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EXECUTIVE SUMMARY

Introduction and Scope

Inventory and monitoring are key components to land management practices. This includes the measurements of forage production to determine stocking rates and the effectiveness of certain land treatments such as burning, herbicide applications, and fertilization.

Forage production values are used in conjunction with measurements of residual forage on areas that were previously grazed so forage utilization levels can be monitored on grazing allotments. Wildlife habitat managers, range management specialists, and other land monitoring employees use these plant production measurements to monitor whether livestock use levels are in compliance with maximum allowable use standards prescribed in the allotment management plans.

There are various methods used to obtain plant productivity measurements. The current standard for herbaceous plant productivity is a time consuming process of clipping, weighing, and drying vegetation in an oven.

This study involved a comparative analysis between various commercially available herbaceous measurement devices. Precision, accuracy, correlation, and performance characteristics of capacitance probe, oven meter, and sliding plate technologies were compared to the standard clip and weigh oven method.

Findings

The Sigma Delta Technologies Pty Ltd, Fuel and Soil Moisture Meter Neosystems II (Neosystems II) had the highest degree of correlation, accuracy, and consistency when compared to the standard oven. It had a 94 percent positive correlation, followed by the Tru-Test Limited GrassMaster (GrassMaster) capacitance probe with 74 percent and Jenquip Filips Folding Plate Pasture Meter (Filips Folding Plate Pasture Meter) with 58 percent. All other devices had a lower correlation. The Neosystems II unit has a better than 99 percent accuracy, unlike all the other devices tested. Development of forage constants for specific pasture plots and the issue of minimum stubble height needs to be addressed before field use for any application requiring less accuracy than currently provided by the standard oven or Neosystems II.

The Neosystems II is an improvement over the standard oven. Key differences include a decreased amount of time necessary to determine forage production values, automation to reduce human error, and the capability to download data to a personal computer. It takes 21 hours for the standard oven to determine forage production values, 1 hour if using 3 Neosystems II meters or 3 hours if using 1 Neosystems II meter.

In addition to the forage production measurements, there is a need to develop a field users guide for sampling, collection, and processing forage production samples, including sampling collection, handling, and processing techniques for use with the standard oven or Neosystems II meter.

INTRODUCTION AND SCOPE

The measurement of forage production is a key component to land management practices. Measurements are made frequently when certain land treatments are applied such as burning, herbicide applications, and fertilization. By analyzing forage production on treated and untreated sites, differences can be tracked to determine what process has been the most successful in revegetation efforts. Forage production measurements are also used to estimate livestock and wildlife grazing capacity when grazing allotments are analyzed. These production values are used in conjunction with measurements of residual forage on areas that were previously grazed so forage utilization levels can be monitored on grazing allotments. Wildlife habitat managers, range management specialists, and other land monitoring employees use these plant production measurements to monitor whether livestock use levels are in compliance with maximum allowable

use standards prescribed in the Allotment Management Plans.

There are various methods used to obtain this measure of plant productivity. The current standard for an accurate measurement of herbaceous plant productivity is with a time consuming process of clipping, weighing, oven drying, and reweighing vegetation. There are more practical methods that include clipping and weighing plant material with ocular estimates.

This project involved conducting a comparative analysis between various commercially available herbaceous measurement devices. Precision, accuracy, correlation, and performance characteristics of capacitance probe, oven meter, and sliding plate technologies were compared to the standard clip and weigh oven method.

The optimum forage production measurement device promotes accuracy, consistency, and efficiency for various types of forage involved in inventory and monitoring activities.

HERBACEOUS MEASUREMENT DEVICE TECHNOLOGIES

Six herbaceous measurement devices utilizing capacitance probe, rising plate, and portable oven meter technologies were field tested and compared to the standard cut and weigh oven method. The capacitance probe devices were the Tru-Test® Limited GrassMaster (GrassMaster), Draminski Inc. Pasture Meter (Pasture Meter), and Alstair George Manufacturing PastureGauge© (Pasture Gauge). The rising plate devices were the Kencove FarmTracker™ Rising Plate Meter (Farm Tracker) and the Jenquip Filips Folding Plate Pasture Meter (Folding Plate Pasture Meter). The field portable oven device was the Sigma Delta Technologies Fuel and Soil Moisture Meter Neosystems II (Neosystems II).

Herbaceous measurement devices typically indicate the amount of forage present within a given area. Forage is the weight factor of any plant-like living organic material. Forage per land area is the weight of the combined grass, seedlings, and other small plants within a given area. Forage is usually measured in kilograms of dry matter per hectare (kg DM/ha) or pounds of dry matter per acre (lb DM/acre).

RISING PLATE TECHNOLOGY

Rising plate meters have a plate of a known area, sliding up and down a shaft in relation to the density of the forage (figure 1). The shaft is positioned vertically and the plate rests horizontally at the bottom of the shaft. The device is lifted vertically and gently positioned on the ground. The shaft rests on the ground, where the plate rises and is held up by the forage.

This movement of the sliding plate turns a manual counter or is attached to a computer where a reading is displayed electronically, depending on the device. The manufacturer recommends that 20 to 40 readings be obtained per pasture. The Folding Plate Pasture Meter has a manual counter for the number of samples taken and displays the combined estimate of forage. The amount of forage in terms of kilograms of dry matter per hectare is calculated by using these values in equations provided in the operator's manual. Corrections to the measured value are recommended for each specific cover type. The Farm Tracker has a similar design with an electronic readout for the amount of



Figure 1—Typical rising plate meter.

forage. Information regarding changing the reading for specific cover types is provided.



Figure 2—Typical capacitance probe.

CAPACITANCE PROBE TECHNOLOGY

A capacitance probe device uses an electric field to determine the amount of forage in terms of kg DM/ha (figure 2). The capacitance probe sets up an electric field and measures changes to the field. The capacitance change is directly proportional to the moisture content of the plant material. The meter is mounted on a plastic shaft approximately the size of a walking stick with a length of up to 4 feet (1.2 m). The shaft has a 1/8 to 1/3 in (3.2 to 8.5-mm) metal prong at the end to prevent the shaft from direct contact with the ground. Measurements are obtained by walking across a pasture and placing the shaft on the ground vertically, every 2 to 6 paces.

An electric field is set up at the bottom portion of the shaft. When the unit is first activated to measure for kg DM/ha, the unit takes an air reading. The prong is held above the forage. When the prong is placed on the ground, the bottom portion of the shaft is surrounded by forage. The change in density in the air moisture content of plant material changes the electric field characteristics. This change is recorded and used in calculations with an output reading of average kg DM/ha.

NEOSYSTEMS II METER TECHNOLOGY

The Neosystems II meter is a portable oven meter with the capacity to dry plant material in 4 to 20 min, depending on the type of forage, and provide a value for forage production in terms of kg DM/ha or lb DM/acre or (figure 3). This meter contains a small oven, electronic balance, motorized conveyor, digital readout, and vacuum pump.



Figure 3—Neosystems II meter.

The Neosystems II meter carrier is weighed empty. Plant material is placed on the carrier dish and into a compartment with an electronic balance scale. A conveyor moves the carrier dish between the scale and oven. The forage within the dish is compressed between two hot oven plates at a constant pressure, causing moisture to be released.

The oven plates are designed with ridges and holes for the rapid removal of moisture under compression. A high flow vacuum pump pulls moisture away from the dish environment and water vapor is ejected through a plastic tube on the side of the meter. The oven temperature is uniformly 284 °F (140 °C) across the plates, higher than the standard 220 °F (104 °C) oven. The manufacturer states that this increase in temperature is offset by the substantially decreased bake time (1 h versus 21 h), oven plate design, and use of a high flow vacuum pump.

After a preset time period in the oven, the conveyor again places the dish back onto the electronic balance to be weighed. The Neosystems II meter computer subtracts the final weight from the initial weight and indicates the percentage of moisture content on a liquid crystal display (LCD) screen. Using a separate scale, the larger sample (total sample from a given area of the pasture) is weighed and the weight is entered into the meter to determine the forage in kg DM/ha or lb DM/acre. Other indicated values include the weight of the carrier before and after baking, and the amount of kg DM/ha or lb DM/acre.

Various forage types can be evaluated with this device by varying the bake time. The standard Neosystems model allows for dual bake times. Bake times are specified at the time of purchase, or an additional add-on option allows the user to program specific bake times. The forage production value readout is in lb DM/acre unless otherwise indicated at time of purchase. The Neosystems II meter also determines moisture percent of various materials, including leaves, plant material, soil, and any material with moisture percent up to 1,000 percent.



Figure 4—Mechanical convection oven used for cut and weigh method.

CUT AND WEIGH OVEN TECHNOLOGY— STANDARD PRODUCTION MEASUREMENT

The current standard method for production measurements is the cut and weigh oven method. All plant material, within a designated sample area, is clipped as close to the ground as possible. The material is weighed, placed in an oven at 220 °F (104 °C) for a designated time period, removed, and weighed again. The amount of dry matter per area, in terms of kg DM/ha or lb DM/acre, is determined by comparing the initial and final weight, divided by the total sample over the plot area (figure 4).

$$\text{Forage in kg DM/ha} = \frac{\text{final weight} \times \text{weight of total sample of plot}}{\text{initial weight area of plot}}$$

HERBACEOUS PRODUCTIVITY MEASUREMENT DEVICES

Six herbaceous measurement devices utilizing capacitance probe, rising plate, and field portable oven meter technologies were field tested and compared to the standard cut and weigh method (table 1).

Table 1—Herbaceous productivity measurement devices.

Product	Technology type	Price (U.S. \$)	Weight lb (kg)	Memory files	Powered by	Manual calculations required
Standard oven cut and weigh	standard oven	approximately 2,200	>30 (>13.6)	none	ac	yes
Filip Pasture Mtr	rising plate	202	3.1(1.4)	none	manual	yes
Farm Tracker	rising plate	366	2.4(1.1)	20	9 V dc	yes
Pasture Meter	capacitance	362	1.8(0.8)	147	9 V dc	no
Pasture Gauge	capacitance	588	1.9(0.9)	1,000	Ni Cd internal	no
GrassMaster	capacitance	760	2.4(1.1)	120	Ni Cd internal	no
Neosystems II	oven meter	3,300	21(9.5)	254	ac or 12 V dc	no

Jenquip Filips Folding Plate Pasture Meter—Rising Plate Technology (figure 5).

Standard model includes:

- A falling plate meter with no electronic parts
- Manual gear driven counter display related to amount of forage
- Top manual counter for number of operator readings taken, used in calculating amount forage
- Handle folds down, plate can be removed for storage, mounting bracket to hold plate
- All-weather notebook
- Readings from counter need to be plugged into equation to calculate average kg DM/ha
- Sphere at top for use as a handle
- Height: 37.5 in (0.97 m); diameter of shaft: 0.61 in (15.5 mm); diameter of plate: 14 in (355.6 mm).

Additional options include:

- Extra all-weather notebook
- Storage tube
- Pasture management software for Windows 3.1 or Windows 95.



Figure 5—Jenquip Filips folding plate pasture meter.



Figure 6—The Kencove FarmTracker™ rising plate.

Kencove FarmTracker™ Pasture Meter—Rising Plate Technology (figure 6).

Standard model includes:

- Electronic counter for number of readings taken
- Carrying case
- Screw-on adjustable handle and plate
- Equation calibration feature, can be calibrated for different covers
- Auto save feature when unit is shut off
- Can display average height of forage or average kg DM/ha
- Height (maximum setting): 37 in (0.94 m); shaft diameter: 0.75 in (19.1 mm); plate diameter: 14.25 in (362 mm)
- One line digital LCD display located on side
- 2 button driven interface
- Required a 9 V battery [a Nickel Cadmium (Ni Cd) rechargeable may also be used]
- 20 memory files.

Additional option includes:

- Farm Tracker™ software developed mainly for livestock production.

Draminski Pasture Meter—Capacitance Probe Technology (figure 7).

Standard model includes:

- Personal computer (PC) compatible (computer interface cable is not provided)
- 141 paddock memory files
- Displays output data (e.g., total DM, average DM, maximum DM, minimum DM)
- Low battery indicator
- Automatic switch off after 3 min of nonuse
- Paddock areas can be stored, area figures used for statistics
- Internal date and time
- Displays directions while measuring (raise stick, stand stick)
- Height: 47.75 in (1.2 m); shaft diameter: 0.97 in (24.6 mm)
- Alphanumeric digital LCD display
- Menu-driven interface
- Requires a 9 V battery.



Figure 7—Draminski Pasture Meter.



Figure 8—Alistair George PastureGauge©

Alistair George Pasture Gauge—Capacitance Probe Technology (figure 8).

Standard model includes:

- Measures in kg DM/ha, lb DM/acre, or corrected meter reading (CMR)
- PC compatible RS 232 output (computer interface cable is not provided)
- Records average kg DM/ha or lb DM/acre for each measured surface
- 1,000 paddock memory files
- Gauge index can be changed for higher or lower sensitivity
- Detachable computer box
- Carrying shoulder strap
- Height: 43.6 in (1.1 m); shaft diameter: 1.06 in (26.9 mm)
- Digital LCD device
- Menu driven interface
- Pasture Gauge polish and cloth used to clean the pole and stud prongs where computer box connects
- Power pack to charge up Ni Cd internal battery
- European male plug adapter
- Auto shut off, after 3 min (when not in measure mode)
- Quick find feature to access a file instantly
- Set index feature to suit certain pasture conditions.

Additional options include:

- Farm totals and cover functions



Figure 9—Tru-Test® Limited GrassMaster Pasture Meter.

Tru-Test Limited GrassMaster Capacitance Probe Technology (figure 9).

Standard model includes:

- Ni Cd internal battery
- Offset calibration feature
- Changing equation for calibration feature
- PC download feature
- PC compatible with COM port via RS 232 format (computer interface cable is not provided)
- Polish and rag
- Power box for charging and downloading
- Height: 49 in (1.2 m); shaft diameter: 1.06 in (26.9 mm)
- 16 character alphanumeric digital LCD display
- Two measurement modes, fast and slow
- Battery charger and low battery warning
- UNDO feature for removing accidental measurements
- 120 memory files.

Neosystems II Fuel Moisture Meter—Portable Oven Technology (figure 10).



Figure 10—Neosystems II Fuel Moisture Meter.

Standard model includes:

- Height: 8 in (203 mm); width: 17 in (431.8 mm)
- Nylon carrier diameter: 4.6 in (117 mm)
- Moisture level indicator device
- Indicates initial and final weight of plant material
- Can measure moisture levels of plant material from 1 to 1,000 percent
- Menu driven interface
- Heater LED indicators
- Balance locking feature when unit is not in use
- Electronic balance with additional LCD display
- 12 V dc operation, uses approximately 10 amps truck battery recommended
- Two bake times, selectable by external switch (bake times to be specified by the user at the time of ordering, if not specified, it will be preset to 4 and 10 min)

- High flow vacuum pump combined with dual heating plates to remove moisture
- PC download feature via RS 232 15 pin (computer interface cable is not provided)
- 253 memory files
- Repeat function
- Carrier calibration function
- Carrier with two spare sets of mesh
- Pan clean feature to clean area around the balance
- Low battery warning
- Reset feature to reset the unit from any function.

Additional options include:

- 12 V dc operation replaced by ac power supply
- Dual power supply option, for both 12 V dc battery and 110 V ac operation
- Additional bake times, up to eight set externally by switch
- Programmable bake times, to be set at start up
- Indicates kg DM/ha or lb DM/acre
- Replacement carrier kit (includes carrier and five sets of mesh); one mesh set includes both top and bottom mesh for carrier.

Blue M Electric Oven—Typical Standard Mechanical Oven (figure 11).

Standard model includes:

- Exterior: length 21.1 in (537 mm); width 26.7 in (678 mm); height 36.7 in (932 mm)
- Interior: length 15 in (381 mm); width 19 in (482.6 mm); height 18.3 in (465 mm)
- Temperature range 100 to 500 F (38 to 260 °C)
- 1/6 hp (1.95 kW) motor with 230 V



Figure 11—Typical standard mechanical oven used for cut and weigh method.

SAMPLING METHODS AND TEST PROCEDURE

Pilot testing was conducted to determine the optimum forage sample collection, the handling and processing method, and the test procedure. No publications were found that describe detailed sampling collection, handling, and processing. In addition, sampling methodology varies according to the specific plant material.

Testing with capacitance probes and rising plate devices were conducted at one test site on a grid within the pasture boundary. There were 20 and 40 points sampled for each device at the same sample point. For use in the standard oven and Neosystems II meter testing, four sample points within the test site were chosen as representative points describing the average forage over the pasture plot. Twenty grid test points, including the four original sample points, were indicated by flagging. Consequently, all devices were tested on the same grid within the same sample points for the capacitance probes, rising plate, standard oven, and Neosystems II meter decreasing the variability of measurements.

The forage contained within these four sample points was collected by the use of a frame of a known area of 1 cubic foot (2.4 liters.) All plant material was collected within the plot frame to bare soil (refer

to: USDA Forest Service publication *Rangeland, Analysis and Management Guide, August 1996* and the National Wildfire Coordinating Group—Forest Service publication “*Measuring Moisture Content in Living Chaparral*”). Testing was conducted in Los Angeles County in California, elevation 1,100 ft in uniform grassland, June in the year 2000.

Sample collection was conducted in the afternoon, with a temperature range of 80 to 90 °F. Samples were not collected in shaded areas or within 24 h of rainfall. Plastic gloves were worn to prevent moisture and oil from the hands contaminating the samples. All samples were cooled below the condensation temperature. Cooling was achieved by using a plastic lunch pail and an ice pack. Samples were stored in a refrigerator during processing. All samples were placed in zip-lock plastic bags, and double bagged with as much air removed as practical. Samples were handled with care to prevent moisture contamination during processing. Bag contents were examined and extra debris (e.g., dirt, rocks, and pellets) were removed. Plant material was cut into 1-in (25.4 mm) pieces, the minimum sample size, to ensure uniformity and the desired accuracy of 10 g for the standard oven and 7 g for the Neosystems II meter tests. The greater the variability of plant material, the smaller the pieces need to be cut. The larger the sample size, the greater the accuracy, but a larger sample size necessitated a longer the bake time. By cutting the samples into smaller pieces, accuracy was not affected. The sample was spread uniformly across the surface of the carrier dish.

Before processing the test samples, the Neosystems II nylon oven carrier was preheated in the oven meter for 20 min to remove moisture typically absorbed by nylon at room temperature. The carrier must be preheated to ensure accuracy. Large errors will result if preheating is not done. All the test samples were placed inside the pan or carrier with no plant material hanging over the edges. All equipment was calibrated daily. Bake times for this test were 16 and 20 min. This consisted of a 4 min bake with 3 repeat cycles for a total time of 16 min and a 10 min bake with 1 repeat for a total of 20 min. The method used to determine an accurate productivity measurement to represent a pasture plot was with 4 representative samples. Each sample was tested 3 times for a total of 12 tests at 20 min each. The total test time used in this project was 4 h. Further analysis indicates that at this test site, this accuracy can be achieved with 3 representative samples, each sample was tested 3 times, for a total test time of 3 h using only 1 Neosystems II meter. However, the total test time is reduced to 1 h using 3 Neosystems II meters, as compared to 21 h for the standard oven.

A mechanical convection oven was used in the standard oven method at 220 °F (104 °C) with a bake time of 21 h. The aluminum pans were weighed cold and hot. These weights were used appropriately in the calculation of initial and final weights.

CHANGING THE FORAGE CONSTANT

The rising plate and capacitance probe devices are indirect type measurement devices; therefore these devices require a change of the forage constant in the productivity equation to allow for different pasture types and seasonal variations. The standard oven and Neosystems II meter do not require this change in forage constant because these devices take a direct measurement of the plant material.

The development of a forage constant for indirect measurement devices requires a productivity measurement by a direct device, (i.e., by the standard oven or Neosystems Oven Meter in order to determine a new forage constant).

The GrassMaster Pasture Meter Company has developed a software program using statistical analysis to develop this forage constant. The input values necessary to develop a new constant are obtained by supplying a direct measurement of productivity measurement obtained by use of the standard oven or Neosystems unit. The GrassMaster provides the optimum method to determine the appropriate forage constant.

The Effect of Minimal Stubble Height

Grazing practices, based on established agronomic principles, indicate that stocking rates on grazed forages be managed to allow for a minimum stubble height of 2 to 3 in (50.8 to 76.2 mm) in order to maintain a productive pasture. This minimum stubble ensures that the plant has enough energy reserves after grazing to support regrowth, allowing roots to become stronger and deeper, providing for a pasture with adequate forage, resistance to insect and disease damage, and drought and weed resistance. Erosion control and water quality are also improved. Stubble also includes residue and litter mass.

Sampling protocol for obtaining productivity measurements with the standard oven and Neosystems II meter is to collect the total residual biomass to bare mineral soil. This total residual biomass is weighed and used in the forage productivity calculation.

In contrast, rising plate and capacitance probes are not able to measure total residual biomass by design. The shaft of the rising plate has a 1.25-in- (31.75-mm-) diameter metal washer on the end, preventing the tip from penetrating the residual biomass. Capacitance probe shafts are 1 in- (25.4 mm-) diameter with a 0.25-in (6.4-mm) metal prong tip at the end. The tip is designed to prevent the shaft from direct contact with the ground. However, the residual biomass mat is thicker, typically 2 to 3 in (50.8 to 76.2 mm) in some pasture plots. The 1-in- (25.4-mm-) diameter shaft prevents the probe from penetrating the biomass mat beyond the 0.25-in (6.4-mm) tip for a complete measurement of the residual biomass.

Consequently, the rising plate and capacitance probe device measured values were expected to vary from the measured values for the standard oven method and the Neosystems II meter.

Results

Seven herbaceous measurement devices were used to collect data from the same pasture plot. The standard error and correlation between all devices and the standard oven were determined. The findings are indicated in tables 2 and 3. There is significant variability between the direct and indirect type measurement devices. This is anticipated due to a need to change the forage constant for all indirect devices and the effect of collecting on bare soil rather than minimum stubble height, as is the current practice in the direct measurement devices.

Table 2—Productivity measurement device data analysis.

			Plate Meter		Capacitance Probes		
Standard oven (lb DM/a)	Neosystem Oven Meter (lb DM/a)	Number of Samples Operator Average	Jenquip (lb DM/a)	Kencove (lb DM/a)	GrassMaster (lb DM/a)	Draminski (lb DM/a)	Alistair (lb DM/a)
3,964	3,920	20	1,507	1,637	1,562	1,129	1,536
~	~	40.	1,517	1,651	1,582	1,172	1,550
Standard	0.97	Standard error	62	59	74	61	62
Standard	0.94	Correlation	0.58	0.47	0.74	0.11	0.42

Standard error—Standard error is a measure of variability or dispersion of data compared to the standard oven method. The least variability is indicated in the Neosystems II meter at less than 1 percent, with all other devices indicating a high standard error.

Correlation coefficient—The correlation coefficient (r) is a measure of the degree that the measured data from two devices move together or in opposition. When $r = 0$, there is no correlation. When $r = 1.0$, there is perfect correlation. The higher the r , the greater the correlation. General practice indicates that r values be generally evaluated as follows:

$r = 0.00$ to 0.25 = doubtful correlation
 $r = 0.26$ to 0.50 = fair correlation
 $r = 0.51$ to 0.75 = good correlation
 $r = 0.76$ to 1.00 = superior correlation

The Neosystems II unit had a 0.94 correlation with the standard oven. This degree of positive correlation is considered superior. The GrassMaster had a 0.74 correlation and the Filip Folding Plate Pasture Meter had a 0.58 correlation, all considered good. However, forage constants for the GrassMaster and Filip Folding Plate Pasture Meter devices need to be developed for specific pasture plots and the issue of minimum stubble height needs to be addressed before these devices are used in the field for any application requiring less accuracy than currently provided by the standard oven or Neosystems II meter.

Precision denotes degree of repeatability in taking of the measurement. The range of percent differences is an indicator of precision. The data reduction results are presented in table 3.

Table 3—Data reduction.

	Folding Plate Pasture Meter	Farm Tracker	Pasture Meter	Pasture Gauge	GrassMaster	Neosystems II
Inaccuracy to standard oven	62.2	62.1	74.2	61.4	62.2	2.6
Inaccuracy all operators (%)						
Bias all operators (%)	-62.3	-62.1	-74.0	-61.3	-62.2	0.4
Range of percent differences compared to standard oven						
Minimum	-59.6	-55.7	-68.8	-53.4	-59.6	-2.4
Maximum	-65.5	-60.0	-80.2	-69.2	-64.1	3.8

Percent inaccuracy—Percent inaccuracy is the specification that could be met at the 95 percent confidence level. Assumptions are made that the data here was not a 1-in-20 or rarer anomaly and that the test measurements follow a normal distribution with the mean equal to the standard measurement. Accuracy denotes the absolute nearness to the true value. The smallest inaccuracy determined was with the Neosystems II meter at 2.6 percent; with the Pasture Gauge at 61 percent less than the oven measured value. All other devices had less accuracy.

Accuracy can be improved, up to a point, with some devices by the collection of more samples. Testing was conducted using sample sizes of 10, 20, 30, and 40, with each of two operators. These values were compared to the standard oven method. The greatest increase in accuracy with increased sampling was realized with rising plate technology by increasing the sample size to 40.

Percent bias—Percent bias indicates if the device is consistently over or under measures values. Bias can be used as a correction factor for measured values to obtain the true value. This correction factor is specific for each device and may vary across the range of measured values. The smallest bias standard is met by the Neosystems II meter at 0.4 percent, followed by the Pasture Gauge, the Farm Tracker, the Filip Folding Plate Pasture Meter, and the GrassMaster.

Percent difference—Percent differences were calculated between measured values for the standard oven and the test device. The smaller the range of percent differences the better. The smallest

Tracker, and Filip Folding Plate Pasture Meter.

Variability—There is significant variability between all sliding plate and capacitance probe devices as compared to the standard oven method. However there was minor variability between measured values for the Neosystems II unit and the standard oven.

Sources of variation contributing to these variable results include differences among operators, ambient atmospheric conditions, test procedures, test instruments, and differences over time. Pilot testing, conducted prior to testing, determines the best test method with decreased variability and increased repeatability. A detailed test plan was developed from pilot testing with concise specific instructions for each device, including standard test conditions, test procedures, and test conditions. Testing of all devices was conducted over a minimum time period to reduce the variability over time.

Variability was expected between the direct and indirect measurement devices. The Neosystems II and standard oven methods take a direct measurement. A direct measurement can be expected to have improved accuracy over an indirect method, such as capacitance probe and rising plate technology (see previous section). Findings of this study support this with the best accuracy and lowest standard error from Neosystems II, followed by capacitance probe and rising plate technologies.

Comparison Between Neosystems II Meter and Standard Oven

The Neosystems II portable oven has the highest degree of correlation, accuracy, and consistency of all devices when compared to the standard oven. The time to obtain a productivity measurement representing a pasture plot with best accuracy is with 3 representative samples for the lot, each sample was tested 3 times at 20 min each. It takes 1 h to determine productivity measurements if 3 Neosystems II meters are used or 3 h if 1 Neosystems II meter is used. This is an improvement over 20 to 24 h for the standard oven. The Neosystems II does not require the determination of the forage constant. In addition, this device is designed for use in various types of forage involved in inventory and monitoring activities. Consequently, it is recommended that consideration be given to designating the Neosystems II meter as the standard for obtaining production and utilization measurements.

Operator Comments

Comments were solicited from the operators participating in pilot and field testing. Their comments are recorded in table 4.

Table 4—Summary of the comments concerning the different devices tested.

Device	Pros	Cons
Jenquip Filip Folding Plate Pasture Meter	The Jenquip can measure small, dry grasses, unlike the capacitance probes. Folds up and is easy to carry. No electronics. This eliminates problems and dying batteries while in the field. Easy to use.	Cannot see results right away. Requires manual calculations. No reset button on bottom counter. No memory feature. The handle is uncomfortable to hold. A carrying case is not provided. The height of the holding rod is too short.
Kencove FarmTracker™	Kencove is the only device that has a carrying case with a strap. Dry cured grasses can be measured easily. Stores away easily. This plate meter gives readings right away. Easy to change out the 9 volt batteries in the field.	Electronic display is located in an odd position where you have to pick it up to read it and press the buttons. Requires manual calculations. No memory to store readings. Single readings are shown as a number with little information until calculations are completed. The handle is too small. The plate can be difficult to remove from shaft for transport.

Draminski Pasture Meter	The Draminski has an easy to read display. Nice foam grip on the handle. Menu driven. Gives stats like minimum and maximum field measurement and average field measurement. Easy to change out the 9 volt battery. Does not require manual calculations.	Doesn't work on dry cured grasses. For a single representative plot measurement the rod has to be cleaned several times in grasses with a lower moisture content. Hesitant on some readings. Cannot see single readings. Not much to the operator's manual.
Alistair PastureGauge	The Alistair PastureGauge® has an easy to read display, showing single readings and running average. Display options are shown on the screen. Decent operator's manual. Does not require manual calculations.	Meter falls off the shaft too easily. Doesn't work in dry cured grasses. Measuring shaft too small. No carrying case provided. Too many buttons makes it confusing what to press at times. Sometimes it pauses, (causing) confusion. The rod requires frequent cleaning. Inconvenient if battery runs low.
Tru-Test GrassMaster	The GrassMaster is easy to use. Easy to read display. Electronic case is attached strongly on measuring shaft. Comfortable to hold. You can see each single reading. Has the best operator's manual of all the capacitance probe devices. Does not require manual calculations.	Doesn't work on dry cured grasses. The GrassMaster needs a carrying case or carrying strap. Requires frequent cleaning of the probe. Battery life is too short. Inconvenient to charge after batteries die. Requires special handling to use battery charger. Cannot pause measuring to maneuver over or around bushes.
Neosystems II Meter	Neosystems II is easy to learn. Takes 4 to 20 min for measurement depending on forage type. Nice display with easy controls. Field portable if needed. Good operator's manual. Simple instructions. Stores readings in memory. Can download to a PC into Excel or typical data acquisition software. You can let it run and leave for a few minutes. Can repeat bakes easily. Baking times can be switched. Uses ac or 12 V car battery to run. Does not require manual calculations.	Like the standard oven method, requires a lot of preliminary work to go out, cut the grasses inside a frame, and collect in bags. The balance display needs to be at eye level. Carrier requires preheating so it takes longer to perform readings. Carrying case is extra. Scales have to be locked into place for transport.
Standard Oven Cut and Weigh	As the current standard, is a proven technology. Capital investment of equipment already made. Personnel already trained to this method. Accurate measurements.	Takes up to 21 h for results. Like the Neosystems II meter, it requires a lot of preliminary work to go out, cut the grasses inside a frame, and collect in bags. Overall labor intensive, increasing chance of human error. Room gets hot with oven going. Takes a long time to prepare and process samples. Additional cost for scales and calibration of equipment. Cannot download data to PC. Requires manual calculations.

Discussion

The Neosystems II meter temperature is set at 284 °F (140°C) across the plates. The temperature for the standard oven was set at 220 °F (104°C), 64 °F (18 °C) lower than the Neosystems II meter. This increase in oven temperature alone would typically increase the release of volatile oils from the plant material and adversely affect the accuracy of the measurement. The manufacturer of the Neosystems II meter states that this was taken into consideration in the design. A fine balance was developed between an increase in oven temperature, offset by a substantial decrease in time to bake (1 h versus 21 h), oven plate designed with ridges and holes for the rapid removal of moisture, vacuum pump, and oven plates compression. All focused on significantly decreasing bake time, without increasing the release of volatile oils from the plant material.

Differences in readings between operators are due to technique, such as using a greater force in positioning the rising plate meter or capacitance probe onto the ground. Also, all readings must start in open air and the device must be brought straight down (vertically). The capacitance probe shaft picks up debris and must be cleaned frequently. This must be recognized and performed by the operator.

Capacitance probe meters were having difficulty picking up readings in the plant material with low fuel moisture content, such as dry, cured grasses. Occasionally, the capacitance probe would indicate a reading and display a value of "500 kg DM/ha," in dry, not cured grass. This was determined to be a minimum reading for the given unit and did not reflect an accurate measurement. Capacitance probe measured values are directly proportional to plant moisture content.

measurements.

Conclusions

The findings are as follows:

1. The Neosystems II portable oven has the highest degree of correlation, accuracy, and consistency compared to the standard oven. Use of the Neosystems II requires more labor than the sliding plate or capacitance probe meters.
2. The Neosystems II meter has 94 percent superior correlation with the standard oven. The GrassMaster capacitance probe has a 74 percent correlation followed by the Jenquip Sliding Plate with 58 percent. The Kencove sliding plate and Alistair capacitance probe have fair correlation, and the Draminski has doubtful correlation with the standard oven method.
3. The type of device appropriate for use in a particular application will depend on the required accuracy for that application.
4. Rising Plate devices have a low correlation and accuracy when compared to the standard oven method. Capacitance probe correlation and accuracy varied.
5. The most accurate capacitance probe was the GrassMaster Capacitance Probe. The GrassMaster had a 74 percent correlation with the standard oven method and accuracy much lower than the Neosystems II or standard oven method. Forage constants must be developed for specific pasture plots and the issue of minimum stubble height needs to be addressed before field use of the GrassMaster capacitance probe for any application requiring less accuracy than currently provided by the standard oven or Neosystems II Meter.
6. The most accurate sliding plate was the Jenquip Sliding Plate. The Jenquip had a 58 percent correlation with the standard oven method and accuracy lower than the Neosystems II or standard oven method.
7. Consideration should be given to the Neosystems II meter as the standard for obtaining production and utilization measurements when replacing the oven method.
8. There is a need for a field users guide for sampling, collection, and processing forage production samples for use with the standard oven and/or Neosystems II oven meter. This evaluation should consider minimum stubble height.

Recommendations

Based on the findings of this study, the following is recommended:

1. Use the Neosystems II meter to obtain accurate forage production measurements in the determination of stocking rates and the effectiveness of certain land treatments such as burning, herbicide applications, and fertilization.
2. A field users guide for sampling, collection, and processing be developed regarding forage production samples for use with the standard oven or Neosystems II meter. This guide should address sampling considerations regarding minimum stubble height.
3. Forage constants need to be developed for specific pasture plots and the issue of minimum stubble height needs to be addressed, for the GrassMaster capacitance probe or Filip Folding Plate Pasture Meter, before field use for an application requiring less accuracy than currently provided by the standard oven or Neosystems II meter.

Herbaceous Measurement Devices Manufacturer Information

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Appendix A

Neosystems II Meter—Model Fmm-1 Short Instructions

Please see the operator's manual for specific detailed instructions.

Warnings

- DO NOT remove power from the meter until a run is completed or it is in the main menu.
- Ensure the RED lead is connected to the POSITIVE of the battery and the BLACK lead to the NEGATIVE.
- DO NOT move the meter unless the balance is locked. This is indicated by no display on the balance LCD. If there is a display showing, then reset the meter (press STOP) again until the display shows nothing. If this fails to occur after a number of tries, then remove the nylon base plate under the meter and screw the lock pulley clockwise until the lock is in place (i.e., it is fully up). DO NOT over tighten or else it will not be able to be unlocked by the lock motor. DO NOT ship the meter with the balance pan in position, remove it and put aside.
- DO put the meter on a level surface free of any vibration. Keep the meter clean and free of dirt.

Operation

1. Turn off the meter by use of the switch at rear of the unit.
2. Connect the red lead to the positive of the battery and the black lead to the negative.
3. Turn on and wait for approximately 10 seconds for the meter to initialize. When complete, the message "NORMAL OP'NS" will be displayed.
4. This is the start of the main menu. If you wish to have normal operations, press the "SELECT" button. The message "WAITING FOR TEMP" will be displayed until the set temperature of the bottom and top heating plates is reached.
5. Then the message "READY" will be displayed. Place the sample in the carrier holder and put in on the balance pan within the balance ring. Close the lid and press "START" to initiate a measurement.
6. The sample will be moved to the left and the balance will be tared. The sample will be placed over the balance and the wet sample weight taken.
7. The sample then moves to the left, over the bottom hot plate. This plate is then raised until the sample is firmly compressed between the two plates and the lift motor will be turned off. When the lift motor starts to operate, the vacuum pump will be turned on. This is to start heating up the vacuum pump.
8. After approximately 3 1/2 min, the bottom plate will be lowered to put the sample level with the balance. The vacuum pump will be turned off and the balance will be tared. The sample will be conveyed to the balance, weighed, the moisture percentage calculated, and the result displayed.
9. The operator is then given the choice of repeating the run, by pressing the "REPEAT" button. A repeat is necessary in the event of very wet samples.
10. If a new sample is to be run, press the "START" button. This process can be continued indefinitely.

11. After a reading is displayed, there is the option to store the result by pressing the "STORE" button. The memory can store 253 results. To return to the main menu, press the "STOP" button.

See the full manual for specific detailed features and other functions.

Sampling and Obtaining Consistent Results

At each point of the sampling (collection, measuring, and putting into the carrier) there is a potential source of errors. These errors may even be cumulative so care should be taken at each step.

1. Make sure that when collecting samples you collect enough to be representative of what you are trying to measure. Do not let anything contaminate the samples. To avoid this, wear gloves when collecting samples and do not let any moisture come into contact with the samples at any time. If not measuring the samples right away then bag each sample and ensure an airtight container is used. Keep the samples cool if they are not to be measured right away.

2. When preparing the sample, ensure that the full sample is homogeneous and uniform throughout. For instance, Chemise is very uniform and pieces as large as 1 to 2 in (25.4 to 50.8 mm) can be used. In the case of grasses, there can be great variability so care must be taken to cut the sample into small portions so that the sample to be measured is representative of what was collected. If you do not follow these steps, then you will find wide variations in the readings measured. This is particularly evident in high moisture samples.

3. Once having prepared the samples in step 2, mix the sample thoroughly using gloved hands. Next select a "bunch" from the sample and place it in the outer carrier holder. You should try and get a minimum of 7 g in the carrier. DO NOT select one leaf, blade, etc at a time. "Grab a handful" so that the sample is more representative. Spread the sample out evenly in the carrier and place the inner the carrier on top of it. Press down to ensure that the inner carrier does not protrude above the outer carrier. If this happens it may interfere with the weighing mechanism and lead to false results. Also, ensure that no sample protrudes above the outer carrier.

4. Place the carrier and sample on the balance pan by first making sure that the pan is clean and centrally placed. Close the lid and press "START." Allow the meter to measure the moisture percentage.

5. The outer carrier is made from nylon, which is hygroscopic and thus will vary in weight. The carrier needs to be dried out completely or alternatively the weight should be continuously entered into the meter (see CALIBRATE function). Calibrate the Neosystems meter only after preheating the oven carrier. Using old values of calibration can lead to significant errors. The time to drive off all the moisture in the nylon carrier will vary. However, 24 h in an oven at 221 °F (105 °C) should accomplish this. On existing meters a 10-min bake with the nylon carrier empty, carried out for a number of cycles would suffice. Further checks need to be done to determine the optimum preheat times of the nylon carrier.

6. The larger the sample size and the larger the sample pieces, the longer it takes to remove all the water; and the smaller the size, then less representative it is. If the sample is cut into small pieces, the drying time will be quicker and you will also be able to use more samples and be more representative. Sigma Delta suggests that you experiment to see what is optimal at each area of moisture percent. Each species will be different. Trial and error will show the size versus time considerations.

Data output

Data may be downloaded from the oven meter to the PC. This is achieved with Hyperterminal. In Windows 95, Hyperterminal is located in the accessories folder and in Millennium Edition it is located in accessories/communications.

The Hyperterminal program can be used to capture the data coming from the Neosystems II meter in ASCII, comma delimited data. From there the file can be imported into a spreadsheet program or data acquisition program, such as Labview.

Incorrect results—Results of 0.0 percent can arise if no sample is put in the sample holder and “START” is pressed.

Readings too low—This will occur if you have not prepared the sample. It could also occur if the sample moisture is very high. This may mean that a repeat reading is necessary. It could also result from some species where bound water is such that a longer time is necessary in the oven. Repeat samples will get over most of these problems. Another solution where the sample is uniform is to reduce sample size. Reducing sample size when the sample is not uniform will lead to variable results.

Readings too high—This could be due to incorrect balance readings or oils being driven off. High readings can be due to the inner carrier or sample protruding above the level of the outer carrier. The high readings may also show on the display as *D12.5%* for instance where the alphabetical character may be A, B, C, D, E, or F. This says that the readings are above 1,000 percent, which should never occur. This indicates that the initial wet weight is higher than it should be and is caused by an incorrect balance reading. If you encounter this continuously, leave the lid open so you can observe any interference to the weighing operation.

Error on results—This will be due to the dry weight being more than the wet weight, something that should never occur. The cause of this could be incorrect balance readings due to the sample holder not being free of the balance ring.