SHORT COMMUNICATION

An evaluation of five methods for the determination of moisture in grass seeds

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Fairey, N. A. 2002. **An evaluation of five methods for the determination of moisture in grass seeds**. Can. J. Plant Sci. **82**: 401–405. Seed of four grass species was re-hydrated to 11 pre-determined moisture concentrations ranging from 100 to 600 g kg^{-1} fresh weight (FW) to simulate seed maturation during swathing and combining. The performance characteristics of three thermogravimetric and two electronic capacitance methods of moisture determination were evaluated. The thermogravimetric methods had no moisture range limitations and were, in general, more accurate than the electronic methods. The thermogravimetric Koster tester is suitable for grass seeds of all moisture concentrations, and can be easily adapted for use at field sites. The John Deere Moisture-Chek electronic tester is suitable for the rapid determination of moisture in grass seeds but is limited to concentrations of 80–250 g kg^{-1} FW.

Key words: Grass seed crops, seed moisture measurement, swathing, combining, time of harvest

Fairey, N. A. 2002. **Évaluation de cinq méthodes servant à mesurer la teneur en eau des semences de graminées**. Can. J. Plant Sci. **82**: 401–405. Les semences de quatre graminées ont été réhydratées à 11 concentrations prédéterminées allant de 100 à 600 g d'eau par kilo de poids frais, de manière à reproduire la maturité des semences à l'andainage et à la récolte. L'auteur a ensuite évalué les paramètres de rendement de trois méthodes thermogravimétriques et de deux méthodes électroniques de détermination de la capacité utilisées pour mesurer la teneur en eau. Les méthodes thermogravimétriques ne sont pas limitées par la teneur en eau des semences et sont généralement plus précises que les méthodes électroniques. L'analyseur thermogravimétrique Koster convient aux semences de graminées, peu importe leur teneur en eau, et est facile à adapter pour les relevés sur le terrain. L'analyseur électronique Moisture-Chek de John Deere convient au dosage rapide de la teneur en eau des semences de graminées, mais ne fonctionne que dans l'intervalle de 80 à 250 g kg^{-1} de poids frais.

Mots clés: Culture grainière des graminées, teneur en eau des semences, andainage, récolte, moment de la récolte

The time of swathing for forage seed crops is usually determined by the seed moisture concentration of the ripening crop. The optimum seed moisture concentration for swathing varies considerably among forage species, but is generally in the range of 200 to 450 g kg^{-1} FW (Klein and Harmond 1971; Andrade et al. 1994). After a period of maturation and drying in the swath, the seed is subsequently combined. If the seed moisture concentration after combining is below 120 g kg^{-1} FW, grass seeds may be stored without further drying (Simon et al. 1997). If the seed moisture concentration exceeds 120 g kg^{-1} FW, the seed must be aerated, with heated air if necessary, until seed moisture concentration is reduced to a safe level for medium- or long-term storage. Forage seed growers, therefore, require a reliable and relatively rapid method of determining seed moisture concentration over the range of 50 to 550 g kg^{-1} FW, preferably with a portable unit that can be used at field sites.

A study was conducted to determine the applicability of five methods for determining the seed moisture concentration of four species of grass: creeping red fescue (*Festuca rubra* L. var. *rubra*), tall fescue (*Festuca arundinacea* Schreber), smooth brome (*Bromus inermis* Leyss.) and timothy (*Phleum pratense* L.). Sub-samples from a batch of stored seed of each species were re-hydrated with water to 11 pre-determined moisture concentrations (100, 150, 200, 250, 300, 350, 400, 450, 500, 550 and 600 g kg^{-1} FW basis) using the procedures of Sijbring (1963). Briefly, sub-samples of known weight (300 g for red and tall fescue and 250 g for smooth brome and timothy) and known moisture concentration (81, 58, 97 and 84 g kg^{-1} FW for red fescue, tall fescue, smooth brome and timothy, respectively) were taken from each batch of stored seed and placed in sealable polyethylene bags. The required weight of distilled water was added to each sub-sample of seed to obtain a full set of the 11 pre-determined moisture concentrations for each species. Before use, each bag of re-hydrated seed was mixed several times per day while being stored in the dark at 4°C for 14 d; this procedure ensured uniform re-absorption and distribution of the added moisture. A total of 72 bags of seed of each species was prepared, one for each of six replications for each of the 12 seed moisture concentrations (the stored seed plus the 11 pre-determined moisture concentrations).

Abbreviations: **AC**, alternating current; **FW**, fresh weight; **ISTA,** International Seed Testing Association; **PAMI,** Prairie Agricultural Machinery Institute

For each species, the moisture concentration of each sub-sample of seed was measured by each of five methods, three based on the thermogravimetric principle: viz. 1. High constant-temperature oven method of International Seed Testing Association (ISTA 1999), i.e., ISTA prescribed method 9.5.9 (weight loss from a 5-g sub-sample heated to 130–133°C for 60 min) (ISTA); 2. Koster General Purpose Crop Moisture Tester (Koster Crop Tester, Inc., 13477 Prospect Road, Site 103C, Strongsville, Ohio 44136-3867, USA) using the required 110-g sub-sample (Koster); 3. Mettler Toledo HR73 Halogen Moisture Analyzer (3–4 g sub-sample dried at a temperature of 120°C using the rapid drying program, and with the end-point determined when the weight loss in 50 s was less than 1 mg) (MTHMA); and two based on the electronic capacitance principle: viz. 1. Wile/PreAgro-35 Grain Moisture Tester (Preagro Inc., 3131 Western Avenue, Seattle, Washington 98121, USA) fitted with the sample-chamber extension cylinder and piston accessory (73 mm × 42 mm diameter), and using the seed moisture scale provided for perennial ryegrass seed (Preagro-35); and 2. John Deere Moisture-Chek Tester Model SW16060 (sample chamber of 45 mm × 54 mm diameter) set to use the canary seed scale (i.e., the seed option most similar to the grasses under evaluation), and with each moisture determination being the average of three readings (JDMC). The moisture determinations for each species were made in random order of the five methods of moisture determination and, within each method, in random order of the 12 moisture concentrations. Six replicates in time were utilized for each species. For each of the 20 combinations of the four grass species and five methods of moisture determination, three regressions of the pre-determined moisture concentration values on the measured moisture concentration values were conducted: 1. On all values within the full range of pre-determined moisture concentration of 50–600 g kg^{-1} FW but, where applicable, restricted by the operational limits of each method; 2. On all values within the range of pre-determined moisture concentration suitable for the Preagro-35 capacitance tester (50–400 g kg^{-1} FW); 3. On all values within the range of pre-determined moisture concentration suitable for the JDMC capacitance tester (80–250 g kg^{-1} FW). The FIT procedure of Genstat 5 Release 4.1 (Lawes Agricultural Trust 1997) was used for the analyses, the results of which are summarized in Table 1.

For each species, the three thermogravimetric methods provided a more reliable indication of seed moisture concentration than the two electronic capacitance methods, with the former accounting for 98.9 to 99.9% of the variance while the latter accounted for only 92.1 to 98.3%. The range restrictions for moisture concentration with the Preagro-35 and JDMC testers resulted in a reduction in the number of degrees of freedom available for the residual terms of the respective regression analyses (Table 1).

Values of unity for the slope and zero for the intercept are indicative of a theoretically perfect association between the pre-determined and measured seed moisture concentration values in the linear regression equations. Regardless of the species of grass, the slopes of the regression relationships for the three thermogravimetric methods were close to the theoretical value of unity, being in the range of 0.980 to 1.076, while those for the two electronic capacitance methods were more variable, ranging from 0.580 to 1.055 (Table 1). The values for the intercepts for each of the four grasses were only statistically ($P \leq 0.05$) equivalent to the theoretical value of zero when the moisture concentration was measured by the ISTA method; the only other intercept that was statistically equivalent to zero was for the MTHMA method with timothy (Table 1).

The SE of the observations was generally much higher for timothy than for the other three grasses, regardless of the method of moisture determination, with the regression analyses incorporating all values within the operational range for each method (i.e., the “full” range) than with those pertaining to the restricted Preagro-35 and JDMC ranges (Table 1). The greater magnitude of these SE values is therefore associated with the moisture values in the range 400–600 g kg^{-1} FW, and can be attributed to the physical characteristics of the timothy seed, i.e., small with little chaff, and thus a lower capacity to re-absorb water than the seed of the other three grass species. This assessment emanates from the difficulties that were observed in the ability of timothy seed to absorb and retain the higher concentrations of water. The small size of the timothy seed also made it necessary to use a finer screen in the sample container of the Koster tester, in order to prevent seed loss during the drying process.

With the exclusion of values of 400–600 g kg^{-1} FW for timothy (for the reasons discussed above), the SE of observations for the three thermogravimetric methods were all within 3.88–9.54 g kg^{-1} FW (Table 1). The best indicators of the relative accuracy of the five methods of moisture determination, both within and among species, is given by the SE of observations for the regressions that were restricted to moisture concentrations for the Preagro-35 and JDMC ranges. With the exception of the JDMC method with the seed of creeping red fescue, the SE of observations, within each of these restricted ranges, for the two electronic capacitance testers were generally greater than those for the three thermogravimetric methods. However, the SE of observations associated with the JDMC tester were generally lower than those associated with the Preagro-35 tester. The SE of observations, for each of the three regression ranges, for the JDMC method with seed of creeping red fescue was similar to that of the ISTA and MTHMA methods and approximately half of those for the Koster method (Table 1). Thus, within their operational moisture ranges, each of the five methods can provide useful information on the seed moisture concentration of a range of types of grass seeds, from the small non-chaffy seeds of timothy to the large chaffy seeds of smooth brome and the intermediate seeds of creeping red and tall fescue. As individual requirements vary, the selection of an appropriate method for determining the moisture concentration in specific batches of grass seeds may be assisted by a summary of the performance characteristics of the five methods evaluated in this study (Table 2).

Of the three thermogravimetric methods, the ISTA and MTHMA methods are of greatest use in laboratories because they involve the use of more expensive precision-

Table 1. Coefficients and statistical significance of the linear regressions of the predetermined seed moisture concentration values (PSM, g kg^{-1} FW) on the measured seed moisture concentration values (MSM, g kg^{-1} FW) for four grasses by each of five methods of moisture determination. (Note: Except for the SE of observations, each set of regression parameters pertain to all values within the operational range for that method)

	Degrees of freedom		Regression		Regression coefficients for linear equation (PSM = m × MSM + c)								Variance accounted for (%)	SE of observations (g kg^{-1} FW) for pre-determined moisture concentration range[y]		
			Variance ratio	*F*-probability	Slope m				Intercept c (g kg^{-1} FW)							
Method of moisture determination[z]	Regression	Residual			Estimate	SE	*t*-value	*t*-probability	Estimate	SE	*t*-value	*t*-probability		Full	Preagro-35	JDMC
Creeping red fescue																
ISTA	1	70	79205	<0.001	1.003	0.004	281.4	<0.001	0.31	1.31	0.24	0.811	99.9	5.12	4.90	3.88
Koster	1	70	33863	<0.001	0.980	0.005	184.0	<0.001	10.51	1.95	5.39	<0.001	99.8	7.83	8.06	9.54
MTHMA	1	70	76387	<0.001	0.996	0.004	276.4	<0.001	9.99	1.30	7.62	<0.001	99.9	5.22	4.97	6.14
Preagro-35	1	41	567	<0.001	0.937	0.039	23.8	<0.001	35.10	10.50	3.33	0.002	93.1	28.40	16.80	11.40
JDMC	1	10	435	<0.001	0.580	0.028	20.9	<0.001	88.36	4.32	20.45	<0.001	97.5	4.11	4.11	4.11
Tall fescue																
ISTA	1	70	52422	<0.001	1.001	0.004	229.0	<0.001	-0.23	1.61	-0.14	0.887	99.9	6.35	5.88	5.12
Koster	1	70	64482	<0.001	0.983	0.004	253.9	<0.001	7.73	1.42	5.43	<0.001	99.9	5.72	5.56	6.99
MTHMA	1	70	51466	<0.001	0.992	0.004	226.9	<0.001	10.00	1.58	6.31	<0.001	99.9	6.40	6.02	7.07
Preagro-35	1	36	2100	<0.001	0.875	0.019	45.8	<0.001	37.76	5.36	7.05	<0.001	98.3	12.20	12.20	6.66
JDMC	1	11	140	<0.001	0.696	0.059	11.8	<0.001	72.91	9.46	7.71	<0.001	92.1	9.17	9.17	9.17
Smooth brome																
ISTA	1	70	61272	<0.001	1.000	0.004	247.5	<0.001	1.34	1.48	0.90	0.370	99.9	5.71	5.49	5.05
Koster	1	70	71558	<0.001	0.980	0.004	267.5	<0.001	10.86	1.34	8.09	<0.001	99.9	5.28	6.08	7.15
MTHMA	1	70	92903	<0.001	0.997	0.003	304.8	<0.001	7.76	1.19	6.54	<0.001	99.9	4.64	4.57	4.62
Preagro-35	1	48	2470	<0.001	0.960	0.019	49.7	<0.001	30.00	4.95	6.05	<0.001	98.1	16.40	12.40	12.10
JDMC	1	16	333	<0.001	0.897	0.049	18.2	<0.001	61.52	7.90	7.79	<0.001	95.1	9.28	9.28	9.28
Timothy																
ISTA	1	70	9885	<0.001	1.046	0.011	99.4	<0.001	-3.08	3.73	-0.83	0.412	99.3	14.30	5.52	5.42
Koster	1	66	11117	<0.001	0.980	0.009	105.4	<0.001	25.28	3.29	7.69	<0.001	99.4	12.90	5.64	5.15
MTHMA	1	70	6271	<0.001	1.076	0.014	79.2	<0.001	-1.19	4.66	-0.26	0.799	98.9	17.90	5.83	5.91
Preagro-35	1	42	651	<0.001	1.055	0.041	25.5	<0.001	-22.50	10.10	-2.23	0.031	93.8	25.70	23.90	19.70
JDMC	1	21	476	<0.001	0.866	0.040	21.8	<0.001	15.47	5.65	2.74	0.012	95.6	9.48	9.48	9.48

[z]ISTA = ISTA (1999) prescribed method 9.5.9; Koster = Koster General Purpose Crop Moisture Tester; MTHMA = Mettler Toledo HR73 Halogen Moisture Analyzer; Preagro-35 = Wile/PreAgro-35 Grain Moisture Tester; JDMC = John Deere Moisture-Chek Tester.

[y]Full = all values within the range 50–600 g kg^{-1} FW that are also within the operational range for the specific method of moisture determination; Preagro-35 = 50–400 g kg^{-1} FW; JDMC = 80–250 g kg^{-1} FW.

Table 2. The suitability of five methods for the determination of moisture in grass seeds

	Method for the determination of moisture[z]				
Characteristic	ISTA	Koster	MTHMA	Preagro-35	JDMC
Moisture range (g kg^{-1} FW)	Full range	Full range	Full range	50–400	80–250
Accuracy within tester's operational moisture range (g kg^{-1} FW)[y]	4–6	5–10	5–7	12–24	4–10
Suitability for determining when to swath or direct combine	Good	Good	Good	Fair but only when crop taken at seed moisture <400 g kg^{-1} FW	Unsuitable
Suitability for determining when to combine from swaths	Good	Good	Good	Fair	Good
Suitability for use in a laboratory and/or in the field	Laboratory only	Laboratory and field	Laboratory only	Laboratory and field	Laboratory and field
Sample size	5 g	110 g	3–4 g	101 mL	103 mL
Minutes to complete one moisture determination	80–90	15–30	5–30	<5	<5
Direct indication of moisture concentration	No. Precise initial and final weights and a calculation are required	Yes. A spring–dial, weigh–scale provides both moisture and dry matter readout, and is used for deter–mining initial size of sample	Yes (Digital readout)	No. Read needle position on 0–50 scale and then use a printed chart to give moisture concentration	Yes (Digital readout)
Relative cost of equipment	High	Low	High	Low	Low
Special requirements	Electrical power and a precision weighing scale	Electrical power. A non–combustible wind shield and a level platform are required for field use	Electrical power	None	None

[z]ISTA = ISTA (1999) prescribed method 9.5.9; Koster = Koster General Purpose Crop Moisture Tester; MTHMA = Mettler Toledo HR73 Halogen Moisture Analyzer; Preagro–35 = Wile/PreAgro–35 Grain Moisture Tester; JDMC = John Deere Moisture–Chek Tester.
[y]Based on SE of observations in Table 1, excluding those in which timothy had a moisture concentration of 400–600 g kg^{-1} FW.

weighing mechanisms, small samples, and more intricate procedures. The JDMC tester is suitable for the rapid determination of moisture in grass seeds, but is limited to moisture concentrations of 80–250 g kg^{-1} FW. Within this restricted operational range, the JDMC tester was more accurate than the Preagro-35 tester for each of the four grass species. Also, with creeping red fescue seed, the JDMC tester had an accuracy as good as, or better than, any of the three thermogravimetric methods. These results support an earlier report that electronic capacitance testers are unsuitable for seed moisture concentrations in grass seeds above about 250 g kg^{-1} FW (Ministry of Agriculture, Fisheries and Food 1968). Prairie Agricultural Machinery Institute (PAMI 1981) rated the performance of the Koster tester as excellent with chopped alfalfa herbage and corn forage, although its requirement for 120 volt AC electrical power was considered to make it impractical for use in the field. The present results extend the utility of the Koster tester to grass seed samples, provided precautions are taken to prevent the loss of small seeds from the sample container. Also, the requirement for AC electrical power is not as difficult to overcome in field situations today as it would have been in the 1980s when PAMI evaluated the Koster tester; lightweight, portable AC power generators are now commonplace on most farms. Regardless of the method of moisture determination, any seed sample must be as representative as possible of the crop that is to be swathed or combined, so it should be comprised of sub-samples taken from a random distribution of points throughout the field site.

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Andrade, R. P., Grabe, D. F. and Ehrensing, D. 1994. Seed maturation and harvest timing in turf type tall fescue. J. Appl. Seed Prod. **12**: 34–46.

International Seed Testing Association. 1999. International rules for seed testing: Rules 1999. Seed Sci. Technol. **27** (Suppl.): 47–50.

Klein, L. M. and Harmond, J. E. 1971. Seed moisture – a harvest timing index for maximum yields. Trans. ASAE **14**: 124–126.

Lawes Agricultural Trust 1997. Genstat 5 Release 4.1 Command Language Manual. Genstat 5 Committee, Statistics Dept., IARC-Rothamsted, Harpenden, Hertfordshire, AL5 2JQ, UK. Numerical Algorithms Group Ltd., Oxford, UK, 384 pp.

Ministry of Agriculture, Fisheries and Food 1968. Conditioning, handling and storing the crop. Pages 60–67 *in* R. Ede, ed. Grass and clover crops for seed. Bull. 204. Her Majesty's Stationery Office, London, UK.

Prairie Agricultural Machinery Institute. 1981. Koster forage moisture tester. PAMI Evaluation Rep. No. E0678B. Prairie Agricultural Machinery Institute, Portage La Prairie, Manitoba.

Sijbring, P. H. 1963. Results of some experiments on the moisture relationship of seeds. Proc. Int. Seed Testing Assoc. **28**: 837–843.

Simon, U., Hare, M. D., Kjaersgaard, B., Clifford, P. T. P., Hampton, J. G. and Hill, M. J. 1997. Harvest and postharvest management of forage seed crops. Pages 181–217 *in* D. T. Fairey and J. G. Hampton, eds. Forage seed production. Volume 1. Temperate species. CAB International, Oxford, UK.