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Publication date:
1997

Document version
Early version, also known as pre-print

Citation for published version (APA):
Stubsgaard, F. (1997). *Calibration of Seed Moisture Meters*. Danida Forest Seed Centre. Technical Note no. 47

TECHNICAL NOTE NO. 47 -

NOVEMBER 1997

CALIBRATION OF SEED MOISTURE METERS

by

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DANIDA FOREST SEED CENTRE

Titel
Calibration of Seed Moisture Meters

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Publisher
Danida Forest Seed Centre

Series - title and no.
Technical Note no. 47

ISSN:
0902-3224

DTP
Melita Jørgensen

Citation
Stubsgaard, F. Calibration of Seed Moisture Meters, 1997. Technical Note nr. 47. Danida Forest Seed Centre, Humlebæk, Denmark

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Electronic Version
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Danida Forest Seed Centre (DFSC) is a Danish non-profit institute which has been working with development and transfer of know-how in management of tree genetic resources since 1969. The development objective of DFSC is to contribute to improve the benefits ofgrowing treesfor the well-being ofpeople in developing countries. DFSC's programme isfinanced by Danish International Development Assistance (Danida).

CONTENTS

1. INTRODUCTION

Seed centres and seed producing units must be able to determine seed moisture content:

1. Immediately upon collection to determine the best temporary storage conditions before processing, and
2. During drying to determine when the wanted storage moisture content has been reached.

Very often there will be no access to an analytical balance and an oven for moisture determination in the field where collection and perhaps drying takes place. Consequently there is a need for a portable moisture meter.

Even though an oven for determination of moisture content is available at the seed production unit, a moisture meter will also be valuable as a quick alternative and supplement to the oven method.

Moisture meters measure the electrical properties of the seed sample (conductivity or capacitance). According to ISTA's rules moisture content is defined as the amount of water that evaporates from the seed when it is dried in an oven at a defined temperature over a defined period of hours. Therefore, conversion tables or charts are needed showing the correlation between the electrical properties of the seed measured by the moisture meter and actual moisture content. The conversion will depend both on the design of the instrument and the physiological properties of the type of seed. Therefore individual tables or charts are needed for each type of instrument and each species.

Moisture meters are designed for agricultural crops and are therefore only delivered with conversion tables for agricultural crops. Your tree seed laboratory will therefore have to make conversion tables for each type of instrument and for each tree species within the moisture range you are interested in.

This Technical Note replaces earlier Technical Notes no. 37 and 38. They described the procedures for making conversion tables and gave calibration tables for a number of tropical and temperate species for two moisture meters (Super-Matic 1 and Mettler PE 360ILP15).

These moisture meters are not portable and the Super-Matic 1 is not produced any more.

2. CHOICE OF INSTRUMENT

2.1 Basic parts of moisture meters

The following parts of a moisture meter are accessible for the user:

1. a chamber where the seed sample is placed. The electrical properties of the sample are measured between two metal surfaces of the chamber. Very often the chamber is circular like a can with a circular column inside.
2. a display either as an indicator on a scale, or as a digital display,
3. a power supply, either as a transformer, or as batteries,
4. and a way of setting grain type when the instrument has built-in calibrations,
5. on some instruments it is also possible to adjust readings to fit other instruments.

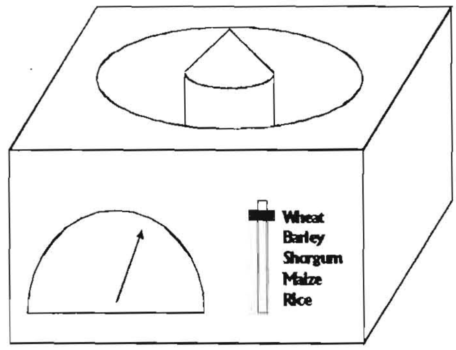


Figure 1: Basic parts of a moisture meter.

Some points one should consider before choosing a moisture meter are discussed m the following.

2.2 Portability and sturdiness

It will in many situations be an advantage if the moisture meter is portable; especially if you also work with seeds of recalcitrant species where an indication of moisture content in the field is valuable during collections. A truly portable moisture meter is lightweight, runs on battery power, and is sufficiently sturdy to withstand transport and use in the field.

2.3 Measurement principle and sample treatment (whole seed or ground seed)

During a fairly fast drying process the surface of the seed may be drier than the inside of the seed. So, if the seed is taken out for measurement directly from the drying process, this may affect the result of the measurement depending on measurement principle and whether whole seed or ground seed is measured.

There are generally two principles of measurement: conductivity and capacitance. Conductivity measures the electrical resistance of the seed material between two metal surfaces in the measuring chamber. Capacitance is the ability of the seed material between the two surfaces to act as a condensator, i.e. store electrical charge. Both conductivity and capacitance increase with increased moisture content. Instruments may be based on measurement of either conductivity or capacitance, or a combination of both. If the seed is not ground to a homogeneous material, measurement of conductivity tends to be more affected by differences in moisture content between the surface and the inside of the seed than measurement of capacitance.

Moisture meters are either designed for measurement of whole seed or homogeneous ground material. The advantages of grinding the material are an increased accuracy that is used to reduce the chamber size, and thereby the necessary sample size, and a security that differences between moisture content on the surface and inside the seed do not affect the measurement. The disadvantages of grinding are that the test is destructive to the seed, that very accurate sampling is necessary because of the small sample, that precautions have to be taken so that the material does not lose water during the grinding process, and that cleaning of the instrument and grinding mill after each measurement generally is more difficult.

The advantages of measuring whole seed are that the process is usually quick and that it does not affect the seed so that they can be poured back into the seedlot afterwards.

2.4 Size of measuring chamber and seeds

A fixed amount of seed or material is poured into the measuring chamber. The amount is fixed either by volume (filling the chamber or a measuring cup to the rim) or by weight (separately weighing a fixed amount to be poured into the chamber, or by a weight built into the instrument that weighs the chamber including its contents).

The way the seed settles in the chamber generally affects the result of the measurement, especially if the fixed amount of material is measured by volume. It is therefore an advantage if the moisture meter is designed so that the material can be poured into the chamber in exactly the same way each time; either by a measuring cup or, when a fixed weight is not used, preferably by leaf valves in the bottom of a funnel mounted on top of the measuring chamber.

Moisture meters designed for measurement of whole seed are manufactured for agricultural crops of which the seeds are generally smaller than tree seeds. The chamber of many moisture meters is therefore too small for testing larger tree seeds accurately without grinding or cutting up the seeds. The chamber should be large enough to hold a reasonable number of seeds (so that a representative sample can be drawn without complicated procedures) and so that the seeds settle in the chamber in the same way each time.

2.5 Temperature correction

For most species the temperature of the sample affects the electrical properties. The result of the measurement will therefore have to be corrected before conversion to moisture content unless the temperature of the seed measured is always nearly the same. Some moisture meters have automatic temperature correction included in the conversion for grain types programmed into the instrument. In these instruments there is an electric thermometer inside the measuring chamber.

As tree species are never programmed into the instruments, temperature correction should be taken into account in one of the following ways depending on the capabilities of the instrument:

1. Temperature correction is not relevant if all measurements are made on seed that has been allowed to reach a fixed temperature, e.g. room temperature of a labo-

ratory with air conditioning. This includes measurements carried out for making calibration tables for the instrument.

2 Temperature correction may be unnecessary when one of the conversions for agricultural grain types programmed into the instrument with automatic temperature correction is used for making further conversion tables for a species of tree seed. This may be possible when the seed of the agricultural species and the tree species are similar in composition, physiology, size, etc.

3. Some instruments have a calibration scale or setting besides the scales for programmed grain types; i.e. a direct reading of the electrical properties of the sample used for calibration for other species than the ones programmed. If the instrument has automatic temperature correction for the programmed grain types, it will often show the temperature of the material in the chamber at the same time or alternating with the figures of the calibration setting. If the instrument does not have any built-in thermometer, the temperature of the seed sample will have to be measured manually with a thermometer. In these cases a temperature correction scale or table can be made in the same way as the conversion tables for each species (see also section 3.6 and Appendix 1).

2.6 Future availability of the instruments

Electronic components have been greatly developed during the last decades. Consequently, within a couple of years it will be possible to make electronic instruments, such as moisture meters, far more accurate, smaller, lighter, less power consuming and cheaper than they are today. Because of this there has been a tendency to replace the various moisture meter models every couple of years.

As calibration tables are specific to moisture meter model and tree species, the laboratory will have to develop new tables for all species every time a new model is bought. This is a rather laborious task. Therefore try to assess future availability of the model which is considered for purchasing; contact the producer if possible, assess the share of the market for this make and model: which models are used in the agricultural sector; which model does the national seed testing institute for agricultural seed recommend; does the distributor offer service for the model, etc.

At the same time investigate whether other tree seed producers in the country or region use a moisture meter that is still on the market, and whether they already have conversion tables for this model for some of the relevant species.

As development of conversion tables is expensive in terms of man hours in the laboratory, one could also consider co-operating with other seed producers in the region on the development of conversion tables for the one model of moisture meter which is agreed on.

It is the general impression that the models made by large international companies remain on the market longer than models made by small local companies. Though, this may not always be the case.

When a decision has been made on which model to buy, it may be considered buying a spare moisture meter to take over when one instrument may be out of order, or if availability in the future is not assured. This will be cheaper than developing new tables.

2.7 Built-in calibrations of grain type

Calibrations for agricultural grain types programmed into the instrument (or delivered with the instrument as tables) reflect the agricultural crops on the market for which the instrument was developed. Some producers offer to programme the instrument for your tree species. Depending on model, the number of species charts that are memorized by the instrument is usually around 8-10, which in many cases is too few for a seed centre. The price of making the producer develop the conversions and programme the instrument often greatly exceeds the cost of having the laboratory develop conversion charts or tables.

If the instrument does not have a calibration setting with temperature reading, conversion charts or tables should be developed for a grain species that resembles the tree species in question. It is therefore an advantage if, within the range of agricultural grain types the instrument is calibrated for, there are grain types that resemble the tree species to be worked with.

2.8 Summary of recoinmendations

Look for a moisture meter that:

- is robust with as few small accessories and movable parts as possible,
- is constructed for portability,
- measures the capacitance (dielectric constant) of the seed material,
- is designed for measuring whole seed,
- has a reasonable size of measuring chamber, not too long and narrow; usually 0.4 litre volume (or 200g weight of sample) is sufficient for many tree species,
- has automatic temperature correction and a chart mode or setting; i.e. a setting where temperature and a number reflecting capacitance are displayed,
- is widely used and recommended, also by other tree seed producers in the region,
- can be bought and serviced locally,
- the producer has no plans for changing the model.

3. CALIBRATION OF AN INSTRUMENT

3.1 What is moisture content

The International Seed Testing Organisation (1STA) defines moisture content of tree seed as the loss of weight as recorded after 17 hours at 103°C.

Moisture content on fresh weight basis is calculated as:

formula 1:

$$\text{moisture content} = \frac{\text{Initial weight - Dry weight}}{\text{Initial weight}} * 100$$

i.e. moisture content is the weight that evaporates from the seed during 17 hours in an oven at 103°C as a percentage of the weight of the seed before it was placed in the oven (percent fresh weight). This is not the exact percentage of water present in the seed (some water does not evaporate and some volatile oils also evaporate); but it has been generally accepted as a point of reference that is replicable with commonly available instruments (analytical balance, grinding mill, sieves and oven).

The ISTA rules also prescribe the procedures for preparing a moisture test (see Seed Science & Technology 1996).

As for example, recommendations concerning safe moisture content for storage and safe moisture content for transport of recalcitrant species are given for moisture contents measured according to ISTA's rules, it is important that these rules and procedures are followed accurately when establishing conversion charts and tables for moisture meters. If your laboratory cannot measure moisture content according to ISTA' s rules, it may be possible to send replicates of the samples to an authorised seed testing station.

3.2 Range and points of conversion charts and tables

A conversion chart consists of a number of points forming a graph as in figure 2. Each point is found by measuring the moisture content of a sample, as defined by ISTA, and plotting it against the corresponding reading on the moisture meter. To obtain enough points to form a graph you will have to measure samples with moisture contents evenly distributed within the range of the moisture contents you are interested in.

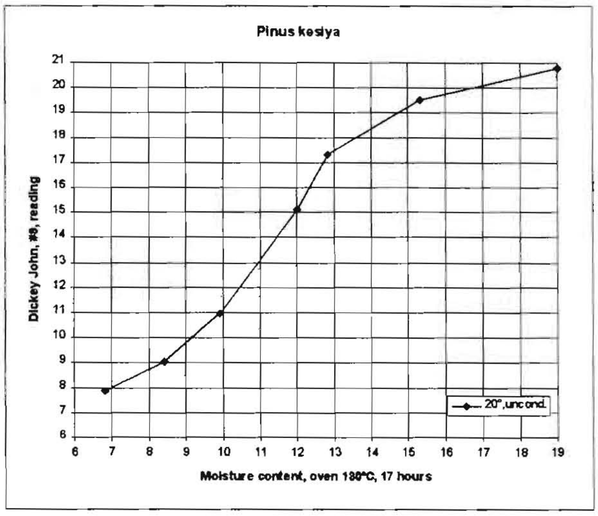


Figure 2: Example of conversion chart

For many, a conversion table may be easier to work with. The entrances to the table in readings of the moisture meter should be easy to work with (e.g. every half percent) as illustrated in figure 3. When samples are tested for the conversions, it is impossible to hit these exact numbers. Therefore a conversion table containing these numbers will have to be constructed based on an already established conversion graph.

Before making the calibrations it is necessary to establish the range of moisture levels which are of interest for the species in question. The lowest moisture content should be below the moisture content needed for long-term storage. The highest moisture content could be fixed as the maximum moisture content tolerated for short transport or short-term storage.

Dickey John multi-grain	
Species: *Pinus kesiya*	
20DC, unconditioned	
Setting: #9, Corn	
Reading	MC%
8.00	7.00
8.50	7.70
9.00	8.40
9.50	8.80
...	...
...	...
20.00	16.80
20.50	18.00

Figure 3: Example of conversion table

6-20 % moisture content would be of interest for orthodox species, such as *Pinus* and *Acacia* species.
8-30 % moisture content would be of interest for more or less recalcitrant species like *Azadirachda indica*.
35-50 % moisture content would be of interest for very recalcitrant species like *Syzygium cuminii*.

The number of points needed in terms of samples at different moisture contents depends on the span of moisture contents to be covered, on the general accuracy needed at different points on the graph, and on the slope of the graph.

Generally, sufficient accuracy for establishing a graph is obtained if a point is selected for every 2-3 % moisture content when the moisture meter is to be used in general seed production as a supplement to testing moisture content by the oven method, i.e. if an oven test verifying the result from the moisture meter is made before the seed is placed in store.

The accuracy needed varies within the range. The exact moisture content of e.g. orthodox species is normally not very important at moisture contents above 15%. The exact moisture content of a recalcitrant species is on the other hand very important near the lower limit of the species toleration.

The graphs one finds are very seldom linear; the slope (or inclination) of the graph generally varies over the range. The slope of the graph determines how accurately one can measure the moisture content. If the inclination in one area of the range is 45°, then the relationship between moisture content readings of the instrument (y-axis) and 'true moisture content' according to ISTA's oven method (x-axis) is L 1. If the inclination in another area is 26° then the same relationship is 1:2 and the accuracy of true moisture content readings is half of what it was before. This can be compensated for by measuring more samples in this area in order to be able to draw the graph more accurately.

3.3 Choice of grain type setting to be used

As discussed before there are two options when choosing between the grain settings on the instrument. Calibration can be carried out 1) on the basis of a grain-type setting programmed into the instrument, or 2) on the basis of a 'chart mode' if available on the instrument.

1. The advantages of using a grain type resembling the seed of the species in question are:

- temperature correction for the grain type is included in the conversion and will in many cases be sufficient over a large part of the range,

- one may also be lucky that the graphs do not change when the producer changes his model.

The disadvantages are:

- if the temperature corrections for the grain type are inadequate for the tree species, one will be limited to measurement at the temperature for which the conversion chart is made,

- in many instruments the producer has only programmed the range of interest for the agricultural species. This is often a range of moisture content higher than we are interested in. Therefore, in some cases it will not be possible to make measurements of low moisture contents. This should be checked with a dry sample before a grain setting is chosen.

2. The advantages of choosing a 'chart mode' are:

- the chart will be more accurate (the figures of the chart mode generally cover a larger range on the Y-axis, consequently the slope of the graph will be steeper),

- a wider range of moisture contents can be measured,

- some producers offer programming of results into the instrument, especially if they can sell more instruments - perhaps other seed producers in the region would be interested? (some producers also offer to make the calibration charts on the supplied seed material and programme the results of the calibration into the instrument, but this is generally a very expensive solution).

The disadvantages are:

- a temperature-correction chart will have to be made if the seed to be measured is not always of approximately the same temperature.

3.4 Preparation of samples with moisture contents corresponding to the calibration points chosen

In order to make a conversion table a 'working sample' is drawn from a seed lot of each of the species required. The size of the working sample depends on: the number of points to test, how much seed is needed for the oven test (2 times 5g or 10 g depending on container diameter + some extra if you are grinding the seed), how much the moisture meter needs for a test, and on whether the seed for the moisture meter is ground or the same seed is used through the whole process.

A fair amount of extra seed should always be added to the working sample as some seed might be lost during the process, and the weight of the seed falls as it dries and therefore more seed is needed for each sample when the seed is dry. It is an advantage to put a separate amount of seed in a thin net bag (made of e.g. mosquito netting) to be able to monitor the weight during drying (see later).

Either simultaneously prepare a number of lots, each with the moisture content specified for each measuring point, or measure one lot at different points while drying down. When a number of lots are prepared, the work is concentrated to one period, which is an advantage if e.g. the samples are sent for moisture testing to another laboratory. The process is simpler and easier to control when measurements are taken on samples of one lot while drying down and less seed is needed, especially if the seed is not ground for the moisture meter.

How the samples are actually prepared with the chosen moisture contents depends on the initial moisture content of the working sample and type of seed:

1. The simplest way that probably gives the most accurate results is to choose a reasonably moist seed lot immediately upon seed collection and measure it at regular intervals while drying down.
2. If the calibrations are made outside the collection season, choose a dry working sample and remoisten it. If the seed is hard-coated, the working sample will have to be scarified and fully imbibed; immediately dry it slightly to avoid germination, and remove all seeds that have not imbibed before drying the working sample.
3. If using the method of simultaneously preparing a sample for each measuring point on a species that is not hard-coated (i. e. readily absorbs moisture), and the initial moisture content of the working sample lies somewhere in the range of interest, the following procedure can be used: divide the working sample into the number of measuring points wanted. Mark and weigh each sample according to required target moisture contents.

   For samples with moisture content above target moisture contents, calculate the weight of the sample at desired moisture content as explained below; cf. formula 2.

   For samples with moisture content below the target moisture content, calculate the amount of water that needs to be added, as explained below, put the sample and the required amount of water in a plastic bag, seal and place the bag at below 15° to avoid germination for about 4 days, while the seed in the bag is mixed and turned regularly, cf formula 3.

For drying a sample from initial moisture content ime to target moisture content tme, use the following formula for weight of the sample at target moisture content:

formula 2:

$$\textbf{Weight of sample at tmc} = \textbf{Weight of sample at imc} * \left[\frac{100\% - imc}{100\% - tmc} \right]$$

Example:

1500 g of seed at **imc** of 50%. What is the weight when the seed is dried to a **tmc** of 30% ?

$$1500\ g * \frac{100\%-50\%}{100\%-30\%} = 1071\ G$$

For moistening a sample from initial moisture content imc to target moisture content tmc, use the following formula to calculate the amount of water that should be added (it may also be used for calculating the amount of water that should be removed during drying):

formula 3:

g (ml) water to add = Weight of sample at tmc minus weight of sample at imc

Example:

1500g of seed at **imc** of 11%. How much water should be added to obtain a **tmc** of 30% ?

$$\text{g (ml) water to add -} \left[1500g * \frac{(100\% - 11\%))}{(100\% - 30\%)} - 1500g \right]$$

$$= 1907.14\ g - 1500\ g = 407.14\ g = \mathbf{407.14\ ml}$$

3.5 Suggested procedure

The following procedure is based on option 1. above (see 3.4) where one working sample is regularly measured while dried through the whole range of moisture contents. Each step of the procedure is explained in detail below.

1. Determine exact initial moisture content of working sample by the ISTA oven method and read the corresponding measurement of the moisture meter.
2. Put a sample in a net bag and calculate weight of bag and sample (in the following called 'bag sample') at the target moisture contents.
3. Dry the working sample and bag sample together until weight of bag sample reaches first target weight.
4. Determine new moisture content of working sample by the oven method and corresponding reading of moisture meter.

5. Repeat step 3 and 4 down through the whole range of target moisture contents
6. Make a conversion chart based on the results.
7. Make a conversion table based on the chart.

Step 1:
Mix the working sample. Draw minimum two representative samples for testing by ISTA oven method. Draw three representative samples for testing in the moisture meter. If the moisture meter test is non-destructive to the seed, repeat testing of each representative sample e.g. four times and return samples to working lot. Be careful when drawing samples to ensure that they are truly representative of the lot (cf. Lecture Note C-8 on seed sampling).

Prepare a table as the one illustrated with columns for target moisture contents, measured moisture contents, and corresponding readings on the moisture meter at a specified setting.

Target	ISTA oven MC%			Meter reading at setting #			
MC%	A	B	Average	A	B	C	Average
20	19,81	19,65	19,73	17,6	17,5	17,6	17,57
17							
15							
13							
11.							
9							
8							
7							
6							

Step 2:
To be able to monitor the moisture content easily during drying put e.g. 500g of seed drawn from the working sample in a thin net bag. The bag can be made of e.g. mosquito netting tightly closed with a string so that no seed can fall out. Accuratel y weigh the bag and the seed separately. Calculate the weight of the bag with the seed using formula 2 adding the weight of the bag as illustrated.

Initial:	MC%	sample g	bag g
	19,73	**500,000**	**5,258**
Target:	**MC%**	**sample g**	**sample + bag g**
	20	501,688	506,946
	17	483,554	488,812
	15	472,176	477,434
	13	461,322	466, 580
	11	450,955	456,21 3
	9	441,044	446,302
	8	436,250	44 1,508
	7	431,559	436,817
	6	426,968	432,226

The bag sample should be dried at the same speed as the rest of the working sample. Place the bag sample in the working sample so that the part of the bag that is exposed to the surface equals the exposed part of the working sample.

The drying speed of the bag sample and the working sample must be the same. So, if moisture percentages measured by the oven method begin to deviate from the moisture percentages calculated based on the weight of the sample bag during drying, a new sample bag must be prepared and new calculations made.

Step 3:
It is important that all seeds in the working sample and the bag sample dry evenly. This can e.g. be done by drying in thin layers in trays with net bottoms and regularly mixing the seed in the layers. Take care not to dry the samples faster than one would normally dry seed. Monitor when the seed reaches the next target moisture content by regularly weighing the bag sample.

Step 4:
Draw samples and make the tests as described in step one.

Step 5:
Step 3 and 4 are repeated the required number of times.

Step 6:
Draw the chart on millimetre paper, or as in figure 2 and below, using a spreadsheet in a computer. The charts in this note have been made entering the results into Excel version 5.0. The graphs are very seldom linear, usually they are more or less S-shaped.

Step 7:
Some people find conversion easier when using a table (figure 3) rather than a chart (figure 2). The entries to the table are readings of the moisture meter. They should be easy to work with. For example, if a setting for a grain type that gives figures close to actual moisture content is used, then they should state actual moisture content for every half percent moisture content reading: 20, 19.5, 19, 18.5, etc.

3.6 Temperature correction scale

As discussed in section 2.5, it may be necessary to make a temperature correction scale or make several charts for each species if the moisture meter is to be used at different temperatures; e.g. during drying in the sun, at 15°C and at 4°C in the cold store.

The producer of the instrument might be able to provide a general temperature correction chart or table for groups of species if temperature correction for the instrument is reasonably unaffected by type of species. E.g. for some agricultural species in some instruments the temperature correction is made by subtracting 0.1% moisture content from the result for every °C the temperature is above 20°, and adding 0.1% for every °C below 20°C in the range 10-30°C; for other agricultural species the temperature does not affect the readings on the same instruments. If this is not the case, the only option is to repeat the procedures above for each species at the relevant temperatures.

4. RESULTS FROM CALIBRATION OF TWO INSTRUMENTS

In order to select the best field moisture meters for testing, information on available meters was collected and additional enquiries sent to four companies.

Three moisture meters and five species were selected for the test. After the tests were finalised, one of the meters was unfortunately out of production.

4.1 Material

4.1.1 Moisture meters

The following measurement methods were used:

1. Dickey-John Multi-Grain field moisture meter. This meter is already in use at several seed banks, therefore it was relevant to test it. 1997 prices range from 270-680 US$. The working principle is capacitance-measurement, with automatic temperature correction for programmed grain types.

2. A SAMAP field moisture meter from Foss-Electric with manual temperature correction, the same working principle as Dickey-John and very similar to this but having a simpler calibration routine. The meter was included for comparison with the Dickey-John. The instrument may not be robust enough, because some parts are of hard plastic material. The moisture meter is not manufactured any more.

3. HE-50 Pfeuffer field moisture meter. The price (1997) lies about 1000 US$ including carrying case and battery charger. The seed has to be ground (the equipment includes a grinder); the conductivity of the ground seed is measured, with automatic temperature correction for programmed grain types.

4. The reference-standard is the oven method at 103°C for 17h, and grinding/predrying according to ISTA prescriptions.

Specifications and addresses of suppliers of the two moisture meters still available are given in appendix 4.

4.1.2 Seed

The following species were selected as representatives of many of the species encountered at the various DFSC-serviced projects.

1. *Pinus kesiya* from Thailand, an example of a conifer (15-20 g/ 1000 seed).
2. *Gmelina arborea* from Thailand, an example of a bulky seed without hard seed coat (600 g /1000 seed).
3. *Acacia nilotica* from Tanzania, an example of a hard-coated species having relatively large and thick-coated seeds (100-160 gl1000seed).
4. *Acacia tortilis* from Tanzania, an example of a hard-coated broad-leaved species having relatively small and thick-coated seeds (20-55 g/1000seed).

5. *Prosopis tamarugo* from Chile, a hard-coated broad-leaved species having small and thincoated seeds (12-14 g/1000 seed).

4.2 Methods

As all the seed was received dry, the following procedure was followed :

Samples of the five species were drawn. The hard-coated seeds were scarified using hot wire burner, all seeds were fully imbibed by soaking at ambient temperature. The seeds were then slightly dried (to avoid germination) and the initial moisture content determined. Upon this the seed was dried stepwise at 15% relative humidity and 15°C while the target moisture contents were calculated based on the loss of weight. 8-10 points were determined for the calibration graphs in the range 5-30% moisture content.

Grain type settings programmed into the meters were chosen as basis for the conversion to the chosen tree species.

At each drying step three individual samples were drawn for measurement methods 1, 2, and 3, and two individual samples were drawn for method 4 (cf. 4.1.1.). Four consecutive measurements were made on each of the three samples for measurement methods 1 and 2. Afterwards the samples were returned to the working sample for further drying. Measurement methods 3 and 4 are destructive methods, consequently these samples were only measured once and then discarded.

At each drying step the seed was measured twice, i.e. immediately upon drying and after equilibration for 2 days in a thin PE-bag before measurements. This two-step procedure was included to determine possible effects of uneven moisture distribution within the seed.

For measurement methods 1, 2 and 3, the moisture content was also measured on the equilibrated seed at 4°C, i.e. in the cold store at DFSC. This was to test if the automatic temperature correction in the chosen grain type settings in the meters is reliable for the tree species.

Study plan and data form for the laboratory are presented in appendix 4.

The data was entered into the spreadsheet Excel version 5.0 and graphs generated. For the four consecutive measurements on each of the three samples for non-destructive measurement methods 1 and 2, a standard deviation was calculated reflecting effect of how the seeds settle in the measuring chamber. The high low bars in the graphs indicate the average of the three standard deviations. Appendix 1 presents examples of the effects of equilibration and temperature on the charts. Appendix 2 presents the charts at 20°C, unequilibrated for the five species and the two instruments still available.

4.3 Results

4.3.1 Dickey John

The Dickey-John moisture meter gives a sufficiently precise determination of seed moisture for field use. Seed moisture levels up to 45% can be determined when the meter is set on grain type_ corn. The meter is easy to use and the measurement is very quick, without destruction of seed. The meter appears to be robust. Apparently the meter does not have a 'battery low' indication.

The graphs are generally Sshaped especially when unconditioned seed is measured at 20°C.

The repeatability of measurement of the same sample (i.e. variations in how the seed settles in the chamber without the variations deriving from sampling) depends on moisture content. Below 15 % moisture content the general standard deviation is below 0.4% moisture content. Below 8 % moisture content iti is below 0.2 % moisture content.

Effect of equilibration:
The effect of equilibration depends on measurement principle of the moisture meter, drying speed and seed physiology. At the tested drying speed the effect of equilibration can, for the Dickey John, be seen above 10-20 % moisture content depending on species: above 10 % there was a significant effect for *Pinus kesiya*, but the effect was not really significant for *Prosopis tamarugo*.

Effect of temperature:
The effect of temperature depends on the moisture meter and seed physiology.

As for equilibration some effects of temperature can be seen above 10-20 % although not so marked: for *Acacia tortilis* and *Prosopis tamarugo* the effects were really not significant, and the variations for *Gmelina* may derive from inaccuracies in the test (see 4.4.1 below).

4.3.2 HE-50

The HE-50 moisture meter gives a sufficiently precise determination of seed moisture for field use. The meter is easy to use but preparation of samples and especially cleaning of instrument after measurement are time consuming. Grinding is destructive to the seed but sample size is small (9 ml ground material). The HE-50 meter gives very consistent results and the moisture determination is very precise. Seed moisture levels up to 20-25 % can be determined, which is 5-10 % less than for the other meter. Measurement above 25 % is in most cases not relevant. The relationship between seed moisture and meter reading is almost linnear.

Effect of equilibration:
For *Acacia nilotica, A. tortilis* and *Prosopis tamarugo* minor effects of equilibration were found even though the seed was ground.

Effect of temperature:
Minor effects of temperature was found above 15 % moisture content.

4.4 Conclusions

In conclusion it can be stated that both meters can fulfil field needs of moisture testing. The need for cleaning makes the HE-50 less handy. It also costs at least 300 US$ more than the other meter. Based on this the Dickey-John meter seems to be most recommendable.

4.4.1 ISTA oven method

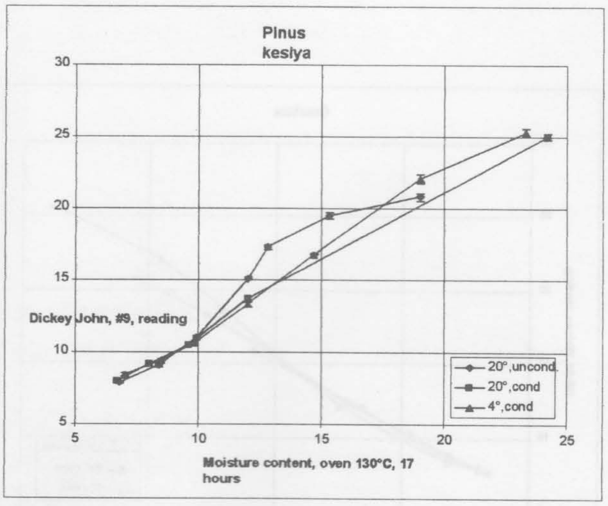
ISTA prescribes sampling procedures and maximum tolerance levels between measurements.

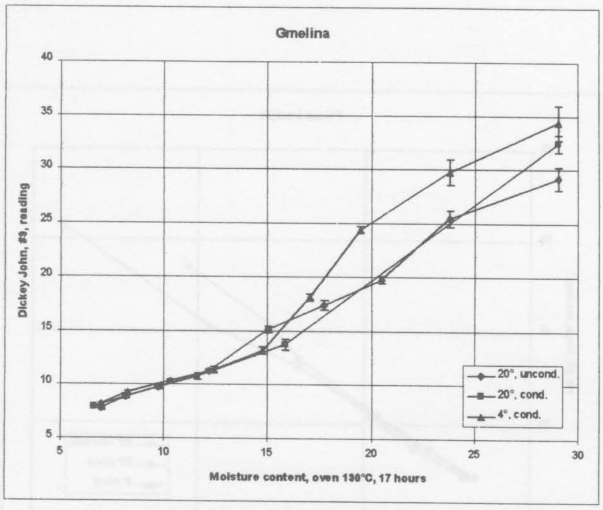
Some of the inexplicable variations in the results of the test may derive from inaccuracies in measuring moisture content by the oven method. As many of the future moisture measurements will be based on the measurements made with a moisture meter, it is recommended that uttermost care is taken when drawing and preparing samples for the oven method during calibration of a moisture meter. Consider also increasing the number of samples to 3 or 4, or reducing the accepted deviations between the samples.

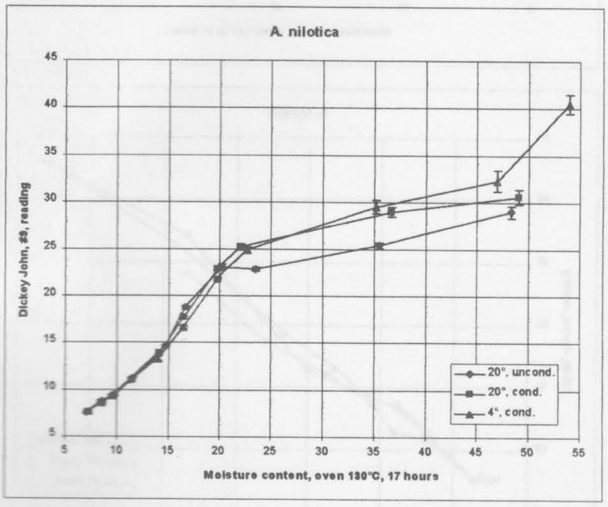
For clearly curved graphs, it should be considered placing more points of measurement within the range to be calibrated in order to get a more accurate graph.

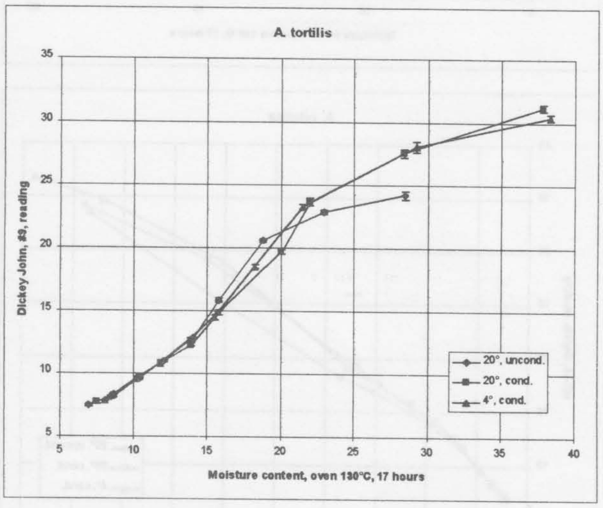
APPENDIX 1:

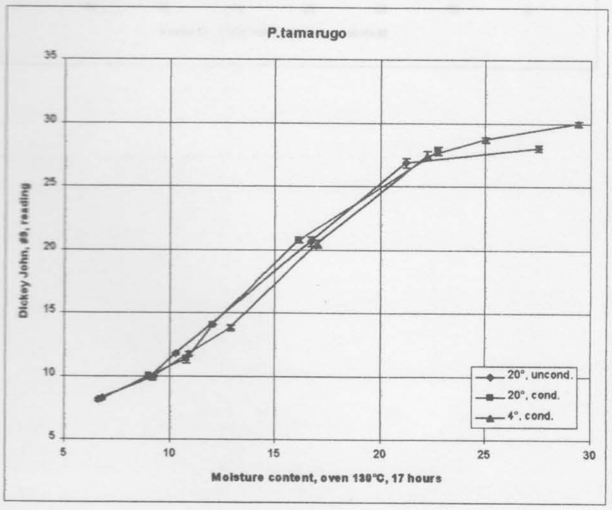
The effects of equilibration and temperature on the charts:
Dickey John Multi Grain Moisture Meter





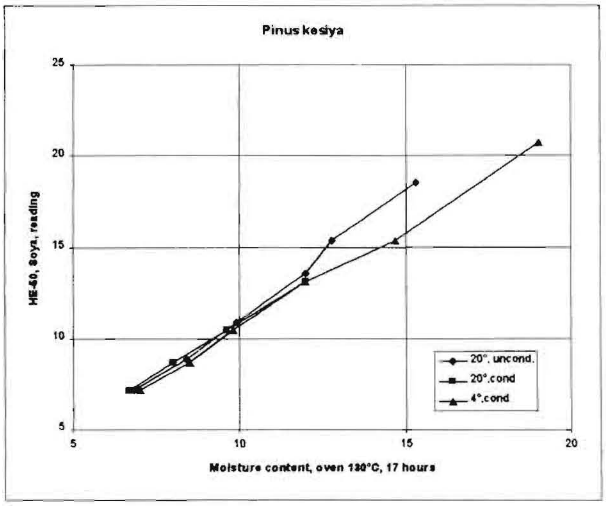


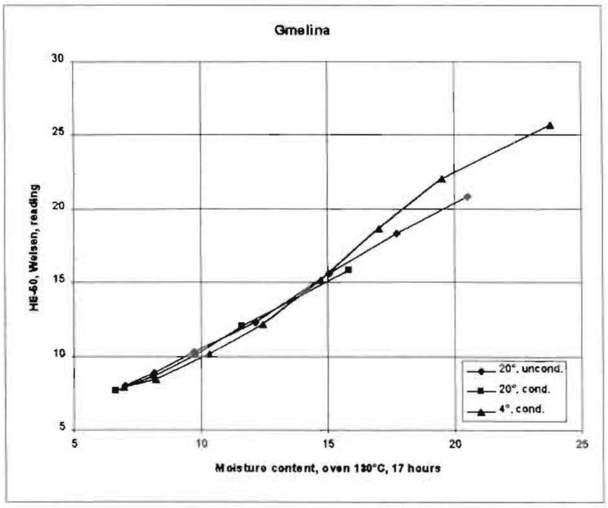


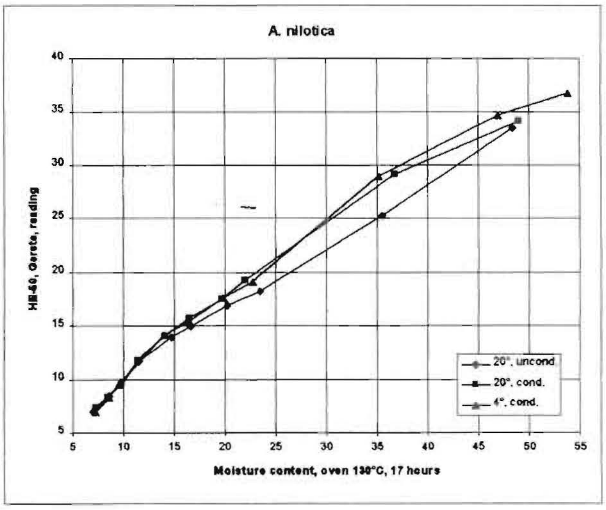


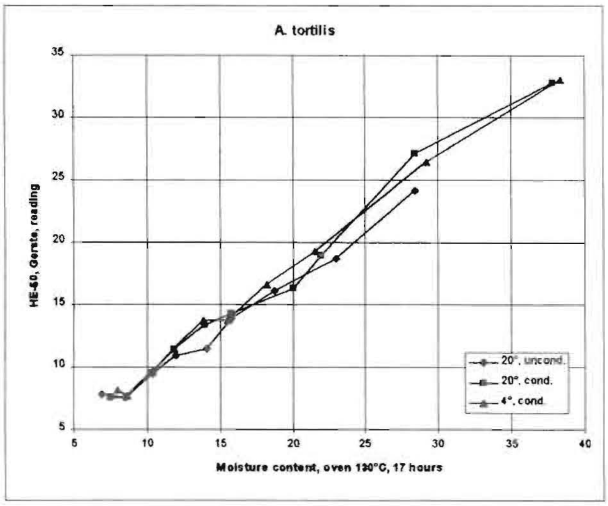
Legend:
20°, uncond.: measured immediately after drying at 20°C.
20°, cond.: measured after equilibration for two days in blown up PE-bag at 20°C.
4°, cond.: measured on equilibrated seed at 4°C.

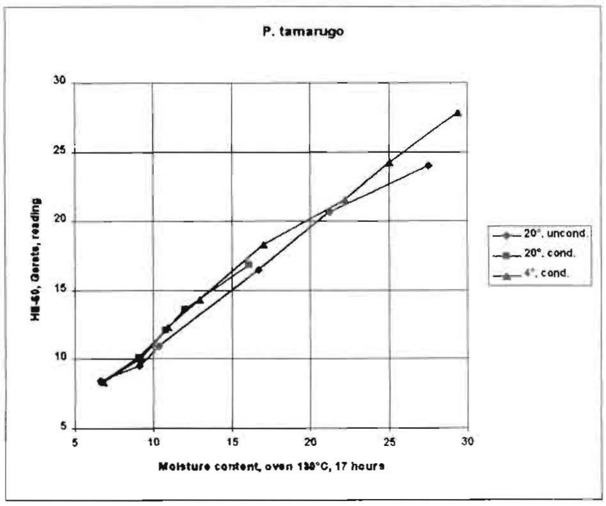
The effects of equilibration and temperature on the charts:
HE-50 Pfeuffer HOH-EXPERSS





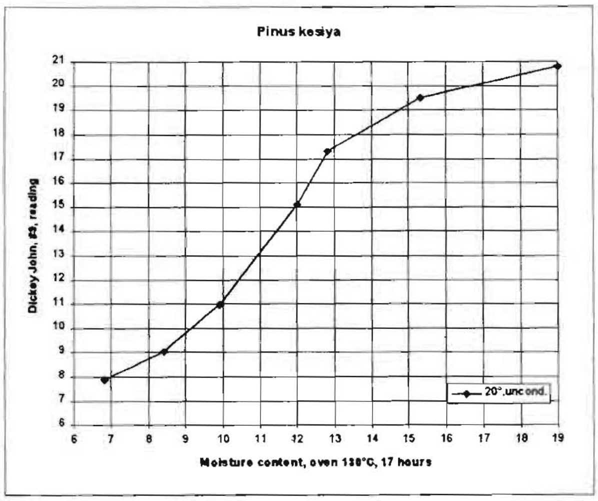


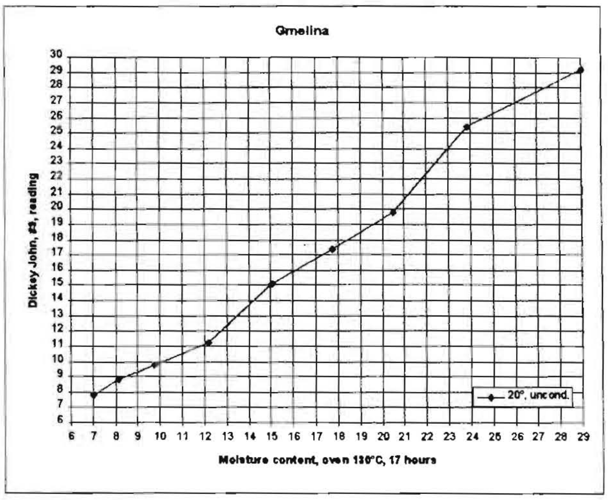


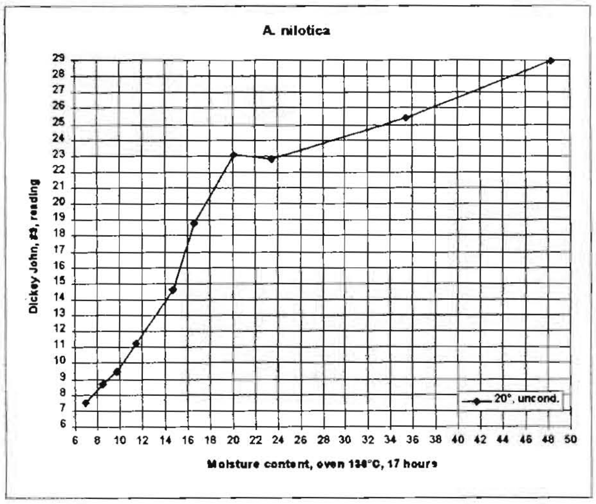


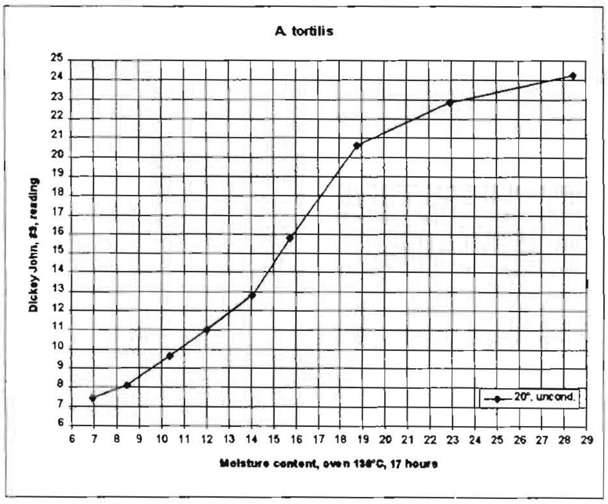
APPENDIX 2:

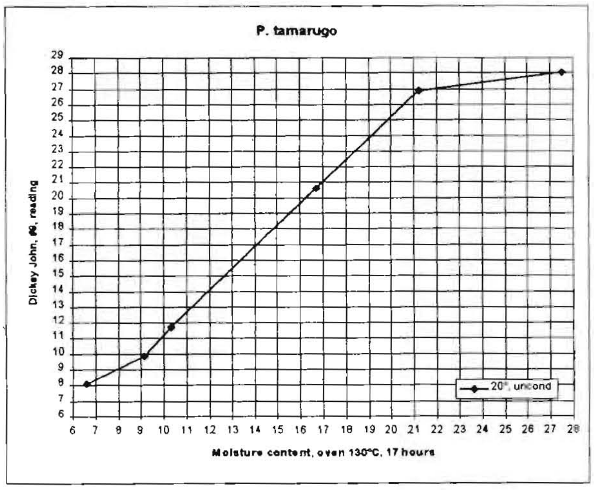
Charts at 20°C, unequilibrated for the five species: Dickey John Multi Grain Moisture Meter



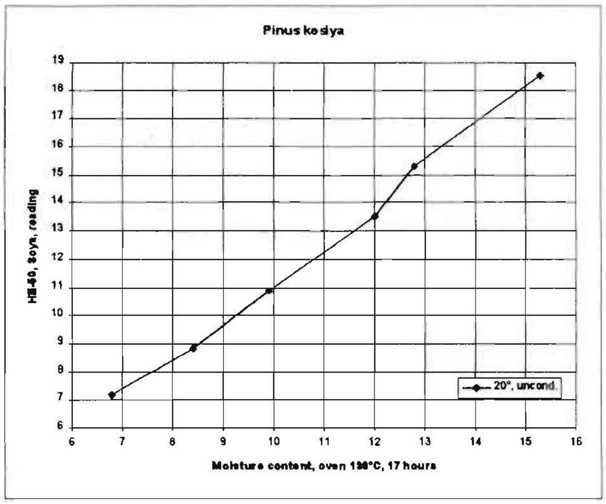


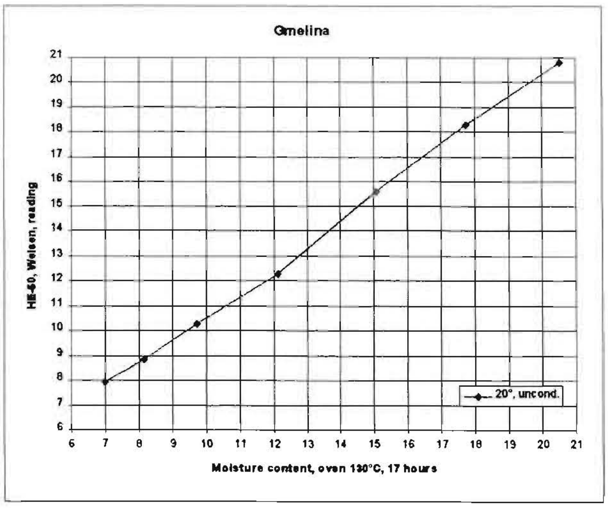


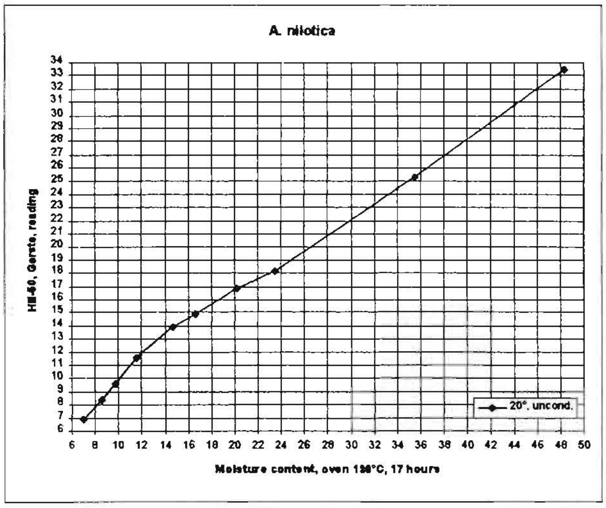


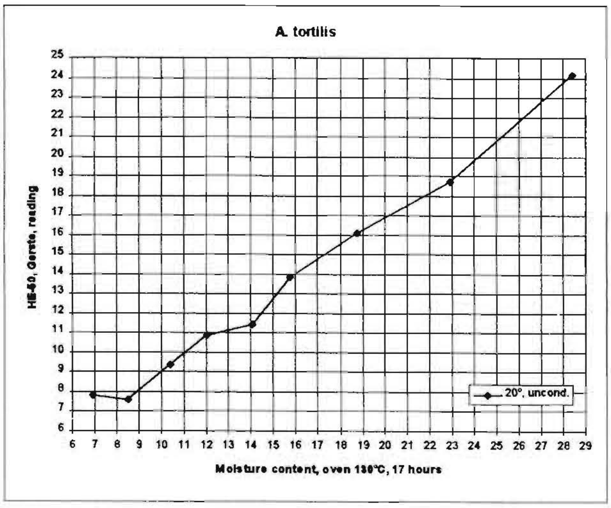


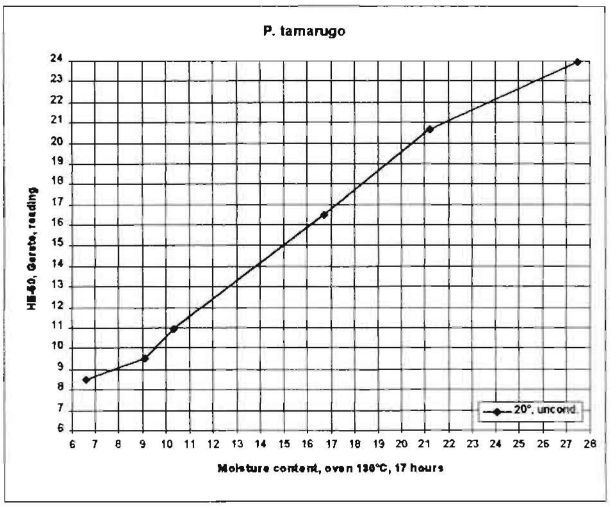
Charts at 20°C, unequilibrated for the five species: HE-50 Pfeuffer HOH-EXPERSS











APPENDIX 3: Selected tables at 20°C, unconditioned

Dickey John multi grain tester

Dickey John multi grain	
Species: *Pinus kesiya*	
20°C, unconditioned	
Setting: #9, Corn	
Reading	MC%
8.0	7.0
8.5	7.7
9.0	8.4
9.5	8.8
10.0	9.2
10.5	9.6
11.0	9.9
11.5	10.2
12.0	10.4
12.5	10.7
13.0	10.9
13.5	11.2
14.0	11.4
14.5	11.7
15.0	11.9
15.5	12.1
16.0	12.3
16.5	12.5
17.0	12.7
17.5	13.0
18.0	13.6
18.5	14.2
19.0	14.8
19.5	15.3
20.0	16.8
20.5	18.2

Dickey John multi grain	
Species: *A. tortilis*	
20°C, unconditioned	
Setting: #9, Corn	
Reading	MC%
7.5	7.1
8.0	8.2
8.5	9.0
9.0	9.6
9.5	10.2
10.0	10.8
10.5	11.4
11.0	12.0
11.5	12.6
12.0	13.1
12.5	13.8
13.0	14.2
13.5	14.5
14.0	14.8
14.5	15.0
15.0	15.2
15.5	15.5
16.0	15.9
16.5	16.2
17.0	16.5
17.5	16.8
18.0	17.1
18.5	17.5
19.0	17.8
19.5	18.1
20.0	18.4
20.5	18.7
21.0	19.5
21.5	20.5
22.0	21.4
22.5	22.3
23.0	23.5
23.5	25.5
24.0	27.5

Dickey John multi grain	
Species: *P. tamarugo*	
20°C, unconditioned	
Setting: #9, Corn	
Reading	MC%
8.0	6.4
8.5	7.1
9.0	7.8
9.5	8.5
10.0	9.2
10.5	9.5
11.0	9.8
11.5	10.1
12.0	10.5
12.5	10.8
13.0	11.2
13.5	11.5
14.0	11.9
14.5	12.3
15.0	12.7
15.5	13.0
16.0	13.4
16.5	13.8
17.0	14.1
17.5	14.5
18.0	14.8
18.5	15.2
19.0	15.5
19.5	15.9
20.0	16.2
20.5	16.6
21.0	17.0
21.5	17.4
22.0	17.7
22.5	18.1
23.0	18.4
23.5	18.8
24.0	19.2
24.5	19.5

Selected tables for HE-50 Pfeuffer HOH-EXPRESS

HE50 Pfeuffer	
Species: *Gmelina*	
20°C, unconditioned	
Setting: Weisen	
Reading	MC%
8.0	7.1
8.5	7.7
9.0	8.3
9.5	8.8
10.0	9.4
10.5	10.0
11.0	10.6
11.5	11.2
12.0	11.8
12.5	12.3
13.0	12.8
13.5	13.2
14.0	13.6
14.5	14.1
15.0	14.5
15.5	14.9
16.0	15.4
16.5	15.9
17.0	16.4
17.5	16.9
18.0	17.4
18.5	18.0
19.0	18.5
19.5	19.1
20.0	19.6
20.5	20.2

HE50 Pfeuffer	
Species: *A. nilotica*	
20°C, unconditioned	
Setting: Gerste	
Reading	MC%
7.0	7.0
7.5	7.5
8.0	8.1
8.5	8.6
9.0	9.1
9.5	9.6
10.0	10.1
10.5	10.6
11.0	11.1
11.5	11.6
12.0	12.1
12.5	12.7
13.0	13.4
13.5	13.7
14.0	14.8
14.5	15.7
15.0	16.7
15.5	17.7
16.0	18.6
16.5	19.5
17.0	20.5
17.5	21.8
18.0	23.1
18.5	24.0
19.0	24.9
19.5	25.8
20.0	26.7
20.5	27.5
21.0	28.2
21.5	29.0
22.0	29.9
22.5	30.8

HE50 Pfeuffer	
Species: *P.tamarugo*	
20°C, unconditioned	
Setting: Gerste	
Reading	MC%
8.5	6.6
9.0	7.8
9.5	9.0
10.0	9.5
10.5	9.9
11.0	10.3
11.5	10.9
12.0	11.4
12.5	12.1
13.0	12.7
13.5	13.2
14.0	13.8
14.5	14.4
15.0	15.0
15.5	15.6
16.0	16.1
16.5	16.8
17.0	17.2
17.5	17.7
18.0	18.3
18.5	18.8
19.0	19.4
19.5	20.0
20.0	20.5
20.5	21.1
21.0	21.8
21.5	22.8
22.0	23.8
22.5	24.8
23.0	25.8
23.5	26.7
24.0	27.7

APPENDIX 4: Study plan for laboratory

Imbibition:

Acacia and Prosopis seeds are hot wire burned and the following imbibition procedures are undertaken:

Acacia: 17h soak at 20°C, will result in a moisture content of approx. 40%
Prosopis: as Acacia.
Pinus: 24h in moist filter paper rolls at 20°C followed by 17h soak at 4°C, moisture content will reach approx. 35%
Gmelina: 72h soak at 20°C

Change soak water twice/day

After imbibition dry the seed slightly (e.g. 5-10% loss of weight) in the laboratory on trays. Leave the seed to equilibrate in blown up PE-bags for two days in the laboratory (aerate at least once a day) before initial moisture content is measured by oven-method.

Field moisture meters:

See the meter manuals.

Dickey-John and Samap:
Draw a sample from the seed lot and measure moisture content using the meter, repeat altogether four times using the same sample. Replace the sample in the seed lot and mix, draw a second sample and measure as above. Repeat step again (i.e. a total of three samples).

HE-50:
Draw 3 samples from the seed lot and measure the moisture content.

Stepwise drying:

Dry the seed from around 30% to 6% m.c.
Targets are: 25%, 20%, 17%, 14%, 12%, 10%, 8%, 6%
Dry in net bags at 15% RH, 20°C and measure the loss of weight.

Measure the moisture content as follows:

A) Immediately upon drying, measure at 20°C, in the lab., using moisture meters and the oven method.
B) Leave the seed to moisture-equilibrate at 20°C, in the lab. in blown up plastic bags (aerate twice/day) for 2 days. Measure again using the meters and the oven method.
C) After step B) seed and moisture meter are transferred to temperature equilibrate in the cold store for 3 hours. Measure at 4°C using the moisture meters.

FIELD MOISTURE METER TESTING - Data sheet, laboratory

Date:______________ Species:_____________________________________

Moisture content: ___________; replicate a:____________, replicate b:_____________

Temperature:________°C (20 or 4°C), Equilibrated:___________(yes or no)

Dickey-John Grain type:__________

Sample no.	Measurement no.	Meter reading
1	1	
1	2	
1	3	
1	4	
2	1	
2	2	
2	3	
2	4	
3	1	
3	2	
3	3	
3	4	

Samap Grain type:__________

Sample no.	Measurement no.	Meter reading
1	1	
1	2	
1	3	
1	4	
2	1	
2	2	
2	3	
2	4	
3	1	
3	2	
3	3	
3	4	

HE-50 Grain type:__________

Sample no.	Meter reading
1	
2	
3	

APPENDIX 5:: Specifications for the two moisture meters

Instrument	Dickey John Multi Grain Moisture Tester	HE-50 Pfeuffer HOH-EXPRESS
Dimensions	19x12x20 cm	30x38x8 cm
Weight	1.22 kg	2.85 kg
Power	4 x AA Alkaline battery	Normal or chargeable 9V battery
Accessories	-	Battery charger
Optional accessories	50 g weight, 100 g weight 198 g calibration weight for balance	External temperature probe English manual
Measuring principle	Capacitance of fixed weight, undestructive	Conductance of ground material
Sample size	200 g (150/100 g with optional weights)	9 ml ground material
Included calibrations	12 agricultural grain species	14 agricultural grain species ?
Calibration scale	Temperature and frequency scale	-
Temperature calibration	Automatic on included calibrations. Manual on frequency scale, digital thermometer inside instrument	Automatic on included calibrations, digital thermometer inside instrument
Programmable calibrations	-	-
Language of manual	English	German
Suppliers	Seedburo Equipment Company Jackson blvd. Chicago, IL 60607-2990, USA int. Phone:+1 312 7383700 int. Fax: +1 312 7385329 ED Service Center Oestergade 38 DK-4000 Roskilde Denmark int. Phone: +45 46361515 int. Fax: +45 46373906 Foss Electric Slangerupgade 69 DK-3400 Hilleroed Denmark int. Phone: +45 42268400 int. Fax: +45 42269322	Pfeuffer GmbH Flugplatzstr. 70 D-8710 Kitzingen Germany int. Phone: +49 9321 31031 int. Fax: +49 9321 36968 Rationel Kornservice Gammel Moellevej 4 DK-6700 Esbjerg Denmark int. Phone: +45 75122588 int. Fax: +45 75129089
Price 1997	268-680 US$ depending on supplier	1000 US$ in Denmark