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Research to develop practical user guidelines to maximise the accuracy of moisture meters

by

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Contents

ABSTRACT

Accurate and reliable moisture measurement is essential for drying calculations, as well as for safe storage and marketing of grain and oilseeds. Most farmers rely on capacitance or resistance moisture meters for this task. These have limitations of accuracy: usually in the range ± 0.5%. This has implications for quality loss during storage as well as sale to end-users with added costs of rejections or claims.

The aim of this project was to assess problems that might occur under practical conditions and develop end-user recommendations to improve the accuracy of moisture measurement on farms. A review of factors most likely to cause variation in use was undertaken, in co-operation with meter manufacturers and selected farmers. This was followed by a survey of farmers and meter use on a number of farms to assess the variations under practical conditions.

Laboratory experiments were devised to compare readings from meters with the oven method (ISO 712:1998). No difference between the performance of capacitance and resistance meters was shown. Moisture content readings were repeatable for homogenous samples but readings from variable, but well-mixed, samples gave variable results even with the meter that used the largest sample.

The effect of variety on the results given by several different meters was assessed during both laboratory and field testing. A number of hard and soft endosperm varieties of wheat were compared in laboratory tests but no consistent effect on meter reading was found. No differences were detected in response of meters when testing different varieties of barley.

Resistance meters were inaccurate when the sample was under-compressed and the need for regular servicing of grinders was identified. Capacitance meters should only be used on a level surface.

Samples were taken from the output of a high temperature dryer. Readings taken using a capacitance meter were higher on average by 0.4% after six days when compared with readings taken immediately ex drier. No such difference was observed using a resistance meter.

An assessment of moisture probes showed their value in obtaining *in-situ* data from grain bulks. However, results were more variable than those of conventional meters and there was often a significant difference between moisture contents determined by probes and oven tests on samples removed close to the probe sensor.

On-farm assessments indicated that some farm meters gave markedly different results from manufacturer supplied test meters used in the work or oven tests. In several cases poorly maintained grinders were the source of error. Meters tended to under-read moisture at values above about 17%, often by more than 1%. This error was not seen during laboratory testing of samples.

A survey showed that most farmers had a realistic view of the accuracy of their meter, but were often more concerned with their meters agreeing with those of the merchant or end-user than with accuracy. This could have serious implications for quality and food safety, as accurate moisture content measurements are important when deciding on the need for drying to the correct moisture content and preventing ochratoxin A formation during storage.

SUMMARY

Measurement of moisture in cereals is of fundamental importance to safe storage and, ultimately, consumer safety. It also influences the value and saleability of a crop. The UK is often relatively damp at harvest time so that drying may be essential before grain can be stored safely, making moisture and its measurement of particular relevance in the UK. Farmers rely on electrical moisture meters to make these important measurements. Modern moisture meters measure an electrical effect in grain or oilseeds that is related to moisture content. They do not measure moisture directly and rely on an inbuilt calibration between moisture and the electrical parameter measured – usually capacitance or resistance.

There are many different models that adopt the two main approaches to measurement. This project did not attempt to assess individual meters, but used instruments from the main UK manufactures/suppliers that covered both principles of measurement.

The aim of this project was to assess problems that might occur under practical conditions and develop end-user recommendations to improve efficiency of moisture measurement on farms. It also addressed some specific issues that had been raised during HGCA Training Days and Road Shows or questions directed at HGCA researchers.

The first stage was completed with co-operation from meter manufacturers and selected farmers and provided an initial review of the factors most likely to cause variation in use. The factors identified were:

- Types of moisture measurement device (e.g. resistance, capacitance) and sample size
- Calibration issues
- Temperature effects
- Differences between varieties and crops (e.g. hard and soft wheat, oilseeds and cereals)
- Issues surrounding compressing or loading a sample

The International Organisation for Standardisation (ISO) routine reference method for the determination of moisture content for cereals and cereal products (ISO 712:1998) is the standard used for measuring moisture content. It was used throughout this

project to provide the ultimate assessment of the moisture content of all wheat and barley samples used for testing the meters.

A laboratory test was undertaken to test the variability of results obtained using the standard method employing the equipment used throughout this project. The moisture contents of 25 test portions taken from a single well-mixed sample of cereal were analysed. Tins containing test samples were spread over the top shelf of the oven to give the maximum variation of results. The maximum and minimum moisture content given by the test portions were 15.80 and 15.52 %.

Laboratory experiments were devised to estimate the scope of a number of problems, comparing meter readings with the ISO oven method. Five meters from four manufacturers were used in this part of the study. Two meters used resistance to determine moisture content and the other three meters used capacitance. One manufacturer of capacitance meters provided two different models and testing was done using one or other of these models and so laboratory tests were usually done using four meters from four manufactures.

The meters were operated in accordance with manufacturers' instructions.

Varieties of freshly harvested wheat and barley were collected from a number of sources to cover as wide a range of moisture content as possible. These were checked against at least one resistance and one capacitance meter in the field. The moistures were confirmed via oven tests and tested again in the laboratory using four meters. Where possible, the samples were tested using the farmer's meter.

The responses of the four meters were noted for three varieties of hard wheat (Welford, Brompton and Gladiator) and three varieties of soft wheat (Consort, Claire and Alchemy) at three levels of moisture content for each variety. Similar readings were also taken for three varieties of barley. Additional tests were done in both field and laboratory using a wider range of varieties of wheat and barley.

No difference between the performance of capacitance and resistance meters was shown and no difference between the response of the meters to hard and soft varieties of wheat or different varieties of barley was identified.

For all species and varieties, moisture content readings were repeatable for homogenous samples. However, readings from variable, but well mixed samples gave variable results even with the meter that used the largest sample. This was especially pronounced with freshly harvested grain.

A sample of wheat (Director) was dried in an oven for 3.5 hours at 45°C. Readings were taken using three of the four meters every hour for the first four hours after drying and then daily for four days. Readings taken in the first hour varied greatly, possibly due to the variation of moisture content within the sample. No consistent pattern of variation of moisture content readings over time from recently dried grain was found in this small-scale study.

Samples were collected on-farm during the high-temperature drying process. At each farm, samples were collected from the same batch before and after drying. These were tested immediately using a capacitance meter and a resistance meter. The samples were then taken for oven testing. The samples were tested again after at least 48 hours using both meters. No difference was seen between readings taken immediately and those taken after at least 48 hours using the resistance meter. However, when the capacitance meter was used, the readings taken after a delay were slightly higher than those taken straight away. This effect was most evident when the delay was six or more days, when the average increase in moisture content reading was 0.4 %.

Errors were introduced when the temperature of the sample and meter were not the same. Temperature differences of 9.9 to 14.4°C between meter and sample introduced errors of up to 0.7% moisture content. These results were confirmed during on-farm testing when some meters required time to equilibrate before they gave a reading and others gave a slightly different result after they had been allowed to equilibrate for one minute. Where there is a temperature difference between the meter and the sample, the moisture content should not be measured straight away. The sample should be left in a sealed sample bag or jar until the temperature of the meter and sample has equilibrated.

Errors of up to 0.5% moisture content were observed in the laboratory when the sample was under-compressed using resistance meters and a farm meter with a worn grinder gave errors of up to 1.2% of moisture content. This highlights the need for regular servicing of grinders.

Under-compression caused under-estimation of moisture content by an average of 0.4% in one resistance meter, where compression was delivered by a clamp. An error of 0.3% was introduced using this meter when the sample was ground too finely.

An error of 0.4% was introduced when a capacitance meter was used at an angle of 30^{o}. This was due to the inbuilt balance not operating correctly when at an angle. Capacitance meters should only be used on a level surface.

The loading aids provided with 2 of the capacitance meters appeared to work effectively and no loading problems were noted.

Moisture probes are tools that were designed to support the management of bulk drying systems. They work on the same principles as conventional moisture meters and probably share the same software calibrations. However, they are considered to be inferior to conventional meters in respect of accuracy and consistency. An assessment of probes showed the value of these instruments in obtaining in-situ data from grain bulks. However, results were more variable than those of conventional meters and readings taken using probes varied from oven test results on samples removed close to the probe sensor by as much as 1.8% moisture content.

A survey of 158 farmers showed that most farmers had a realistic view of the accuracy of their meter of ± 0.5%, but 37% expressed a need for greater accuracy.

Although the overwhelming majority of farmers surveyed said that they have calibrations checked at least once a year, only 17% get their instruments checked by the manufacturer. The most popular methods of checking the calibration of moisture meters are to attend a clinic (49% of farmers) or to check against the meter of the end user of the product (27% of farmers).

Although not included in the questionnaire, many farmers commented that it was less important that their meter gave an accurate reading than that it agreed with the meter of the end user. This could have serious implications for quality and food safety as accurate moisture content measurements are important when deciding on the necessity of drying to the correct moisture content to prevent formation of ochratoxin A during storage.

Only 7% of farmers reported ever having had problems with their meters. Surprisingly, 65% of farmers had never had a moisture claim, but this could be explained by their adoption of a large safety margin (>0.5%) below the contractual value. Although 35% had suffered claims for high moisture content, most of these had known that they were near or above the maximum moisture level and so had been expecting a claim.

INTRODUCTION

Accurate and reliable moisture measurement is essential for drying calculations, safe storage and marketing of grain and oilseeds. Even before grain is harvested decisions must be made based on assessments of moisture and then at harvest a further decision must be made regarding the need for drying. Key aspects of safe storage, protection against mould, mycotoxins and mites, and the preservation of germination, are controlled by storage moisture content in conjunction with temperature. Finally, when grain is sold, its moisture content must be below the maximum level specified in the contract or it may be rejected or attract a claim. Any decision about moisture relies on a consistent method of determination.

Most farmers rely on electrical moisture meters for this important task. These have limitations of accuracy: usually a range of up to ±0.5% as defined by a previous HGCA project (HGCA, 2000) and this has implications for quality loss during storage as well as sale to end-users with added costs of rejections or claims.

Not surprisingly, given the importance of moisture determination, farmers are concerned about any issue that might have an adverse influence on the accuracy or consistency of these measurements.

Modern moisture meters measure an electrical effect in grain or oilseeds that is related to moisture content. They do not measure moisture directly and rely on an inbuilt calibration between moisture and the electrical parameter measured – usually capacitance or resistance. The calibration is made against samples that have been analysed for moisture content using the International Organisation for Standardisation oven-based method (ISO 712:1998). Therefore, the consistency and accuracy of this method sets the absolute limit of accuracy that can be given by a moisture meter.

To the end-user, one of the most important issues is to determine the best meter to use. It was not the function of this project to conduct a full assessment of all available meters, because it would be necessary to check the consistency of each meter by looking at the performance of several individuals of the same model. This was beyond the scope of the project.

The interpretation of meter results by a farmer is not necessarily straightforward. It is obvious that the accuracy can be important, i.e. that the difference between meter reading and oven standard is minimal. However, although the difference between these two readings is important, if the error is consistent and known, this can be taken into account. For instance, very often the most important comparison for a farmer is between his machine and that of the merchant or end-user. It may be that the latter is also inaccurate, but the crucial issue for trading and avoiding penalties is to ensure that the readings coincide or that sufficient leeway is allowed. In this case, the important features are repeatability and consistency. However, inaccurate meter can lead to insufficient drying and hence possible spoilage or over–drying with a cost penalty.

The aim of this project was to assess problems that might occur under practical conditions and develop end-user recommendations to improve efficiency of moisture measurement on farms. It also addressed some specific issues that have been raised during HGCA Training Days and Road Shows or questions directed at HGCA researchers.

The first stage was an initial review of factors most likely to cause variation in use, with co-operation from meter manufacturers and selected farmers. The factors identified were:

- Types of moisture measurement device (e.g. resistance, capacitance) and sample size
- Calibration issues
- Temperature effects
- Differences between varieties and crops- e.g. hard and soft wheat, oilseeds and cereals
- Issues surrounding compressing or loading a sample

The review was followed by a survey of farmers and meter use on a number of farms to assess the variations under practical conditions.

Limited laboratory experiments were devised to estimate the scope of a number of problems, comparing meter readings with ISO oven methods. Approaches included: exposing meters and samples to a range of temperatures, testing calibrations with a range of varieties over a range of moistures. The issue of apparent changes in measured moisture content immediately after drying, which may be caused by moisture re-distribution within the grain, was also examined.

TESTS AND RESULTS

1 Standard oven test method

The International Organisation for Standardisation (ISO) routine reference method for the determination of moisture content for cereals and cereal products (ISO 712:1998) is the standard method by which the moisture content of standard samples are determined. It was used throughout this project to provide the ultimate assessment of the moisture content of all wheat and barley samples used for testing the meters.

In the case of oilseed rape the ISO method for the determination of moisture and volatile matter content in oilseeds (ISO 665:2000) was used for moisture content determinations.

A laboratory test was undertaken to test the variability of results obtained using the ISO cereals method employing the equipment used throughout this project. The moisture content of 25 test portions were taken from a single well-mixed sample of cereal were analysed. The test samples were spread over the top shelf of the oven to give the maximum variation of results.

The method gave an average moisture content of 15.70% with a standard deviation of 0.07% moisture content. The maximum and minimum moisture content given by the test portions were 15.80 and 15.52%.

Moisture meters are calibrated against samples analysed using this method and so this sets an absolute limit on the accuracy of the meters.

2 Laboratory assessment of moisture meters

Five models of moisture meter from four different manufacturers were used in the laboratory tests. Three of the meters used capacitance to determine moisture content and the other two meters used resistance.

One manufacturer provided two different models and testing was done using one or other of these models and so laboratory tests were done using 4 meters from 4 manufacturers.

The meters were operated in accordance with manufacturer’s instructions.

i. Effect of variety, wheat hardnes and cereal type.

The response of the 4 meters was examined using 3 soft and 3 hard varieties of wheat. The moisture content of each sample was analysed using the appropriate ISO method and 3 replicate readings were taken using each meter.

The wheat and barley samples were analysed at their original moisture content and then dried on a tray placed in a fume cupboard to produce a second level of moisture content. The third level of moisture content was produced by adding de-ionised water to portions of the dried samples, sealing in jars and shaking intermittently over a period of 4 days. All samples were kept in sealed jars for a week after they had been produced before they were analysed using the ISO method and then 3 replicate readings were taken using each meter as before. The responses of the meters to the 6 varieties of wheat are shown in Tables 1 to 3.

Table 1. Average moisture content readings given by the moisture meters using dry wheat.

Variety		Oven moisture content (%)	Moisture meter readings (%)		
			Resistance 2	Capacitance 1	Capacitance 2
Welford	Hard	11.4	11.4	11.2	11.5
Brompton	Hard	11.1	11.3	10.9	11.0
Gladiator	Hard	11.6	11.2	11.2	11.7
Consort	Soft	11.7	11.5	11.7	12.4
Claire	Soft	11.7	11.6	11.5	11.9
Alchemy	Soft	11.4	11.3	11.3	11.9

Table 2. Average moisture content readings given by the moisture meters using wheat between 14 and 16% moisture content.

Variety	Oven moisture content (%)	Moisture meter readings (%)			
		Resistance 1	Resistance 2	Capacitance 1	Capacitance 2
Welford	14.2	14.5	14.6	14.1	15.2
Brompton	15.9	-	16.0	14.9	15.2
Gladiator	14.3	14.3	14.3	14.1	14.9
Consort	14.3	14.0	14.2	14.0	14.9
Claire	14.8	14.6	15.2	14.3	15.3
Alchemy	14.9	14.2	14.9	14.7	15.4

Table 3. Average moisture content readings given by the moisture meters using wheat at or above 18 % moisture content.

Variety	Oven moisture content (%)	Moisture meter readings (%)			
		Resistance 1	Resistance 2	Capacitance 1	Capacitance 2
Welford	19.1	-	19.1	18.7	19.8
Brompton	18.0	18.3	19.0	18.3	19.7
Gladiator	21.0	-	19.9	19.7	21.0
Consort	19.5	-	19.3	18.7	19.8
Claire	20.0	-	19.9	19.2	20.3
Alchemy	18.9	-	19.4	18.6	19.9

Resistance 1 meter is not designed to give readings below 11.3 % and so the low moisture content wheat samples were too dry to be measured using this meter. During testing this same meter malfunctioned and was replaced by a new meter of the same type. Unfortunately, there were not enough remaining samples to give a full set of readings using the new meter. Results given by the original meter are not reported here.

Varieties of freshly harvested wheat and barley were collected from a number of sources to cover as wide a range of moisture content as possible. The moistures were determined using oven tests and tested using 4 meters as before. In general samples used in these studies came from stocks of seed grain of known purity of variety.

Tables 4 and 5 show the differences between moisture contents determined by the oven method and average readings given by the four meters from freshly harvested samples of hard and soft varieties of wheat supplied by the National Institute of Agricultural Botany (NIAB).

Table 4. Differences between moisture contents determined by the oven method and average readings given by the four meters from freshly harvested samples of hard varieties of wheat supplied by NIAB.

Variety	Oven moisture content (%)	Difference between meter readings and oven moisture content on samples of freshly harvested hard varieties of wheat (% moisture content)			
		Resistance 1	Resistance 2	Capacitance 1	Capacitance 2
Humber	14.3	0.0	1.0	-0.1	-0.3
Einstein	14.3	-0.1	0.5	-0.2	-0.5
Cordiale	14.0	0.1	0.5	0.2	-0.2
Solstice	14.4	-0.2	0.4	-0.4	-0.5
Gladiator	14.4	-0.1	0.9	-0.2	-0.5
Average		-0.1	0.7	-0.1	-0.4

Table 5. Differences between moisture contents determined by the oven method and average readings given by the four meters from freshly harvested samples of soft varieties of wheat supplied by NIAB.

Variety	Oven moisture content (%)	Difference between meter readings and oven moisture content on samples of freshly harvested soft varieties of wheat (% moisture content)			
		Resistance 1	Resistance 2	Capacitance 1	Capacitance 2
Zebedee	14.4	-0.1	0.0	-0.1	-0.6
Ambrosia	14.2	-0.2	-0.2	-0.2	-0.6
Claire	14.4	0	0.5	0	-0.3
Robigus	14.2	0.2	0.7	0.1	0.1
Alchemy	14.3	0.2	0.7	0.3	0.0
Average		0.0	0.3	0.0	-0.3

Tables 6 and 7 show differences between moisture contents determined by the oven method and average readings given by the four meters from freshly harvested samples of two varieties of wheat collected from a single large farm.

Table 6. Differences between moisture contents determined by the oven method and average readings given by the four meters from freshly harvested samples at varying moisture contents of Gladiator, a hard wheat variety.

Oven moisture content (%)	**Difference between meter readings and oven moisture content on samples of freshly harvested Gladiator at various moisture contents (% moisture content)**			
	Resistance 1	**Resistance 2**	**Capacitance 1**	**Capacitance 2**
16.2	-0.4	0.4	-0.1	-0.4
16.5	-0.4	0.2	0.1	-0.3
16.9	-0.3	0.5	0.3	-0.1
16.7	-0.3	0.1	0.0	-0.1
17.2	-0.2	0.5	0.4	-0.1
17.3	-0.6	0.3	0.2	-0.2
17.4	-0.5	0.5	0.4	-0.0
19.5	-0.8	0.4	0.2	0.1
19.7	-0.8	0.4	0.2	insufficient sample
20.5	-0.6	0.8	0.3	0.5
21.6	-0.8	0.1	0.2	0.1
Average	-0.5	0.4	0.2	0.0
Average for moisture contents between 16 and 16.5 % moisture content	-0.4	0.3	0.0	-0.3

Table 7. Differences between moisture contents determined by the oven method and average readings given by the four meters from freshly harvested samples at varying moisture contents of Robigus, a soft wheat variety.

Oven moisture content (%)	**Difference between meter readings and oven moisture content on samples of freshly harvested Robigus at various moisture contents (% moisture content)**			
	Resistance 1	**Resistance 2**	**Capacitance 1**	**Capacitance 2**
14.8	0.0	0.5	0.0	-0.6
14.8	-0.2	0.3	0.2	0.0
14.8	-0.3	0.2	-0.1	-0.2
14.8	-0.4	0.2	0.1	0.0
15.3	-0.4	0.1	0.1	-0.3
15.4	-0.7	0.4	0.2	-0.1
15.5	-0.3	0.5	0.4	0.1
15.7	-0.4	0.4	0.4	-0.1
15.9	-0.5	0.3	0.1	-0.1
15.9	-0.2	0.5	0.3	-0.1
16.2	-0.1	0.4	0.4	0.1
16.3	0.0	0.2	0.3	0.0
16.4	-0.2	0.5	0.6	0.2
Average	-0.3	0.3	0.2	-0.1
Average for moisture contents between 16 and 16.5 % moisture content	-0.1	0.4	0.4	0.1

In some cases, freshly harvested samples were collected on farm and first tested in situ with two meters of the same model as the laboratory Resistance 1 meter and Capacitance 2 meter. The samples were then taken to the laboratory for testing by the oven method and with the laboratory meters. Tables 8 and 9 show differences between moisture contents determined by the oven method and average readings given by six meters from samples of hard and soft varieties of wheat collected on farm.

Table 8. Differences between moisture contents determined by the oven method and average readings given by six meters from freshly harvested samples of hard varieties of wheat collected on farm.

Variety	Oven moisture content (%)	Difference between meter readings and oven moisture content on samples of freshly harvested hard varieties of wheat (% moisture content)					
		Field Resistance 1	**Laboratory Resistance 1**	**Laboratory Resistance 2**	**Field Capacitance 2**	**Laboratory Capacitance 1**	**Laboratory Capacitance 2**
Oakley	15.2	0.4	0.3	1.4	-0.1	0.3	-0.3
Limerick	14.6	0.2	0.2	0.6	-1	-0.3	-0.7
Battalion	14.9	-0.2	0.2	1.2	-0.4	0.2	0
Monty	14.2	-0.6	0.3	0.8	-0.3	0.2	-0.1
Smuggler	13.5	0.6	0.6	1.1	-0.6	0.1	-0.3
Mallacca	14.5	0.2	0.3	0.9	-0.5	-0.2	-1.3
Einstein	15.3	0	0	0.8	-0.4	-0.1	-0.5
Einstein	15.8	-0.4	-0.3	0.4	-0.6	-0.4	-0.6
Einstein	15.4	-0.5	-0.3	0.6	-0.3	-0.3	-0.3
Average		0.0	0.1	0.9	-0.1	-0.5	-0.5

Table 9. Differences between moisture contents determined by the oven method and average readings given by six meters from freshly harvested samples of soft varieties of wheat collected on farm.

Variety	**Oven moisture content (%)**	**Difference between meter readings and oven moisture content on samples of freshly harvested hard varieties of wheat (% moisture content)**					
		Field Resistance 1	**Laboratory Resistance 1**	**Laboratory Resistance 2**	**Field Capacitance 2**	**Laboratory Capacitance 1**	**Laboratory Capacitance 2**
Glasgow	16.1	-0.1	0.1	0	-0.2	0.2	-0.7
Glasgow	15.1	-0.2	-0.3	0.8	-0.7	-0.2	-0.8
Zebedee	14.3	0.1	0.3	1.1	-1	0	-0.5
Alchemy	15.1	0.3	0.6	1.3	0.1	0.4	0.2
Alchemy	13.6	0	0.4	0.7	-0.3	0.4	-0.1
Average		0.0	0.2	0.8	-0.4	-0.4	-0.4

No difference between the performance of capacitance and resistance meters was apparent and no difference between the response of the meters to hard and soft varieties of wheat was identified. Resistance meter 2 gave results close to the oven moisture content in the first season of testing (Tables 1 to 3). When the same meter was used in the second season of the project this meter gave the largest error with respect to the oven test (Tables 4 to 9). This was the only meter not to be serviced between seasons. This highlights the need for regular servicing.

Tables 10 to 12 show the responses of the meters to 3 varieties of barley at 3 levels of moisture content. The 3 moisture levels were produced in the same way as the 3 levels of moisture content produced for hard and soft varieties of wheat (Tables 1 to 3).

Table 10. Average moisture content readings given by the moisture meters using dry barley.

Varieties	Oven moisture content (%)	Moisture meter readings (%)			
		Resistance 1	Resistance 2	Capacitance 1	Capacitance 2
Unspecified CSL barley	11.6	11.3	11.5	11.6	12.8
Unspecified farm barley	11.4	-	11.0	11.4	13
Pearl	11.9	11.6	11.9	12.5	14.4

Table 11. Average moisture content readings given by the moisture meters using barley at approximately 15% moisture content.

Varieties	Oven moisture content (%)	Moisture meter readings (%)			
		Resistance 1	Resistance 2	Capacitance 1	Capacitance 2
Unspecified CSL barley	14.8	-	14.6	14.7	15.7
Unspecified farm barley	15.2	-	14.6	14.7	16.3
Pearl	14.7	15.2	15.2	15.7	17.6

Table 12. Average moisture content readings given by the moisture meters using barley over 18 % moisture content.

Varieties	Oven moisture content (%)	Moisture meter readings (%)			
		Resistance 1	Resistance 2	Capacitance 1	Capacitance 2
Unspecified CSL barley	18.8	19.3	18.6	19.9	21.2
Unspecified farm barley	18.6	18.5	18.3	19.1	20.7
Pearl	19.2	-	19.4	21.2	21.9

Table 13 shows the differences between moisture contents determined by the oven method and average readings given by six meters from freshly harvested samples of barley collected on farm.

Table 13. Differences between moisture contents determined by the oven method and average readings given by six meters from freshly harvested samples of barley collected on farm.

Variety	Oven moisture content (%)	Difference between meter readings and oven moisture content on samples of freshly harvested barley (% moisture content)			
		Resistance 1	Resistance 2	Capacitance 1	Capacitance 2
Retriever	15.2	-0.2	0.2	-0.5	-1.4
Pearl	13.5	-0.1	0.0	-0.2	-1.5
Spectrum	15.15	-0.8	-0.3	-0.5	-1.3
Carat	14.2	-0.5	-0.4	-0.8	-2.1
Pearl	14.9	-0.4	-0.2	-1.0	-1.6
Pearl	14.9	-0.4	-0.2		
Saffron	13.6	0.4	0.4	-0.1	-0.3
Average		-0.3	-0.1	-0.5	-1.4

The readings for barley from capacitance 2 were consistently high during the first year of testing (Tables 10 to 12). This meter was replaced by a new meter for the second year of testing and this read consistently low. There were no consistent differences between the other 3 meters.

ii. Consistency of replicate readings taken from the same sample and sample variability

Table 14 shows the average difference between the maximum and minimum readings given by three replicate readings for each of the six varieties of wheat and three varieties of barley from Tables 1 to 6 and 10 to 12. This shows acceptable repeatability by all meters on homogeneous samples.

Table 14. Average difference between the maximum and minimum readings of three replicates for each of the six varieties of wheat and three varieties of barley.

Meter	Difference between maximum and minimum given by 3 replicate readings (%)									
	Welford	Brompton	Gladiator	Consort	Claire	Alchemy	CSL Barley	Farm barley	Pearl	Average %
Resistance 1	0.25	0.25	0.40	0.45	0.15	0.35	0.20	0.50	0.37	0.32
Resistance 2	0.13	0.20	0.10	0.17	0.13	0.10	0.20	0.13	0.17	0.15
Capacitance 1	0.30	0.33	0.27	0.23	0.33	0.37	0.30	0.17	0.20	0.28
Capacitance 2	0.20	0.27	0.30	0.20	0.27	0.30	0.27	0.30	0.23	0.26

These results are highly significant as they define the inherent error in a sample of well-mixed grain that was considered homogeneous when measured with a meter. The average difference between replicates makes a significant contribution to the overall error of measurement.

The error between replicates increased when samples were heterogeneous even when the samples were well mixed (Table 15).

The meters were tested against 7 sub-samples taken from each of a series of 46 well mixed but variable samples of wheat. Table 15 shows the average difference between the maximum and minimum readings given by all of the sets of 7 sub-samples for each meter and a typical set of results taken from a sample of Alchemy. This shows the effect of variation of moisture content within samples can have on repeatability.

Table 15. Average difference between the maximum and minimum readings given by a series of 7 sub-samples taken from each of 46 well mixed but variable samples of wheat and barley and a typical set of results from a sample of wheat.

Meter Type	Average difference between maximum and minimum readings (%)	Moisture content given by meters from 7 sub-samples from a well mixed but variable sample of Alchemy (%)						
		1	2	3	4	5	6	7
Resistance 1	0.5	14.8	14.5	15.0	14.7	14.9	15.0	14.9
Resistance 2	0.9	15.3	15.1	15.8	15.1	15.1	16.2	15.3
Capacitance 1	0.4	15.0	15.7	15.4	15.4	15.7	15.5	15.8
Capacitance 2	0.5	16.0	16.1	16.4	16.2	16.0	16.1	16.1

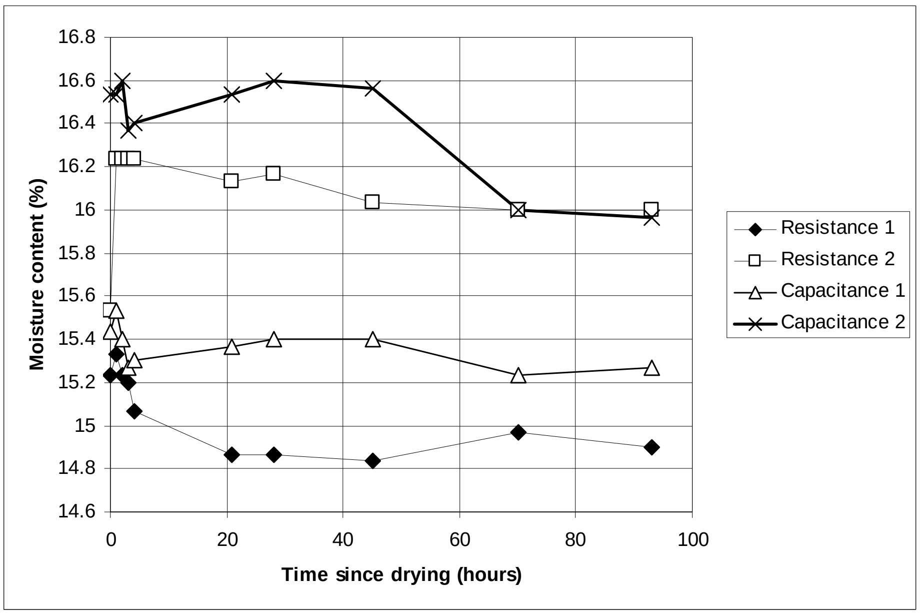
iii. Consistency of readings taken from freshly dried grain

A problem with measuring the moisture content of grain after drying in hot air dryers was identified during the initial review of factors most likely to cause variation in the use of moisture meters. Many users commented that readings taken immediately after drying were significantly lower than readings taken from the same grain a few days later.

This effect was investigated by drying a sample of wheat (Director) in an oven for 3.5 hours at 45°C. Three replicate readings were taken using each of the 4 meters every hour for the first 4 hours after drying and then daily for 4 days.

The moisture content of the oven dried sample of wheat before drying was 19.0% as determined by the ISO method. Immediately after drying, the moisture content of the sample of wheat was 15.0%. This is lower than any of the readings given by the moisture meters in the first set of readings after drying. When the sample was analysed again after 4 days (96 hours) the moisture content values given by the 4 meters was R1 14.9%; R2 16%; C1 15.3% and C2 16% (average 15.8%). Figure 1 shows how the average moisture readings given by four moisture meters changed over time using grain dried in an oven.

Figure 1. Average moisture meter readings taken from a recently dried sample of wheat over four days.



Variable results were obtained from the meters immediately after drying is probably due to variability of moisture contents within the sample. With resistance meter 2, there was a 0.7% rise over the first hour between the first reading and the second. After 4 hours the readings did not change significantly over the next four days with the exception of Capacitance 2 where readings fell by 0.6% after two days.

Samples were collected on-farm during the high-temperature drying process. At each farm, sample sets (2kg) were collected from same batch before and after drying. The samples were tested immediately with a capacitance meter and a resistance meter, three times with each meter. The samples were taken for oven testing and re-tested using the same two meters after at least 2 days.

Table 16 shows the moisture contents given by the ISO oven method and the average moisture content readings given by each meter from samples taken from the outputs of the dryers.

Table 16. Initial average moisture content readings taken immediately after drying using hot air dryers and final moisture content readings taken using the same samples after a delay of at least 2 days.

Dryer	Sample	Average moisture content readings given by each meter from samples taken from the outputs of 5 dryers (%)				Oven moisture content (%)	
		Resistance 1		Capacitance 2			
		Initial	Final	Initial	Final	Initial	Final
1	1	14.8	15.0	14.6	14.9	15.2	15.2
	2	14.6	14.9	14.3	14.7	14.9	15.1
	3	14.6	14.8	14.6	14.9	14.9	15.1
	4	14.4	14.6	13.8	14.4	14.5	14.7
	5	14.3	14.4	14.0	14.3	14.6	14.6
	Average	14.5	14.7	14.3	14.6	14.8	14.9
2	1	14.4	14.4	14.1	14.5	14.8	14.9
	2	14.4	14.5	14.1	14.4	14.8	14.8
	3	14.5	14.4	14.0	14.5	14.8	14.8
	4	14.5	14.4	14.0	14.4	14.8	14.8
	5	14.4	14.4	13.8	14.5	14.9	14.9
	Average	14.4	14.4	14.0	14.5	14.8	14.8
3	1	13.9	14.0	13.8	15.1	13.6	13.7
	2	14.5	14.2	14.0	14.0	14.0	14.2
	3	14.6	14.2	13.9	14.1	13.9	14.2
	4	14.3	14.2	14.2	14.1		
	Average	14.3	14.2	14.0	14.3	13.8	14.0
4	1	14.4	14.3	13.8	14.0		13.3
	2	14.4	14.4	13.7	13.8		13.5
	Average	14.4	14.3	13.7	13.9		13.4
5	1	15.0	14.4	14.2	14.3		15.2
	2	12.9	12.4	12.3	12.4		13.1
	3	13.0	12.8	12.9	12.8		13.5
	Average	13.6	13.2	13.1	13.2		13.9

Table 17 shows the average difference between final and initial readings from each dryer. The table also gives the average input and output moisture contents for each dryer as determined by the oven method and the delay between initial and final moisture content determinations.

Table 17. Differences between initial and final meter readings using the resistance 1 and capacitance 2 meters from the samples taken from the output of the high-temperature dryers.

Dryer	Average Pre-drying moisture content (%)	Average output moisture content (%)	Delay between initial and final moisture content determinations (days)	Differences between initial and final output moisture content determinations (%)		
				Resistance 1	Capacitance 2	Oven
1	16.6	14.9	6	-0.2	-0.4	-0.1
2	16.0	14.9	6	0.0	-0.5	0.0
3	15.9	14.0	10	0.2	-0.3	-0.1
4	16.5	14.6	2	0.1	-0.2	
5	18.6	13.9	2	0.4	-0.1	
Average				0.1	-0.3	-0.1
Average when delay is greater than 2 days				0.0	-0.4	-0.1

No difference was seen between readings taken immediately and those taken after at least 48 hours using the resistance meter. However, when the capacitance meter was used, the readings taken after a delay were slightly higher than those taken straight away. This effect was most evident when the delay was 6 days or more when the average increase in moisture content reading was 0.4 % moisture content.

iv. Effect of temperature differences between the grain and the meter

The four meters were left to equilibrate in a room at 24°C overnight. Readings were then taken using samples of one variety each of hard wheat, soft wheat and barley that had been left in a fridge overnight at about 6°C in moisture tight packaging. Three replicate readings were taken for each variety.

Similar readings were taken after the four meters were left to equilibrate in a room at 9.4°C overnight using samples that had been left at 24°C overnight in moisture tight packaging.

The temperature of the grain and the rooms were monitored using mercury in glass thermometers.

Table 18 shows the difference between average readings taken with and without a temperature difference between the meter and the grain. Negative or positive figures indicate a lower or higher reading respectively, due to a temperature difference.

Table 18. Difference between moisture meter readings taken with the meter and sample at the same temperature and readings taken with the meter and the sample at different temperatures.

Temperature conditions	Average temperature difference (^oC)	Deviation from oven moisture content due to temperature difference (% MC)			
		Capacitance 1	Capacitance 2	Resistance 1	Resistance 2
Warm instrument Cold grain	14.4	- 0.4	- 0.6	- 0.7	+ 0.1
Cold instrument Warm grain	9.9	- 0.1	+ 0.4	+ 0.5	+ 0.1

Where the difference in reading is significant, the readings obtained when the instrument was warm and the grain was cold were lower than those obtained when the temperatures were the same. When the instrument was cold and the grain was warm, higher readings were obtained.

These results were confirmed during on-farm testing when some meters required time to equilibrate before they gave a reading and others gave a slightly different result after they had been allowed to equilibrate for 1 minute.

v. Effect of coarseness of grinder with resistance meter

Coarsely ground and finely ground sub-samples were analysed using Resistance meter 2. The coarsely ground samples were produced using the grinder supplied with Resistance meter 1 and the finely ground samples were produced using the ISO grinder on a fine setting.

The finely ground samples of wheat and barley gave a greater error than coarsely ground samples using Resistance Meter 2. The average differences from oven moisture content given by finely ground and coarsely ground samples were 0.6% and 0.3% moisture content respectively.

vi. Effect of over and under compression of cells in resistance meters.

A sample of wheat was analysed using resistance 2 meter, with the clamp over-tightened and with the clamp under-tightened. Over compression appeared to have no effect but under compression caused the meter to under-read by up to 0.5%.

Results from a resistance 1 type meter fitted with a grinder that was under-compressing were compared with a similar meter fitted with a correctly functioning grinder. The grinder that was giving poor compression underestimated moisture content by an average of 0.4% compared with the other meter.

vii. Effect of capacitance meter on unlevelled surface

Readings from identical samples were compared with Capacitance meter 1 on a level surface and tipped at an angle of 30^{o}. The deviation from the oven moisture content increased from 0.1 to 0 0.5% moisture content.

Capacitance Meter 2 gave an error message when used in the same way.

3 On-farm assessment of moisture meters

The assessment of farm meters was done in two stages:

- A series of assessments were made to address specific issues
- A series of visits were made to farms, where farm meters were tested against samples of known moisture

i. Assessment of specific issues on farm

The issues assessed were:

1. Variation of readings given by well-mixed samples of freshly harvested grain

The moisture content of grain ex-combine or shortly after harvest, was assessed on 3 farms using the farm meter or a resistance meter loaned by the manufacturer. Samples of 1kg were collected, mixed well and then 6 sub-samples were tested with a meter. A further sample was collected from the same batch of grain 7 to 14 days later and tested in the same way with the same meter.

Table 19. Variation between sub-samples of the same sample of wheat taken shortly after harvest and then re-sampled after 14 days storage.

Ex-combine sample	After 14 days storage
14.5	14.7
14.2	14.8
14.7	14.7
14.8	14.6
14.6	14.8
14.7	14.7
Maximum difference	
0.6	0.2

The variation shown in Table 19 was typical of the results found at the other farms so that it is probably safe to assume an error of measurement of ± 0.5% with freshly harvested grain.

At one farm where grain was sampled immediately before and after drying the variation was reduced from ± 0.5% to ± 0.2%.

2. The effect of a worn-out grinder

Tests at one farm showed a large discrepancy between results given by the farm meter and a resistance meter of the same make loaned by the manufacturer. This discrepancy was eliminated when the grinder of the farm meter was serviced.

Table 20. Readings taken using a farm meter before and after servicing the grinder.

	Farm Meter	**Test meter**
Before service of farm meter grinder	13.7	14.9
	14.5	14.8
	14.2	15.0
After service of grinder	14.9	15.0
	14.9	14.9
	14.8	14.8

Further work at another farm confirmed that a worn grinder caused the meter to give low readings.

3. Consistency/variability of replicate samples

Whenever possible multiple replicate samples from the same batch of grain were tested during on-farm assessment. These tests were done both with resistance and capacitance meters loaned by the manufacturers.

Table 21. Examples of individual replicate samples taken from the same, well mixed sample and tested on-farm with a resistance and capacitance meter.

Rep.	Wheat Glasgow		Wheat Gladiator		Wheat Smuggler		Barley Saffron	
	Res.	Cap.	Res.	Cap.	Res.	Cap.	Res.	Cap.
1	15	14.5	14.9	13.9	14.3	12.8	13.7	13.1
2	14.8	14.6	14.9	14.3	14.2	12.7	13.5	12.7
3	14.9	14.4	14.9	14.2	13.9	12.8	13.6	13
4	14.8	14	14.8	14.5	14.2	13	13.5	12.7
5	14.8	14.3	15	14.2	14	13.2	13.5	12.8

When testing replicate samples of dried grain, the meters gave consistent results. The variation between readings taken from the same sample was about 0.2% for the resistance meter although the capacitance meter was slightly more variable.

4. The effect of temperature differences between the grain and the meter

When meters were tested on-farm any potential temperature difference between the meter and sample was noted and repeat readings were taken after allowing 1 or 2 minutes for equilibration. During this period the reading given by the meter changed, generally to a value closer to that given by an oven test. This was most noticeable with a resistance meter. One capacitance meter seemed to reach the final reading very rapidly in spite of any temperature difference, whilst the other would not give a reading until the cell and sample had equilibrated.

ii. On-farm tests with samples of known moisture content

Samples at 2 moisture contents each of wheat (Robigus), barley (unknown variety) and oilseed rape (unknown variety) were produced by adding water while the commodity was being mixed in a clean concrete mixer. The moisture content of each sample was determined using the appropriate ISO method.

These samples were used to test the moisture meters used by farmers on a series of farms. A range of different meter types and ages were covered. Almost all the meters gave consistent results, but in one case a brand new meter was inoperative.

When possible the meters were cleaned and checked before testing and the method of calibration checking was established.

Farm 1. The meter was a resistance meter about 4 years old. The meter was still as supplied with complete instructions. The grinder compressor was cleaned and checked before testing. No serious wear on baffle plate was noted. A check with the self-test cell gave 36.4, which is within specification. Meter and samples were at the same temperature, three replicate samples tested for each sample. There was no change in reading over time.

Farm 2. The meter was a new and unused capacitance meter. The meter was complete as supplied. However, it completely failed to give any consistent reading. This was not caused by a low battery fault. The farmer said he would send it back, but wasn't too worried as he relied on a moisture probe for all moisture testing, including sales of grain.

Farm 3. The meter was a capacitance meter about 2 years old. The meter cell was cleaned before testing. Readings taken immediately were up to 0.4% mc lower than when the samples were left in the meter for 2 minutes. This was probably due to the samples being colder than the meter when first tested. There were calibration corrections of: Wheat +0.2%, Barley -1.2% and OSR +0.6% set on this meter. The farmer had no idea who had applied these, but assumed it had been done at a calibration clinic.

Farm 4. The meter was a resistance meter which was several years old but complete with instructions. The grinder was cleaned and inspected before testing and signs of wear were noted on the grinder feeder plate. A check with the self-test cell gave 36.3, which is within specification. Only single samples were tested. Samples and meter were at about the same temperature.

Farm 5. The meter was a 'Commercial store' type, using Near Infra Red technology. The meter was serviced each year by the supplier and was used during storage and marketing of 20,000 tonnes of cereals. The farm manager had had no issues with moisture claims, but he reported large differences between moisture test results from different TASCC-Approved laboratories.

Farm 6. The meter was a very old resistance meter using non-ISO scale and converted mincer to grind grain. Meter had been checked at the local merchant each year and the merchants also sent out samples in sealed plastic bottles. No moisture issues over sale of grain were reported.

Farm 7. The meter was a capacitance type, whose calibration was checked annually at local mill (a principal customer). The mill specified certain aspects of usage (using a measuring cup to fill the loading cell) and insisted on attendance at a clinic each year, when meters were checked. The conditions of test were very cold (1°C) and some of the samples were warmer than the meter. The meter appeared to be taking account of this, because there was a delay in obtaining a reading. Leaving the sample longer in the meter did not appear to affect the result.

Table 22 shows examples of replicate measurements using two of the farm meters with two of the samples of known moisture content.

Table 22. Replicate samples taken by two farm meters using samples of known moisture content.

	Replicate 1	**Replicate 2**	**Replicate 3**
Capacitance meter from Farm 7 Wheat 14.6%	13.9	13.9	13.8
Capacitance meter from Farm 7 Barley 15.3%	14.8	14.8	14.7
Resistance meter from Farm 1 Wheat 14.6%	13.6	13.6	13.6
Resistance meter from Farm 1 Barley 15.3%	15.1	15.1	14.9

Table 23. The average response of 7 farm meters to oven tested samples.

Farm	**Response of the farm meters to oven tested samples**					
	Wheat		**Barley**		**Oilseed Rape**	
	17.9 %	**14.6 %**	**18 %**	**15.3 %**	**9 %**	**7 %**
1	16.8	13.6	18.5	15.0	9.4	6.8
2	Meter failed to give a consistent reading					
3	16.9	14.6	16.8	15.3	8.3	10
4	16.8	14	17.8	14.9	9.1	7.2
5	16.2	14.3	17.5	15.2	9.1	6.9
6	17.1	14.1	16.5	14.6		
7	16.7	13.9	17.7	14.7	8.6	7.2

Table 22 shows little variation between replicate samples and confirms that meters are consistent when measuring homogeneous samples. However, all meters tended to underestimate the moisture content (Table 23), particularly with wheat. This could be by as much as 1% at about 18% moisture and the same effect was seen on a commercial NIR machine (Farm 5).

The under estimation of the moisture content of wheat samples could lead to insufficient drying.

Several machines had calibration adjustments installed, which had been applied by merchants or at calibration clinics. However, these often increased the difference between meter readings and the moisture content of the test samples. It was apparent that farmers regard agreement with a merchant or end user as more important than accuracy.

4 Assessment of moisture probes

Moisture probes work on the same principles as meters, but rather than containing the sample to be measured in a cell, they are inserted directly into a heap of grain. Capacitance and resistance moisture probes were tested in the field and compared with results given by a conventional resistance meter and an oven test of a sample.

Initial tests involved inserting the probes into a conical heap of a single batch of dried Xi19 wheat from a batch drier. As this grain had been conveyed and discharged onto a floor it was assumed that the moisture content was fairly consistent. The spears were inserted from the top and horizontally from the side, into the heap.

The moisture content reading of both probes consistently increased from 14.1 to 14.9% with the depth of insertion. This same effect was noted even when the spear was inserted horizontally. The depth of insertion appeared to have an effect on the reading given and this might be important if calibration was adjusted after checking against a small volume of grain.

Further tests were completed at four farms. The probes were fully inserted into bulks of wheat and readings taken. The probes were inserted at 6 different points in the bulk so that the measuring portion of each was at the same depth and about 0.5m apart. A grain spear was then used to collect a sample midway between the probes and at about the same depth as measuring devices on the probes. This sample was tested using a resistance meter and part of the sample retained for analysis using the ISO method. The responses of the probes were noted with the probes fully inserted into grain and also at depths of 0.5 and 1 m.

Table 24 shows the average moisture content readings given by probes, the meter and the ISO oven test on the four bulks of wheat. The resistance probe sometimes required a longer period after insertion, up to 1 minute, to reach a stable reading. This is probably caused by the temperature compensation system.

Table 24. Average moisture content readings given by capacitance and resistance probes, a resistance type meter and the ISO oven test on four bulks of grain.

Variety	Average moisture content readings (%)			
	Capacitance probe	Resistance probe	Resistance meter	ISO oven test
Robigus	16.7	15.7	15.6	-
Xi19	16.1	16.3	15.9	15.9
Claire	15.1	15.6	15.0	15.4
Einstein	14.8	15.2	14.6	15.6

The results from this limited study suggested that moisture probes provide a useful estimate of moisture that is generally comparable to a conventional meter. However, there was a variation of approximately 0.8% between insertions in the same bulk and it cannot be established from these tests if this was a variation of the moisture content of the grain or a measurement error of the probes.

In order to gain more exact information, a further series of tests in wheat and barley were conducted in which samples were collected from close to the probe sensor and sent for oven testing. For this part of the study, a new resistance probe was provided by the manufacturer but unfortunately a similar capacitance probe was not available. Therefore, three different farmer-owned capacitance probes had to be used. The calibration status of these probes was unknown.

Seven bulks of wheat and 5 bulks of barley were used with the probes being assessed at depths of 0.5m, 1m and fully inserted. In addition, a limited number of tests were done in metal or plastic waste bins to simulate the calibration checking process often used at moisture clinics. The results in Tables 25 to 28 show the differences between the Probe results and the oven test on samples removed from as close as possible from the probe positions. However, there is no way of being certain that the oven sample was at exactly the same moisture as the grain around the sensor of the probe. The results are grouped in order of the approximate moisture content of the bulk that was being tested as shown by the oven tests. However, in some cases there was a gradient of moisture from 0.5m to full insertion.

Table 25. Differences between resistance probe readings and oven moisture content on wheat

Depth of insertion (m)	Difference between resistance probe readings and oven moisture content on wheat at 14 to 17% moisture content (% moisture content)						
	14%	14%	14%	15%	15%	15%	17%
0.5	1.0	0.6	2.5	-0.6	0.8	1.0	-0.7
1.0	1.8	0.9	2.0	0	0.9	0.4	-0.2
Full	1.6	0.4	1.7	0	1	1.6	-0.2
Temperature of grain	Cool	Cool	Hot	Cool	Cool	Hot	Cool

Table 26. Differences between resistance probe readings and oven moisture content on barley

Depth of insertion (m)	Difference between resistance probe readings and oven moisture content on barley at 13 to 17% moisture content (% moisture content)				
	13%	14%	15%	16%	16%
0.5	0.3	0.2	0.8	0	-0.7
1.0	0.8	0.8	0.2	0	-1.1
Full	0.9	0.8	-0.1	-0.5	-0.5

Table 27. Differences between capacitance probe readings and oven moisture content on wheat

Depth of insertion (m)	Difference between capacitance probe readings and oven moisture content on wheat at 14 to 17% moisture content (% moisture content)						
	Probe 1		Probe 2			Probe 3	
	14%	15%	14%	14%	15%	15%	17%
0.5	0.5	0.3	0.1	0.5	-0.2	0	0.2
1.0	0.7	0.4	0	0.3	-0.6	-0.2	0.3
Full	0	0.3	0.1	0.6	-0.5	-0.4	0.9
Temperature of grain	Cool	Cool	Cool	Hot	Cool	Hot	Cool

Table 28. Differences between capacitance probe readings and oven moisture content on barley

Depth of insertion (m)	Difference between capacitance probe readings and oven moisture content on barley at 13 to 17% moisture content (% moisture content)				
	Probe 1	Probe 3			
	15%	13%	14%	16%	16%
0.5	-1.7	1	0.7	0.1	-0.9
1.0	-1.5	1.1	0.8	0	-1
Full	-1.5	1.1	0.5	0.1	0.2

With the resistance probe in wheat there was some inconsistency in the results, but there was a tendency for the difference between probe and oven to be reduced at higher moistures. In most cases the resistance probe over-estimated the moisture content. High grain temperatures appeared to add to the error. Where there was a gradient of moisture through the grain, this was reflected in the probe results.

In barley the resistance probe gave results close to oven, and the depth of insertion had no effect on the results.

The 3 capacitance probes appeared to give similar results, but the numbers of tests are too few to be certain. When testing wheat, the differences between oven and probe results were small and the probes tended to over-estimate moisture content. Hot grain did not appear to have an effect on results.

In barley the limited results with two capacitance probes suggest there was a difference between them, with one under-estimating moisture and the other giving a slight over-estimate.

The depth of insertion did not appear to have a consistent effect on the difference between moisture content determined by oven and results given by the probes.

The limited assessments made with the two types of probe inserted into plastic or metal waste bins (Table 29) suggested that this increased the difference between probe and oven results with the resistance but not the capacitance probe.

Table 29. Difference between probe readings and oven moisture content when tested in bins

Probe Type	Commodity	Variety	Difference between probe readings and oven moisture content (% moisture content)		
			Plastic bin	Metal bin	Bulk
Capacitance	Wheat	Robigus	0.3	0.3	0.3
	Wheat	Zebedee	0		0.4
	Barley	Pearl	-1.6		-1.5
Resistance	Wheat	Robigus	-1.6	-1.9	-0.3
	Wheat	Zebedee	-0.4		1.5
	Barley	Pearl	-1.4		0.3

5 Farmer survey

A questionnaire was designed to pinpoint operator farmer concerns and operator error, including calibration issues and these were used to survey more than 150 farmers at the LAMA event in January 2007.

The questionnaire is attached as Appendix 1

A total of 158 farmers were surveyed. The average age of the moisture meters was 10 years and 90% still had the instructions.

Of the farmers surveyed 89% said that they had calibrations checked at least once a year and a further 9% said that they did so every other year. Table 30 shows the way in which the meter calibrations were checked.

Table 30. Methods used by farmers to check the calibration of moisture meters.

Calibration checking method	Percentage of farmers
Clinic	49
Against end user's moisture meter	27
Sent to manufacturer	17
Spot check against a calibrated meter	3
Checked against certified samples	2
Do not check calibrations	2

Although the overwhelming majority of farmers said that they had calibrations checked at least once a year, only 17% had their instruments checked/adjusted by the manufacturer. The most popular method of checking the calibration of moisture meters was to attend a clinic or to check against the meter of the customer (e.g. grain merchant). Although it was not a question included in the questionnaire, many farmers commented that it was less important that their meter gave an accurate reading than that it agreed with the customer's meter.

Most farmers used their instruments for determination of high moisture contents to assess the need for drying (91%) and storage levels (86%). The majority (58%) used their meters in the field and 87% used their meter in their store. Only 9% used their meters in an office or laboratory.

Most farmers had a realistic view of the accuracy of their meters, although 37% said that they had a need for accuracy better than ±0.5%. However, 26% expected accuracy better than ±0.5% for high moisture contents and 25% expected accuracy better than ±0.5% at storage levels.

Only 7% of farmers reported ever having had problems with their meters. Surprisingly, 65% of farmers had never had a moisture claim, but this could be explained by their adoption of a large safety margin (>0.5%) below the contractual value. Although 35% had suffered claims for high moisture content, most of these had known that they were near or above the maximum moisture level and so had been expecting a claim.

DISCUSSION

Measurement of moisture in cereals is of fundamental importance to safe storage and, ultimately, consumer safety. It also influences the value and saleability of a crop. The UK is often relatively damp at harvest time so that drying may be essential before grain can be stored, making moisture and its measurement of particular interest as compared to drier regions. Farmers rely on electrical moisture meters to make these important measurements. There are many different models and two main approaches to measurement. This project did not attempt to assess individual meters, but did use machines from the main UK manufactures/suppliers and covered both principles of measurement. The laboratory tests also included another meter that, whilst no longer in production, is still very widely used.

Moisture measurement in grain is an empirical measurement because moisture is present in several different forms and each approach to measurement may assess these to a greater or lesser extent (Wilkin & Stenning, 1989). The normal "standard" for assessment in the UK is the ISO oven method. However, even this standard is subject to variation and error. Henderson & Wilkin (1985) reported a ring test in which samples of known moisture were sent to a number of laboratories for testing using the ISO 712 method. A range of about 1% occurred across the participants although much of this was accounted for by about half the participants. If this range between laboratories is still occurring, it would account for one of the biggest area of concern expressed by farmers: differences in moisture found by different buyers when assessing the same grain. This variation may have been caused by a number of factors and this is recognised in the specification for the method. For example, there are specifications for temperature variation between shelves within the oven, time taken for the oven to recover temperature after the door is opened and the particle size of the ground sample. Henderson (1986 and 1991) showed the importance of meeting the particle size specification and the influence of different grinders with a variation of up to 1% being found. This project did not attempt to assess the ISO method, but it did show that the use of this method gave consistent and repeatable results (within ± 0.15%) so that proper comparisons could be made between oven and meters assessments of the same sample.

During the course of the project it became apparent that, at a practical level, there were several distinct concerns over the measurement of moisture. Accuracy was of interest, but this was tempered by a more important requirement that a farm meter should give a similar result to the measurement made by the buyer. A meter that was "inaccurate" compared to a definitive oven test might be considered acceptable to a farmer if it gave readings that corresponded to those obtained by his major customer. Unfortunately, this could have serious implications for quality and food safety, as speedy drying to the proper safe moisture content is the only viable approach to the prevention of ochratoxin A formation during storage. Repeatability and consistency were also considered to be of great importance to the farmer. The laboratory tests of four different meters was not intended as an assessment of the individual units but it did provide information on consistency and accuracy, and exposed some potential sources of error. Provided homogeneous samples were used the consistency of all meters was acceptable and there were no consistent differences between resistance or capacitance meters. The consistency of all meters was affected by variability within the sample of grain that was tested. The average spread of readings given from variable samples by 3 out of the 4 meters were at least 0.4 %, with the meter that used the largest sample performing no better than the others. However, the meter that used the smallest sample had the largest average spread of readings of 0.9%. There was always some degree of difference between meter readings and oven tests and there was a tendency for meters to under-read at high moisture contents. These results were largely confirmed during the various field assessments.

Another concern of farmers was that readings taken on freshly harvested and freshly dried grain were unreliable. Laboratory tests with heterogeneous samples gave up to 0.6% variation across multiple sub-samples from the same, well-mixed sample. Even greater variation was found during on-farm tests with freshly harvested grain. Clearly, farmers must allow a large safety margin, of about ± 0.5%, when making decisions about drying on storage when the results are based on meter tests of freshly harvested grain.

The initial laboratory tests on the effect of drying gave inconclusive results. Readings taken in the first few hours were variable. The difference between readings taken from samples taken of the grain as it came out of the drier and readings taken after an hour, using one of the capacitance meters, were as much as 0.7%. After the first day readings from the 4 meters became more consistent. No difference was seen between readings taken immediately after drying on farm and those taken after at least 48 hours using the resistance meter. However, when the capacitance meter was used, the readings taken after a delay were slightly higher than those taken straight away.

This effect was most evident when the delay was six or more days, when the average increase in moisture content reading was 0.4 %. It might be expected that the moisture content of a grain that has just come through a dryer will be higher in the middle than at the surface. Therefore, capacitance meters, which use whole grain samples might be more prone to giving a low reading immediately after drying than resistance meters which use ground samples.

Earlier work (Stenning & Chandra, 1987) investigated sources of error in measuring moisture and found that artificial wetting and/or drying of grain could induce errors of 1% with some moisture meters. Work by Henderson (1988) showed that artificial wetting and drying of wheat and barley samples had some effects on the calibration of two moisture meters. Abnormally high readings were obtained after wetting wheat, but this was less marked with barley. Both meters tended to underestimate moisture content of freshly dried barley, but not wheat. The variation over the majority of the 70-day observation period was not significant. Issues surrounding freshly wetted (e.g. rain just before harvest) or freshly dried grain are recognised in ISO 7700/1 that specifies approaches to the calibration of moisture meters. The Standard recommends that naturally wetted or dried samples should be used whenever possible. This would appear to be an area that justifies further research.

All moisture meters have different calibrations for different species of grain: wheat, barley and oilseeds. However, there are concerns that, in the case of wheat, endosperm characteristics can affect calibration. Indeed, one manufacturer issues different calibrations for hard and soft varieties. Tests on a range of hard and soft varieties at different moisture contents did not reveal any consistent differences between readings given by hard and soft varieties using any of the meters assessed in this project. Therefore, it can be assumed that differences between current varieties of wheat are not likely to cause significant errors in moisture measurement. No consistent differences could be detected between different varieties of barley.

Moisture probes are tools that were designed to support the management of bulk drying systems. They work on the same principles as conventional moisture meters and probably share the same software calibrations. A number of farmers interviewed for the survey commented that they used moisture probes in preference to other meters. However, they are considered to be inferior to conventional meters in respect of accuracy and consistency. Readings taken using probes varied from oven test results by as much as 1.8% moisture content.

The operation of meters is widely considered to have a large potential influence on the results obtained from moisture meters. This was confirmed with both laboratory and farms tests. Temperature differences between meters and grain samples could induce errors although allowing a short time for equilibration reduced this. Other aspects of improper use would also induce errors. However, the majority of farmers questioned in the survey still had the instructions with their meters and on-farm assessments and this suggested that they were generally aware of the methods of use and limitations of meters. Inadequate maintenance and calibration checking issues also resulted in errors. Meter manufacturers recommend that meters be returned to them for regular maintenance. However, the survey showed that most farmers rely of moisture clinics to assess the performance of their meters. At these clinics, meters are tested against samples of known moisture and the farmer is made aware of any errors in measurement. In some cases, when the facility is available, a correction factor is introduced into the meter calibration to reduce errors detected during tests at the clinic. It is interesting to note that some meters examined during farmer assessment had altered calibrations. However, without exception these meant that the meter was less accurate in relation to the samples of known moisture. Undoubtedly some of these calibrations had been altered in response to results from commercial testing of the farmer's grain and it calls into question the accuracy of some commercial tests.

Unfortunately, there are no protocols to cover moisture clinics or other similar assessments.

CONCLUSIONS

Moisture meters are calibrated against samples that have been analysed for moisture content using the ISO oven-based method. Therefore, the consistency and accuracy of this method sets the absolute limit of accuracy that can be given by a moisture meter. In the oven test, using 25 test portions taken from a single well-mixed sample of cereal, the maximum and minimum moisture content given were 15.80 and 15.52%. This indicates that the best calibration of a meter will have a core error of around ±0.15%.

No differences in accuracy or repeatability between capacitance and resistance meters were identified in laboratory testing during this project and no differences were identified in accuracy for hard and soft varieties of wheat. Readings from all makes of meter were repeatable as long as the samples were homogeneous. Variable samples gave variable readings for all four makes of meter, with the resistance meter that took the smallest sample size faring worst. Some field results suggested that there was a tendency by all meters to underestimate moisture at high moisture levels (≥17%) and this has implications for the prevention of mould growth.

Checks at several farms, found a ±0.5% variation in moisture content within a 1kg, well mixed sample of un-dried, freshly harvested wheat or barley. Passage through a high-temperature drier appeared to reduce or eliminate this variability and the variability reduced in un-dried grain 2+ weeks after harvest. This variability with freshly harvested grain is of importance to farmers when assessing need for drying or safe storage life.

Readings taken on freshly dried grain using a resistance meter were no different than those taken after at least 48 hours using the resistance meter. However, when the capacitance meter was used, the readings taken after a delay were slightly higher than those taken straight away. This effect was most evident when the delay was six or more days, when the average increase in moisture content reading was 0.4 %.

Temperature differences between meter and sample introduced an error in readings given by all but one of the meters. The exception was the meter that used the smallest sample size, where the sample could reach the temperature of the meter most quickly.

Compression did impact on the readings given by the resistance type meters. This highlighted the need for regular servicing of the grinder where supplied and the need to avoid under-compression where a clamp type compressor is used.

Capacitance meters that have in-built balances must be used on a level surface.

Results obtained using probes varied from results obtained using the ISO method by as much as 1.8 % moisture content. However, this does not detract from the value of probes as a means of obtaining rapid, *in situ* estimates of grain moisture, particularly during on-floor drying. Many farmers commented that they used probes in preference to meters for moisture content determinations.

A key concern for farmers is that their meter should give a reading that is comparable to the measurement made by the buyer of the grain. Several meters had modified calibrations in order to improve agreement with buyer’s measurements. However, these did not improve results against the test samples. Even meters that appeared to have significant error of measurement when compared with samples of known moisture content were considered by the farmer to be “accurate” in comparison with the measurements made on the grain by the buyer. This poses questions about the validity of some measurements made within the commercial chain.

Key points:

- Moisture meters will give repeatable estimates of grain moisture and this is not greatly influenced by meter type or sample size.
- Oven testing with the ISO method under controlled conditions is highly repeatable and offers an acceptable standard approach to moisture testing.
- Concerns over differences in calibration caused by hard or soft wheat varieties appear to be unfounded.
- Freshly harvested grain is variable and estimates of its moisture are likely to vary by ± 0.5%.
- Readings taken on grain recently dried using a hot air using capacitance meters may underestimate the moisture content by 0.4%.
- Poor maintenance or misuse of meters can lead to significant errors.
- Moisture probes appear to compare well with conventional meters but should be used with caution in relation to commercial decisions.
- Farmers consider that repeatability and correlation with the buyer’s assessment are the most important features of moisture meter performance. However, this may impact on the drying requirements and subsequent safe storage of grain.
- In general, farmers are aware of both the value and limitations of moisture meters and use them accordingly.
- Changes to grain shortly after drying seems to lead to a slight increase in the response of capacitance meters but not resistance meters.

RECOMMENDATIONS

- A better understanding of the apparent discrepancies between the moisture determinations of different commercial organisations is needed. This could be achieved with ring testing of samples.

- Protocols should be drawn up for the operation of moisture meter clinics.
- An HGCA leaflet giving practical guidance to farmers on the use of moisture meters would be of benefit.

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Appendix 1. Moisture meter questionnaire

Contact name:

Addresss:

nb name and address will not be published

1. Meter model ………………………………………………………………

2. Age……………………………………..

3. Do you still have instructions? *Yes / No*

4. Do you:

   Send to manufacturer for calibration/
   attend a mc clinic
   spot test vs end-user meter/
   other (specify)

5. How often? eg annual / bi-annual

6. T compensation on (Protimeter)?

7. Cell loader used ? (Sinar)

8. What is it used for? –

   high mc end for drying/
   low mc end for storage

9. Where is it used? - e.g. in the field / in grain store / inlab or office

10. How accurate do you expect it to be (+/- 0.1, 0.5, 1.0)

    a. High end
    b. Low end

11. How accurate do you NEED it to be ? (*+/- 0.1, 0.5, 1.0)*

12 Have you had storage problems attributed to your meter?

   Y/N If so enter details below:-

13. Have you had claims because of high moisture?

   Y/N If so enter details below:-