about 15 minutes per lorry, whilst the vacuum probe collected the samples automatically in under 2 minutes.

The results of the assessment of the samples are given in Tables 1 - 8. All numbers have been reduced to one decimal place, although some parameters were measured to two places.

Irrespective of the method of collecting samples, the range between maximum and minimal values for moisture content and hectolitre weight were small in relation to the value measured. The largest range within a load for hectolitre weight was 71.2 - 68.7 Kg/Hltr with manual sampling and 70.1 - 66.2 Kg/Hltr with the automatic probe, both of which occurred with the same load. The largest range of moisture was 15.3 - 14.6% with manual sampling and 16.1 - 14.7% with the automatic probe, again both occurred in the same load. Although small, these ranges were large enough to have had commercial significance in some circumstances, particularly for moisture.

The percentage of fine material in the grain used in these trials was high, as was the variation detected within and between loads. The largest range between maximum and minimum values within a load was 27.6 - 13.1%, for manual sampling, and 28.3 - 12.1%, for the automatic probe.

The results of multiple assessments of a single sample for moisture content and hectolitre weight are given in Table 9. These show no indication of calibration drift and the range between the ten values for each parameter was very small.

The results are summarised in Table 10 but full details of the statistical analysis are available from the author. This showed that there was a significant difference between the sampling methods in regard to the determination of fine material. However, the method of loading or the sampling position was of little importance. The calculated number of samples needed to achieve a specific, pre-determined level of error are given in Table 11.

5. DISCUSSION

It is important to realise that none of the values for moisture, hectolitre weight or fine material given in the results are necessarily the true, absolute value for any of the individual loads of grain. Variability within loads was appreciable, confirming earlier work (HGCA Project Report No. 34). As a result, an infinite number of samples would have been needed (or the assessment of the entire load) to give an absolute mean value and a total range. There was also variation between loads, caused by filling several lorries from a bulk that was not entirely homogeneous. This residual error was sufficiently small to be easily accommodated during statistical analysis and only in the case of fine material was the error of any significance. This inherent variability of the grain making up each load, must tend to mask small differences between sampling or loading methods. Therefore, statistical analysis was essential to reveal trends that would otherwise have been obscured by the variability of the grain.

i) Method of loading:

The method of loading the lorry had no statistically significant effect on any of the results obtained, either at different parts of individual loads or between loads. Also, it did not influence the different sampling methods.

ii) Measurement of fine material:

The amount of fine material detected was very variable and the differences between the value from a single sample and a mean result were, therefore, large. The variation between samples is not surprising as fine material is free to move between grains and may accumulate in certain parts of a load. However, there was no correlation between sample points and the amount of fine material detected, suggesting that the variability was present before the grain was loaded and that loading did little to redistribute the fine material. However, as all the samples were, to some extent, core samples from top to bottom of the load, any general tendency for the fine material to move towards the top or bottom of the load, would not necessarily have shown up in these results.

There was a slight, consistent, and statistically significant, difference in the mean percentage of fine material collected by the manual and automatic samplers. Manual sampling consistently gave the lowest levels by about 1.4% of fines. This difference is very small in relation to the total content of fines and may have been caused by the partial blockage of some of the ports on the manual spear or by the vacuum spear tending to draw in more fine material. However, tail-gate samples gave a consistent and very significantly higher value for the fine material that was 3 - 5% of fines above the results for the automatic sampler.

The means produced by measuring the samples individually did not differ significantly from the values of the appropriate composite sample.

iii) Measurement of moisture and hectolitre weight:

The variation between individual samples collected by either method, when measuring moisture or hectolitre weight, was relatively small. However, on several occasions it was sufficient to have had a commercial impact. For example, with moisture, the range sometimes spanned the intervention intake level of 15.0%. Therefore, even when variability is low, the use of a single sample collected from one point in a load cannot be recommended.

When multiple samples were collected, assessing these samples individually gave a slightly lower value for hectolitre weight (up to 0.5 Kg/Hltr) than the value from the composite sample. This was true for both automatic probe and hand spear. However, there was no comparable difference for moisture content.

In general, the method of collecting the samples had little significant effect on the determination of moisture content or hectolitre weight. However, manual sampling gave hectolitre weights that were on average about 0.7 Kg/ Hltr higher than the values for the automatic sampler. Tail-gate samples, by comparison, were about 1.6 Kg/Hltr higher.

iv) Effects of sample position:

There was no consistent relationship between any of the quality parameters measured and the position from which a sample was collected. This was true for both manual and automatic sample collection, and for both methods of loading. Therefore, sample position would not appear to be of great importance when sampling lorries.

This conflicts with the findings of HURBOUGH, C R; BERN, C J and COX, D F (Evaluating grain probing devices and procedures, 1979 American Society of Agricultural Engineers summer meeting, Winnipeg, June 1979). These authors found that with soya beans and maize there was a significant difference in the amount of fine material found at different parts of lorry loads with samples from the centre line having more fine material than samples from the edges. The conflict between the two sets of results may be caused by differences between the relatively coarse grains of soya and maize compared to wheat. Alternatively, American methods of loading lorries could account for the differences.

v) Numbers of samples:

The numbers of samples needed to give a mean result with acceptable deviation, are given in Table 11. These were calculated using the extreme Standard Deviations for moisture content and fine material. The effects of different levels of variability and acceptable error are very apparent, as is the impossibility of meeting some targets for error or in predicting the number of samples needed in absolute terms.

In practice, such calculations have limited value as the variability of each quality parameter is unlikely to be known before samples are collected. Another approach is to use such data to decide what levels of error are acceptable. It is clearly undesirable to demand specific quality parameters when it is impossible to estimate those parameters within the specified band. For example, is would not have been possible to determine the fine material in the most variable load used in this project to within +/-0.5%, unless about 250 samples had been taken from the load!

vi) Impact of these results on sampling procedures:

Manual sampling of grain to the schedule laid down in IS 950 is difficult and time consuming. In particular, it seems unlikely that 8kg of grain will be collected using manual spears, the only sampling equipment mentioned in the current Standard. In the case of commercial stores, the use of an automatic sampling system is likely to be much more cost effective but, such systems may not be able to collect samples from the positions recommended by the IS schedule. The results obtained during this trial suggest that the point at which samples are collected is of little importance. Therefore, automatic samplers are not disadvantaged because of the limitations on the parts of the lorry load that they can reach.

The number of samples collected is important, but this work shows that a wide range of samples may be needed, depending on the variability of the quality parameter being measured and the acceptable error. Obviously, it is not possible to predict the variability before sampling commences, so some arbitrary standard may have to be used. The collection of more data from commercial practice to illustrate the variability encountered within and between individual loads, would allow a much more authoritative prediction of sample numbers needed to give acceptable levels of error.

The relevance of the current IS 950 standard for sampling grain in relation to modern commercial requirements would seem to be open to question. There are no scientific data to support the sampling procedures given in IS 950 and the work reported here suggests an automatic probe taking fewer samples will provide an equally consistent assessment of quality to manual sampling from all the recommend points. It also suggests that the number of samples required to give acceptable levels of error can vary over a wide range. This should be taken into account when the Standard is reviewed.

6. CONCLUSIONS

This report must be considered in the context of the limited nature of the experimental work in which only a single batch of grain was sampled under one set of circumstances. However, the following conclusions can be drawn:

i) Grain is a variable commodity and a single sample taken from a load, irrespective of the method of collection, is unlikely to provide an adequate assessment of quality.

ii) Even with relatively homogeneous grain, the variation within a group of samples can be of commercial significance. Therefore, if either or both the buyer or seller of a parcel of grain, base their quality assessment on a single sample, there is a high probability that there will be a difference in their respective opinions of the grain quality.

iii) Basing an assessment on a single sample is just as likely to give high or low values.

iv) No consistent, significant difference relating to either of the two methods of loading lorries was found in the moisture content, hectolitre weight or fines.

v) There was no relationship between the sample point, with either manual spear or automatic probe, and any of the parameters measured. Therefore, the point from which samples are taken would seem to be of little importance.

vi) If buyers and sellers of grain use the same method and equipment to collect samples and base their assessments of grain quality on a mean value from several individual samples or a composite sample, they are likely to be in agreement. The potential for disagreement is much greater if one or both parties base assessment on a single sample from one point in a load than if they use different methods of collecting samples.

vii) There would not appear to be any advantage in following exactly the procedure laid down in the current IS 950 Standard for sampling grain. Indeed, commercial constraints make it very unlikely that the procedures are ever implemented fully.

viii) There would appear to be considerable value to the industry in the development of a simple, general procedure (or procedures) for sampling of lorry-loads of grain. This procedure(s) would have to accommodate the needs of both farmers and merchants, who are likely to use different methods of collecting samples. It would also require the collection of more data on the variability within and between loads of grain.

7. NEEDS FOR FURTHER RESEARCH

The current research has given a clear indication of the relative importance of some of the variables in assessing grain quality. However, the results were generated from a single batch of grain at one commercial site using only specific pieces of equipment. More data are needed to allow these results to be applied with confidence throughout the U.K. grain industry. In particular, more information is needed to quantify variability, to produce values for acceptable error and to assess the importance of range of equipment available to collect samples.

The above points could be addressed by a combination of limited trials to assess equipment and procedures and liaison with trade and farming organisations to collate data on variability and agree values for acceptable error. Such an approach would have the objective of developing a set of sampling procedures that would have the widest possible application. Developing such procedures via scientific experimentation and liaison with the industry would ensure that the proposed system or systems would be both effective and acceptable.

Table 1: **Lorry 1 – Front Loader**

Sampling method	Sample position	Weight [g]	Hect. Wt. [kg/hltr]	Fines %	M.C. %
Manual	1	466.5	69.2	16.7	15.0
	2	503.0	71.1	16.1	15.1
	3	727.5	70.3	12.8	15.0
	4	823.2	70.7	14.6	14.9
	5	794.6	70.7	16.2	15.1
	6	826.7	70.5	18.4	15.0
	7	766.3	70.3	18.3	15.0
	8	692.1	70.3	13.8	14.9
	Max. Value		71.1	18.4	15.1
	Min. Value		69.2	12.8	14.9
	Mean Value		70.4	15.9	15.0
	Standard deviation		0.5	1.9	0.1
	Composite	650.4	70.0	15.7	15.0
	Tail gate		71.1	19.8	15.1
Automatic	1	536.1	70.2	16.3	15.0
	2	828.2	70.8	21.5	15.2
	3	755.8	69.7	19.5	15.0
	4	684.2	69.6	16.4	14.9
	5	674.4	69.7	19.3	15.0
	Max. Value		70.8	21.5	15.2
	Min. Value		69.6	16.3	14.9
	Mean Value		70.0	18.6	15.0
	Standard deviation		0.5	2.0	0.1
	Composite	500.5	71.0	18.7	15.2

Table 2: **Lorry 1 – Hopper loaded**

Sampling method	Sample position	Weight [g]	Hect. Wt. [kg/hltr]	Fines %	M.C. %
Manual	1	303.1	69.7	9.8	14.7
	2	336.9	70.6	11.2	15.2
	3	537.0	71.0	11.8	14.7
	4	410.9	71.0	10.0	15.3
	5	546.9	70.1	9.6	14.8
	6	574.1	70.2	7.1	14.7
	7	356.3	68.7	10.0	14.6
	8	429.2	70.0	10.0	14.7
	Max. Value		71.0	11.8	15.3
	Min. Value		68.7	7.1	14.6
	Mean Value		70.2	9.9	14.8
	Standard deviation		0.7	1.3	0.2
	Composite	695.4	70.0	7.6	14.7
	Tail gate		70.3	10.4	15.1
Automatic	1	687.5	70.3	11.9	14.7
	2	422.3	69.6	8.9	15.0
	3	697.4	70.2	8.0	15.9
	4	780.7	69.7	8.9	15.0
	5	385.5	67.5	6.3	16.1
	Max. Value		70.3	11.9	16.1
	Min. Value		67.5	6.3	14.7
	Mean Value		69.6	9.0	15.3
	Standard deviation		1.0	1.8	0.5
	Composite	499.3	69.7	9.9	15.5

Table 3: Lorry 2 – Front loader

Sampling method	Sample position	Weight [g]	Hect. Wt. [kg/hltr]	Fines %	M.C. %
Manual	1	458.4	69.0	13.5	14.9
	2	451.9	70.6	16.9	14.8
	3	757.3	70.6	15.8	14.9
	4	819.3	70.3	12.7	14.9
	5	742.4	69.7	15.1	14.8
	6	824.8	70.1	13.6	14.9
	7	747.9	69.1	17.1	14.9
	8	758.8	70.4	15.6	14.8
	Max. Value		70.6	17.1	14.9
	Min. Value		69.0	12.7	14.8
	Mean Value		70.0	15.0	14.9
	Standard deviation		0.6	1.5	0.0
	Composite	657.1	70.7	17.0	14.8
	Tail gate		70.9	17.5	15.0
Automatic	1	708.5	69.2	15.9	14.9
	2	792.3	70.7	16.2	14.8
	3	767.7	67.9	16.7	14.7
	4	520.8	70.2	16.7	14.9
	5	706.9	70.3	17.7	14.8
	Max. Value		70.7	17.7	14.9
	Min. Value		67.9	15.9	14.7
	Mean Value		69.7	16.6	14.8
	Standard deviation		1.0	0.6	0.1
	Composite	499.0	70.0	18.0	14.7

Table 4: Lorry 2 – Hopper loaded

Sampling method	Sample position	Weight [g]	Hect. Wt. [kg/hltr]	Fines %	M.C. %
Manual	1	448.0	69.4	13.1	14.4
	2	342.5	69.0	14.3	14.3
	3	476.5	68.3	14.1	14.4
	4	613.8	68.3	16.5	14.4
	5	753.5	69.0	17.7	14.4
	6	580.1	69.4	25.8	14.6
	7	523.0	68.8	27.6	14.5
	8	783.3	69.2	26.6	14.6
	Max. Value		69.4	27.6	14.6
	Min. Value		68.3	13.1	14.3
	Mean Value		68.9	19.5	14.5
	Standard deviation		0.4	5.8	0.1
	Composite	789.0	69.6	23.0	14.6
	Tail gate		70.4	26.9	14.8
Automatic	1	519.9	68.3	12.1	14.3
	2	747.8	69.5	18.5	14.5
	3	789.4	68.8	28.3	14.6
	4	530.8	68.2	21.5	14.6
	5	570.5	69.4	15.2	14.5
	Max. Value		69.5	28.3	14.6
	Min. Value		68.2	12.1	14.3
	Mean Value		68.8	19.1	14.5
	Standard deviation		0.5	5.6	0.1
	Composite	499.7	70.2	18.5	14.5

Table 5: **Lorry 3 – Front loader**

Sampling method	Sample position	Weight [g]	Hect. Wt. [kg/hltr]	Fines %	M.C. %
Manual	1	568.9	70.1	14.7	14.5
	2	562.6	70.4	18.2	14.7
	3	794.2	70.0	14.4	14.8
	4	476.3	70.2	14.6	14.7
	5	725.6	69.6	13.7	14.6
	6	828.1	70.5	16.0	14.8
	7	724.9	69.9	14.9	14.5
	8	731.3	69.7	13.8	14.6
	Max. Value		70.5	18.2	14.8
	Min. Value		69.6	13.7	14.5
	Mean Value		70.1	15.0	14.7
	Standard deviation		0.3	1.4	0.1
	Composite	664.9	69.9	14.4	14.7
	Tail gate		70.9	19.1	14.7
Automatic	1	619.8	68.6	17.3	14.5
	2	736.6	69.4	12.7	14.6
	3	634.7	69.5	17.8	14.7
	4	544.6	69.6	17.5	14.8
	5	630.7	70.0	17.5	14.9
	Max. Value		70.0	17.8	14.9
	Min. Value		68.6	12.7	14.5
	Mean Value		69.4	16.6	14.7
	Standard deviation		0.5	1.9	0.1
	Composite	498.1	69.6	16.6	14.7

Table 6: **Lorry 3 – Hopper loaded**

Sampling method	Sample position	Weight [g]	Hect. Wt. [kg/hltr]	Fines %	M.C. %
Manual	1	425.5	67.5	21.6	15.4
	2	546.7	70.3	27.3	15.6
	3	736.2	69.3	25.2	15.5
	4	663.6	68.3	26.8	15.1
	5	748.4	68.5	21.8	15.2
	6	723.1	69.7	24.6	15.3
	7	736.4	68.9	25.4	14.9
	8	647.9	68.2	24.8	15.0
	Max. Value		70.3	27.3	15.6
	Min. Value		67.5	21.6	14.9
	Mean Value		68.8	24.7	15.3
	Satndard deviation		0.8	1.9	0.2
	Composite	777.5	72.1	24.5	15.4
	Tail gate		70.1	31.3	15.2
Automatic	1	623.6	68.2	23.6	15.0
	2	781.6	66.5	24.5	15.4
	3	528.0	68.8	31.1	15.1
	4	623.9	66.9	29.2	15.2
	5	479.5	68.8	29.6	15.6
	Max. Value		68.8	31.1	15.6
	Min. Value		66.5	23.6	15.0
	Mean Value		67.8	27.6	15.3
	Standard deviation		1.0	3.0	0.2
	Composite	499.7	68.3	26.6	15.2

Table 7: Lorry 4 – Front loader

Sampling method	Sample position	Weight [g]	Hect. Wt. [kg/hltr]	Fines %	M.C. %
Manual	1	555.5	69.9	13.9	14.5
	2	686.0	70.3	11.8	14.4
	3	669.0	70.3	13.0	14.3
	4	580.4	70.4	14.7	14.6
	5	626.2	69.8	15.4	14.4
	6	613.5	69.4	13.4	14.6
	7	606.2	69.0	12.1	14.4
	8	556.6	68.7	14.5	14.5
	Max. Value		70.4	15.4	14.6
	Min. Value		68.7	11.8	14.3
	Mean Value		69.7	13.6	14.5
	Standard deviation		0.6	1.2	0.1
	Composite	622.9	69.2	12.0	14.5
	Tail gate		70.1	18.0	14.5
Automatic	1	459.0	69.1	15.0	14.6
	2	781.5	68.8	12.2	14.6
	3	643.9	68.1	14.3	14.5
	4	616.4	69.0	16.3	14.7
	5	676.3	70.0	16.9	14.4
	Max. Value		70.0	16.9	14.7
	Min. Value		68.1	12.2	14.4
	Mean Value		69.0	14.9	14.6
	Standard deviation		0.6	1.6	0.1
	Composite	497.3	70.1	14.1	14.6

Table 8: Lorry 4 – Hopper loaded

Sampling method	Sample position	Weight [g]	Hect. Wt. [kg/hltr]	Fines %	M.C. %
Manual	1	586.3	70.3	23.3	15.1
	2	550.0	70.6	23.0	15.3
	3	740.4	69.7	22.7	15.1
	4	662.6	70.6	20.5	15.0
	5	676.1	71.2	22.5	15.1
	6	785.8	68.7	18.1	15.0
	7	664.5	69.4	20.3	15.0
	8	505.0	69.7	17.8	15.0
	Max. Value		71.2	23.3	15.3
	Min. Value		68.7	17.8	15.0
	Mean Value		70.0	21.0	15.1
	Standard deviation		0.7	2.1	0.1
	Composite	653.6	70.6	21.0	15.2
	Tail gate		72.1	29.8	15.4
Automatic	1	527.5	66.2	20.8	15.1
	2	804.5	69.1	26.4	15.1
	3	729.1	67.6	21.0	15.0
	4	643.0	70.1	24.6	15.1
	5	698.8	70.0	26.9	15.2
	Max. Value		70.1	26.9	15.2
	Min. Value		66.2	20.8	15.0
	Mean Value		68.6	23.9	15.1
	Standard deviation		1.5	2.6	0.1
	Composite	499.5	69.1	23.5	15.2

Table 9: Repeated assessments of the same sample

Sample No.	Hect. Wt. kg/H.Ltr	M.C. %
1	70.6	14.6
2	70.9	14.7
3	70.7	14.7
4	70.5	14.8
5	70.7	14.8
6	70.5	14.7
7	70.7	14.8
8	70.7	14.8
9	70.9	14.8
10	70.7	14.7

Table 10: Statistical estimate statement results

Parameters compared	Estimate	Standard error	T	Pr > T
1. Hectolitre weight				
Manual v Auto	0.658	0.161	4.10	0.0001
Manual v manual comp.	−0.502	0.299	−1.68	0.0961
Auto v auto comp.	−0.648	0.309	−2.10	0.0382
TG v Manual comp.	0.475	0.398	1.19	0.2357
TG v Auto comp.	1.535	0.309	5.30	0.0000
2. Fine material				
Manual v Auto	−1.442	0.547	−2.64	0.0096
Manual v manual comp.	−0.062	1.018	−0.06	0.9511
Auto v auto comp.	0.042	1.051	0.04	0.9682
TG v Manual comp.	4.704	1.357	3.47	0.0007
TG v Auto comp.	3.324	1.051	3.16	0.0020
3. Moisture content				
Manual v Auto	−0.089	0.040	−2.23	0.0279
Manual v manual comp.	−0.039	0.074	−0.53	0.6005
Auto v auto comp.	−0.038	0.077	−0.49	0.6264
TG v Manual comp.	0.113	0.099	1.13	0.2591
TG v Auto comp.	0.063	0.077	0.81	0.4176

Auto = Suction probe   Comp. = Composite sample
TG = Tailgate Sample

Table 11. Calculated numbers of samples needed to achieve specific errors

	Acceptable error	Variability (SD)	No. of samples
1. Moisture content			
	0.2	0.1	1
		0.5	12
	0.5	0.1	1*
		0.5	2
2. Fine material			
	0.5	0.5	2
		5.5	242
	0.5	0.5	1*
		5.5	15

* Calculated value = <1