ABSTRACT

Title of Document:	ON-FARM DRY MATTER ANALYSIS FOR FEEDING PRECISION ON DAIRY FARMS
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Uncertainty in dairy ration content impacts feed efficiency, milk production, expenses, and environmental losses. When measuring silage by weight, unknown changes in dry matter (DM) may change the total mixed ration. The objective of this study was to measure variation in silage DM on selected farms and evaluate an electronic method of on-farm DM analysis. Of 31 Maryland farms surveyed, 63% reported DM analysis by an on-farm method, 83% by any method including laboratory measurement. Eight producers performed DM analysis daily for 21 days using a Farmex 1210 Electronic Silage Tester (on-farm) and they recorded precipitation; matching samples were analyzed for DM in a laboratory after oven drying ("standard" method, 55°C followed by 100°C) and by using a Farmex 1210 (laboratory). The standard deviation of mean silage DM varied from 0.72% to 3.33% DM, depending on farm. The electronic method compared poorly to standard DM analysis for most farms.

ON-FARM DRY MATTER ANALYSIS TO IMPROVE FEED DELIVERY PRECISION ON DAIRY FARMS

By

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Dedication

To all struggling graduate students.

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Chapter 1: Introduction

Dairy farm operations are under ever-increasing economic and political pressure to operate more efficiently. Precision feeding is a management strategy that is meant to address some economic and environmental concerns through animal nutrition. The premise of precision feeding is that the animals are fed to their physiological requirements for health and milk production without exceeding those requirements. Precision feeding attempts to minimize excess inputs from supplements and feed, consequently reducing nutrients lost to the environment as leaching, volatilization, and runoff. Excess nutrients that are not used by the animal will be excreted in feces and urine, increasing the potential for lost nutrients when the excreta are stored and recycled as fertilizer (**Figure 1**). Feeding to requirements reduces excess nutrients and prevents environmentally problematic nutrients, particularly nitrogen and phosphorus, from leaving the farm system.

Animal feeding and nutrition represent the largest ongoing expenditure of a dairy farm operation. Consider a typical farm that is milking 100 Holstein cows. Each cow may weigh 410 to 725 kg (900 to 1600 lb), with most of the cows weighing about 680 kg (1500 lb) on this farm. Sustaining the production of milk, which is rich in butterfat and protein, plus regular metabolism may require a dairy cow to eat the equivalent of 4 percent of her body weight in feed dry matter each day (Chase, 1993), depending on how much milk she is producing and other factors. By this rough estimate, the workers on this farm are handling about 6000 lb of feed dry matter per day.

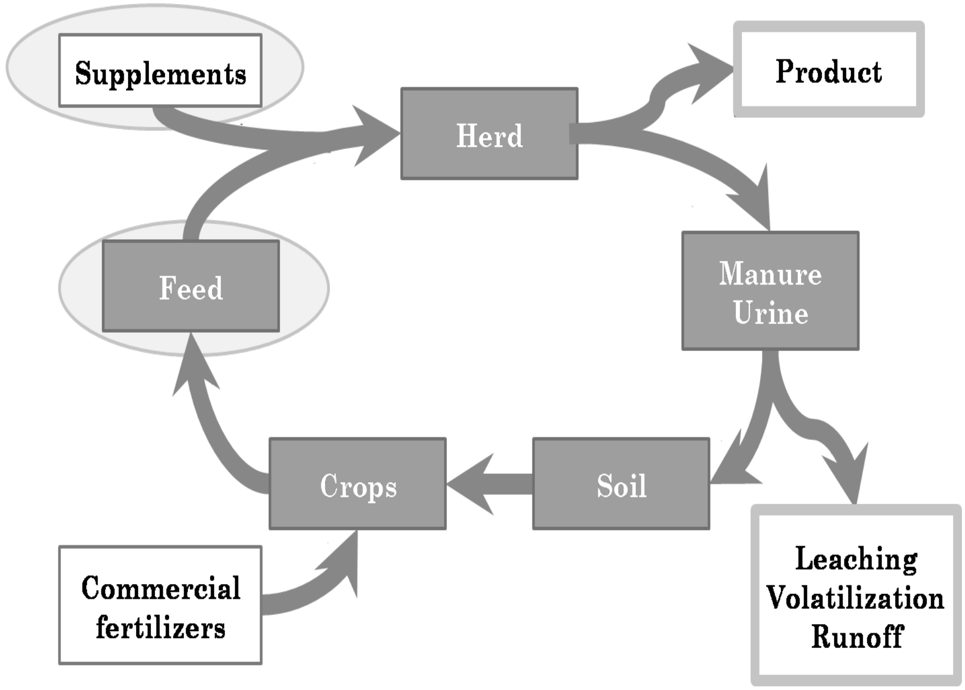

Figure 1. The animal farm nutrient system.

On most modern dairy farms, the animals are fed using a total mixed ration (TMR), which is meant to contain a uniform mix of all nutrients required by the animal. A dairy nutritionist or a knowledgeable farm worker will use a computer program to formulate the composition of the TMR based on the analyzed composition of available feed components and the physiological status of the herd. Feed components may include grains, by-product feeds, vitamins and minerals, as well as corn silage, alfalfa (legume) silage, grass silages, and other forages. For large herds where animals may be fed in groups, each group may receive a slightly different mixture of TMR components.

Ideally, the as-fed ration error (the difference between the fed ration and the formulation) will not be large enough to cause significant adverse changes in feed efficiency and consequently in milk production, feed expenses, or environmental losses. However, as-fed ration error can be difficult to control in farm environments, where feed storage conditions, turnover of ration components, normal feed variation, and nonuniform management practices can introduce unknown variation in feed composition and moisture content. In practice, the content of the TMR that is presented to the animals varies from the formulation followed to prepare the ration.

Some sources of this variation are the error associated with feed composition analysis (sampling error and laboratory error), variation within an analyzed feed component, the use of different feed components without reformulating the ration, and error associated with mixing and delivering the TMR. For example, perhaps a farm has secured a large shipment of whole cottonseed as a TMR component and sends a representative sample to a laboratory for compositional analysis. Information from the analysis, such as protein, fiber, and fat content, is then used to incorporate the component "cottonseed" into a TMR formulation, which a worker will use to prepare the TMR. The variation within the shipment of whole cottonseed and the error associated with the composition values provided by the laboratory are ignored for the purposes of formulation, but will result in variation in the as-fed TMR from the formulation. Furthermore, the feed composition may change over time during storage or, if the feed runs out before a new formulation is made, a different feed may be substituted in the TMR, resulting in further variation.

For farms that feed a TMR, silage is the largest component of the ration, and is thus a reasonable target for decreasing variation and increasing precision of feeding. Silage is forage that is preserved through anaerobic fermentation; forage is sealed in an anaerobic containment system (silo) with enough moisture to allow fermentation. Large silos can contain several months' worth of feed and each silo will be used until the feed is gone, meaning that the variability of a particular batch of silage may affect the ration for extended periods of time.

On farms where silage is measured by weight for inclusion in the TMR, changes in silage dry matter (DM) may significantly affect TMR nutrient content. For example, a formulation may specify 22 lb of silage DM for each animal (only DM intake counts because water is supplied *ad libitum*). The wet weight of silage with that was 35% DM would be about 63 lb, while that of silage that was 40% DM would be 55 lb because of the decreased weight of water (increased nutrient density). In a herd of 100, the difference in wet weight between these silages would be about 786 lb. Failure to account for this 5% difference in silage dry matter may result in overfeeding or underfeeding by as much as 786 lb of silage per day.

Because determination of DM is a relatively simple analytical procedure, on-farm determination of silage dry matter could be a practical and effective means of reducing ration variation to increase precision in feeding. Various recommendations have been made for on-farm DM analysis, including suggestions to perform analysis "once or twice weekly" (Mertens *et al*, 2004) and after rainfall or other precipitation

(Anonymous, 2011, Mertens *et al*, 2004). However, there is little evidence supporting such recommendations. In a search of literature, no references were found that elucidated the magnitude of silage dry matter variation on any timescale, how this variation affects ration consistency, or how silage varies under laboratory conditions versus field conditions. Only one reference was found that evaluated different technologies for on-farm DM analysis (Oetzel *et al*, 1993).

The question of the value of on-farm DM analysis is especially significant for smaller farms, which do not benefit from economies of scale that allow additional time and resources to be spent on activities that are not absolutely essential to farm survival. Census data suggest that, while the total number of farms has been decreasing for decades, smaller farms are more susceptible to dropping out of the dairy business than larger farms. Larger farms have tended to increase as a proportion of total dairy farm operations in the U.S (**Figure 2**); some of that increase is represented by smaller farms that have expanded the herd.

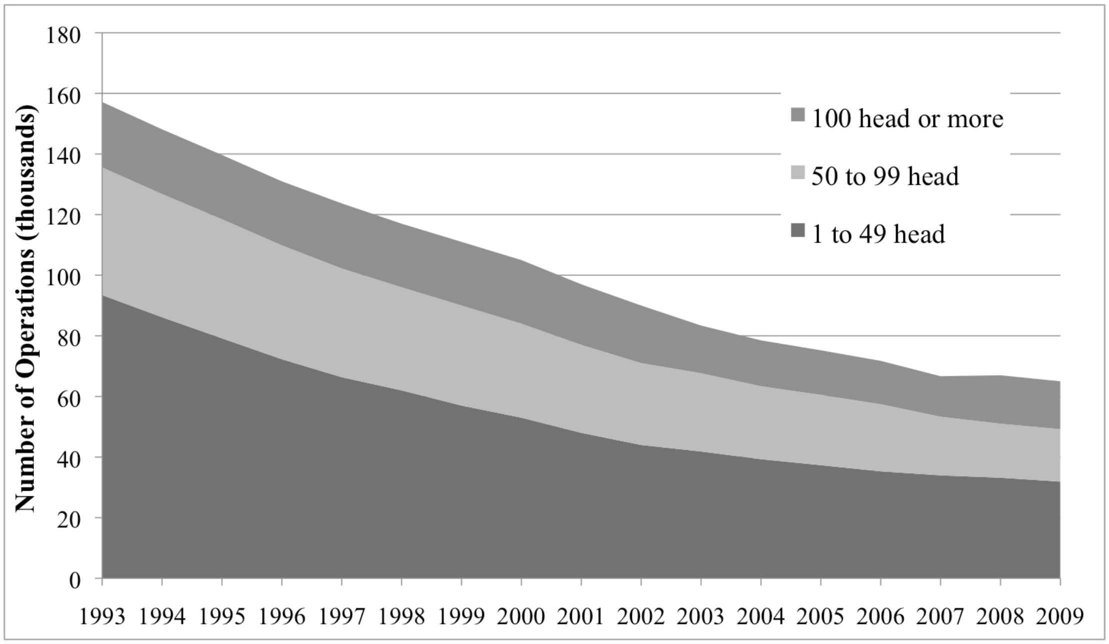

Figure 2. Stacked chart of US milk cow operations (U.S. Department of Agriculture, 2010). From bottom to top: farms with 1 to 49 head, farms with 50 to 99 head, farms with 100 head or more.

Several initial questions should be asked in a study of on-farm DM analysis for dairy farms. It would be useful to evaluate whether some farms already use on-farm DM analysis more than others, characterize the variation in silage DM values on various farms, and look at the potential effect of that variation on the nutrient content of the ration. How variable are DM values for silage as it is fed out of the silo from day to day, and are there differences in variability from farm to farm? In this study, data to answer such questions was captured through a survey of Maryland farms, followed by 21 days of on-farm DM data collection on eight of the surveyed farms.

Because there is little data regarding on-farm DM analysis methods, the use of a "quick" and inexpensive method of analysis DM on the farm was evaluated. The Farmex 1210 Portable Electronic Silage Tester (Farmex Inc, Streetsboro, OH), which can be purchased for approximately $200 and takes approximately 15 minutes to use for DM analysis, claims accuracy to within "2% (average) for silage under 50% moisture" and "3% (average) for silage over 50% moisture." For a DM measurement to be meaningful, the measurement must be accurate, and the variation in the measurement must be less than the variation in the silage on the farm using the method. In this study, the electronic method was compared to a standard method to evaluate accuracy, and the variation measured by the on-farm data collection was used to evaluate potential meaningfulness on real farms.

Chapter 2: Review of Literature

This review addresses literature pertaining to use of on-farm dry matter analysis methods and uncertainty in delivered nutrient content.

A. Models used in formulating dairy rations

Various mathematical models, most notably NRC (National Research Council, 1989, 2001), Cornell Net Carbohydrate and Protein System (Fox *et al*. 2004)), and St-Pierre (2007), have been proposed to create targeted feeding regimens for dairy cattle in various conditions and at various stages of lactation. Such models can greatly increase the efficiency of feeding, both in tons fed and money spent.

The NRC and Cornell models use a frequentist framework, which defines variables as unique values; these models have deterministic outputs in that they imply that solutions are exact, often targeted to the requirements of the average animal in a herd. Calculations for lead factors that adjust the target upward, particularly to the 83rd percentile (based on milk production) of animals in the herd, were recommended as an option to increase the applicability of these models (Stallings and McGilliard, 1984). Additionally, grouping of animals by age or production level has been used to manage problems arising from undesirable social behavior of larger cows (Grant and Albright, 2001), which enables creating a ration targeted to the needs of each group of animals.

The St-Pierre model uses a Bayesian framework, which attempts to account for probability distributions associated with the parameters that are used as inputs for the model. This kind of stochastic model allows multiple solutions by letting parameter values vary randomly according to their probability distributions, and would provide estimates of the uncertainty of predictions. St-Pierre has argued that assumptions underlying frequentist methods, especially constant physiological status of the animals and lack of uncertainty in nutrient analysis, are invalid (St-Pierre, 2007; St-Pierre and Cobanov, 2007; St-Pierre and Thraen, 1999). However, much of the data needed to calculate probability distributions for a stochastic model, such as the DM variability data in the present study, have not been collected.

When a ration is formulated, a dairy nutritionist will typically use software incorporating one of the frequentist animal nutrition models. As inputs for the model, the nutritionist will use estimates of the body condition of the herd, the production of the herd, and the composition of the feed components to be incorporated. A ration is typically reformulated either by an arbitrary fixed schedule or according to observed changes in feed components or production. However, because there are no established practical methods to distinguish meaningless background variation (noise), detection of meaningful changes in feed component analysis is left to the discretion of the dairy nutritionist or producer.

A model for determining the most economically efficient frequency of ration analysis and reformulation, based on quality control charts, has been examined by St. Pierre and Cobanov (2007), who concluded:

> A model with 16 input variables and 3 design parameters can be used to calculate the total quality cost per unit of time of any renewal reward process based on X-bar quality charts. When applied to the control of forage variation, the model reduces to 13 input variables and 3 design parameters. The current practice of taking one forage sample per month and intervening when the results differ by more than 2 SD from the expected value appears to be close to the optimal sampling design in small herds (50 cows). However, it appears to be incorrect in large herds, in which the optimal design requires taking 2 samples every 4 d and intervening if the average of the 2 samples differ by more than 1.2 SD from expectation. This optimal design reduces daily costs by about $250.

Failure to detect meaningful changes in feed composition is associated with reduced feed efficiency, and unnecessary reformulation of the ration is associated with increased labor and analysis costs (Kohn, 2008). In an attempt to prevent production losses due to possible underfeeding of nutrients, nutritionists may overestimate the requirements of the animals when formulating a ration (Kohn, 2008). Ration components change over time, and rations may not be reformulated to reflect these changes. However, there is little information to indicate the actual magnitude of change that should be expected for specific components or the amount of change to be expected over time.

According to St-Pierre and Cobanov (2007), there are essentially three types of "change" (**Table 1**) in composition; these components of variance must be distinguished in order to differentiate background noise from significant changes that can be managed and make a difference to production. For each feed, the determination of what is artificial variation and what is true variation could be estimated using multiple data points for each measurement to show background variation.

The contribution of each separate feed component to the variance of the ration is a function of the square of its inclusion rate (St-Pierre, 2007). Thus, the effect of small differences may become significant, depending on both the inclusion rate and the magnitude of true variation associated with that feed component.

Table 1. Components of variance in feed analysis.

Source	**Class**	**Effect**
Laboratory (human error)	Artifact	Animals do not experience a change.
Analytic (procedural error)	Artifact	Animals do not experience a change.
Chemical (difference in sample)	True variation	Animals are affected; change in nutrients.

Adapted from St-Pierre, 2007.

Further refinement could be made by establishing, for each feed component, the magnitude of true variation that will significantly affect production. By being able to differentiate true variation from background noise, and being able to understand what magnitude of true variation is nutritionally meaningful, an observer could more objectively and reliably interpret when to reformulate a ration.

B. Management practices related to variability in forage content

Literature related to forage or silage management deals primarily with optimizing and preserving nutrient quality and digestibility; little published work pertaining to management of forage variability in nutrient content was found. No peer-reviewed articles were found that elucidated the magnitude of silage dry matter variation on any timescale, how this variation affects ration consistency, or how silage varies under experimental conditions versus field conditions. However, some research in silage management is relevant to variability in forage content.

Silage is forage that is preserved through anaerobic fermentation. Forage is sealed in an airtight container (silo) with enough moisture to allow fermentation. The forage then goes through stages of ensiling: 1. an aerobic phase, in which aerobic microbes produce heat and use oxygen that exists between particles of forage; 2. an anaerobic fermentation phase, in which anaerobic microbes ferment available substrate and pH drops to around four; and 3. a stable low-pH phase assumed to last until feed-out. An underlying precept of creating high quality silage is limitation of the aerobic phase, which can deplete substrate needed for anaerobic fermentation. Some recommendations for limiting this phase are proper initial moisture content, which depends partly on the type of forage being ensiled, and dense packing of the silo to limit initial oxygen availability. It stands to reason that evenly dense packing of the silo could improve consistency of fermentation and therefore consistency of silage.

As described by Tyler and Ensminger (2006), various types of silos are used to create silage:

- conventional upright (tower) silos,
- gas-tight (oxygen-limiting) silos,
- pit silos (similar to a sunken upright silo),
- horizontal concrete (trench or bunker) silos, and
- temporary silos such as enclosed stacks, open stacks, modified trench-stacks, plastic or polyethylene bags, and round bale bagged or wrapped silage.

In terms of consistency of silage produced, each kind of silo may have a different profile. For example, upright silos are more densely packed at the bottom, and moisture may tend to drain from the top, resulting in greater seepage losses for taller structures (Tyler and Ensminger, 2006). Horizontal bunker silos may be more evenly dense from bottom to top, but may be more susceptible to groundwater damage in high water table areas. Muck and Holmes (2000) undertook a study of recommended, but under-researched, management practices that seek to increase the silage density of 168 Wisconsin bunker silos that were packed with tractors. Density, in DM weight per unit volume, was measured in 5-cm by 30-cm cores taken at four places across the silage face, mathematically adjusted for distance below the top of the silage face, and correlated with various recorded management practices (**Table 2**).

Some practices showing a positive correlation with density were weight of packing tractors, smaller initial forage layer thickness, tractor tire condition, and forage particle size. The type of silage (corn or alfalfa) was not found to have a strong relationship with packing density. Alfalfa silage was found to have a higher DM content (42 ± 9.5%) than corn silage (34 ± 4.8%). The wet physical density of packed corn silage was found to be higher than that of packed alfalfa silage because of the lower DM content of corn silage.

Some management practices have also been evaluated in nutrient management research. In a mail survey of 2,500 farms in the mid-Atlantic region of the United States (New York, Pennsylvania, Delaware, Maryland, Virginia), Dou *et al* (2003) found a positive correlation between “no. of lactating cows” (numbering 50 to 1000) and probability of reporting the use of professional ration formulation and regular forage analysis. In a mail survey and milk data analysis of 472 dairies in the Chesapeake Bay watershed (including Delaware, Maryland, Pennsylvania, Virginia, and West Virginia), Jonker *et al* (2002) found positive relationships between farm nitrogen utilization efficiency and reported use of bovine somatotropin (bST), use of photoperiod techniques, and membership in a Dairy Herd Improvement Association.

Table 2. Pearson correlation of adjusted dry matter density in bunker silos to management practices during ensiling (Muck and Holmes, 2000).

Factor	Correlation Coefficient
Initial layer thickness	–0.279*
Average packing tractor weight	0.262*
Average wheel load	0.224*
Dry matter content	0.209*
Total weight of packing tractors	0.200*
Tire condition (1=new, 3=bald)	0.195*
Average particle size	0.194*
Packing time (min/t as-fed)	0.162*
Speed of packing (1 ≥8 km/h; 4 ≤1.6 km/h)	0.147
Number of packing tractors	0.146
Wheels per packing tractor	0.126
Slip during packing (1=none, 3=frequently)	0.101
Tire pressure	0.098
Crop (1 = corn; 2 = alfalfa)	0.086
Packing time (min/t DM)	0.078
Front wheel drive (front wheel drive, assist; rear wheel drive)	0.075
Packing method (horizontal, progressive wedge, distribute)	–0.068
Delivery wagon or truck drives over pile (1 = yes)	0.059

* Significant correlations ($P < 0.05$).

Adapted from Muck and Holmes, 2000.

C. Dry matter analysis methods

The National Forage Testing Association has published recommended procedures for forage dry matter determination (Undersander, Mertens, and Thiex, 1993) including:

- Oven drying for 2 hours at 135°C, followed by hot weighing,
- Oven drying at 100°C for 24 hours or 105°C for 16 hours, followed by hot weighing,
- Oven drying at 55°C for 16 to 24 hours, grinding of sample, and drying at 100°C followed by hot weighing,
- Microwave drying to constant weight,
- Near infrared reflectance spectroscopy (NIRS), and
- Distillation with toluene (recommended for fermented forage samples such as silage).

The oven methods involve weighing the sample before and after drying to determine moisture content. The higher the temperature, the greater the risk of loss in DM by evaporation of volatile chemicals, as well as loss of usefulness of the sample for further compositional analyses. When samples are heated, it is inevitable that “dry matter” composed of nutritionally important volatile chemicals such as acetic acid, propionic acid, butyric acid, and lactic acid will be lost with water evaporation, especially for fermented feeds that have lower pH and more volatile chemicals (Petit *et al*, 1997; Porter and Murray, 2001). Coefficients are sometimes used to adjust the results of oven methods (Haigh, 1979; Petit et al, 1997). Although oven drying can be completed in 2 hours, higher heat can increase loss of DM and loss of sample integrity, thus the lower temperature options for oven drying may be used, though they can take up to 3 days to complete.

The microwave method also works by heating the sample. The method involves weighing the sample, heating for 3 minutes, mixing the sample up, and heating again for 3 minutes, and repeated weighing and heating, 30 seconds or 1 minute at a time, until a relatively constant weight is achieved (Oetzel *et al*, 1993; Undersander, Mertens, and Thiex, 1993). While in theory it is possible for this method to take less than 15 minutes to complete, without excessive care, low heat settings, and short heating periods, it is easy to burn the sample (Oetzel *et al*, 1993). Burning or charring the sample causes weight loss other than moisture; if the sample is burned, the entire procedure must be repeated with a new sample.

In NIRS, special instrumentation is used to measure reflected infrared light from the sample and the results are electronically compared to results of similar samples of known moisture content (calibration samples). Equations selected based on calibration statistics are used to calculate the dry matter content of the sample. Assuming calibration is already completed, NIRS is the quickest of all the methods, and can be done in minutes, with very little manipulation of the sample. Chemical methods such as distillation with toluene, gas chromatography, and Karl Fisher titration are used to analyze samples for calibration of NIRS and result validation (Windham *et al*, 1987).

For distillation with toluene, the sample is weighed and then boiled in toluene while water is distilled off and trapped under a layer of toluene in a graduated receiving container; the water fraction's volume is then measured to determine the total moisture content of the sample. Developed in 1960, this method gained wide use for fermented feeds because fewer volatile chemicals are lost compared to the oven; one study reported a 14.6% increase in DM compared to a 100°C oven (Brahmakshatriya and Donker, 1971). Haigh (1979), in a paper developing a correction coefficient for 100°C oven values, reported that for corn silage samples toluene distillation gave values from 3.5% to 18.9% higher than drying by 100°C oven. However, toluene distillation is a procedure that requires 1.5 to 8 hours to complete, depending on the sample. Additionally, toluene distillation may overestimate water when compared to Karl Fisher titration and gas chromatography methods; when there are large amounts of ethanol, ammonia, and volatile fatty acids in the sample, these may end up in the distillate and increase the apparent water fraction (Petit *et al*, 1997).

Karl Fischer distillation and gas chromatography are both water-specific methods (Petit *et al*, 1997), which largely avoid the problem of other volatile chemicals being mixed in with water. They are also relatively quick methods, requiring less than half an hour. The specificity of Karl Fischer titration relies on the oxidation of sulphur dioxide by iodine in the presence of water, using a titration cell containing an electrode. The gas chromatography method uses anhydrous alcohol to extract the water from the sample, then separation of the water fraction with a thermal conductivity detector (Petit *et al*, 1997). Gas chromatography is quick and the most accurate method available, but requires very expensive equipment. Karl Fischer titration is also very quick, but is also relatively inexpensive.

Forage analysis laboratories typically determine dry matter by either commercial drying ovens or NIRS. A laboratory offers a controlled environment, trained operators, and freedom to follow specific protocols. In the field, as opposed to in the laboratory, there is considerable variation in temperature and ambient moisture over the course of each day, exact procedures may not be followed, and sampling may not be ideal. The major concerns when performing dry matter analyses in the field are speed, reliability, and sturdiness for the dairy farm environment. Only one peer-reviewed article was found that addressed technologies for on-farm dry matter analysis. Oetzel *et al* (1993) compared determination of feed dry matter by commercial drying oven (48 hours at 100°C) to three methods of on-farm forage dry matter analysis: Koster Moisture Tester (forced air drying device), 1210 Silage Tester (electronic DM analysis device), and microwave oven.

Oetzel *et al* (1993) found all four methods to be repeatable within themselves, with coefficients of variation of 1.3, 1.4, 2.0, and 2.1% for the microwave, 100°C oven, Koster, and electronic methods, respectively. Relative to the mean DM for the oven method (34.2% for corn silage, 45.3% for alfalfa silage), DM was overestimated by both the Koster method (37.4% for corn silage, 47.9% for alfalfa silage) and the microwave method (36.0% for corn silage, 48.2% for alfalfa silage). The electronic method underestimated corn silage (27.5%) but overestimated alfalfa silage (48.5%). The authors concluded that the microwave method was the most accurate relative to the drying oven, but required the most operator skill and time; the electronic method required the least skill and time, but may have inaccuracies in some of the conversion tables used to determine DM from capacitance.

In the Koster and microwave methods, the operator weighs a sample and then dries the sample repeatedly until two subsequent dry weights are equal (Undersander, Mertens, and Thiex, 1993; Koster Moisture Tester, Inc, 2011). The 1210 Silage Tester sends a current through the sample and provides a reading of the capacitance of the sample, which is assumed to be water content. The 1210 Silage Tester method involves measuring the temperature of the sample with an analog thermometer, using a screw-down knob to compress the sample in the device, reading the capacitance, and using a chart with temperature adjustments to convert the measurements into an estimate of DM content (Farmex, Inc, 2008).

Various recommendations have been made for the use of on-farm DM analysis. Mertens *et al* (2004) recommended analysis "once or twice weekly." Various sources recommend the use of on-farm DM analysis after rainfall or other precipitation (Anonymous, 2011, Mertens *et al*, 2004). Several others simply recommend performing DM analysis routinely with the use of the microwave method or commercial DM analysis equipment such as the Koster Moisture Tester (Bernard, 2010; Gay, 2009).

Table 3. Major advantages and disadvantages DM analysis technologies for on-farm use.

Method	Advantages for farm use	Disadvantages for farm use
Microwave	Accuracy, relatively short time	Needs operator skill, attention
Koster [1]	Ease, relatively short drying time	None
Electronic [2]	Ease, portability, speed	Relies on tables made based on unknown calibration
Oven (home)	Reliability	Long drying time, inconvenient
Forced air oven	Reliability	Long drying time, specialized equipment
NIRS	Portable units available	Specialized equipment, expensive
Chemical analyses	None	Needs operator training, specialized equipment, may use hazardous substances

[1]Koster Moisture Tester, Koster Moisture Tester Inc, Brunswick, OH.

[2]Farmex 1210 Silage Tester, Farmex Inc, Streetsboro, OH.

It is generally acknowledged that DM analyses take up valuable time, and recommendations have been made to circumvent allocating too much time to follow the recommendation for routine analysis. A common recommendation is to use a “squeeze test,” in which one squeezes a handful of forage to estimate moisture content based on whether any liquid comes out and how well the “ball” of forage holds together in the open palm of the hand (Chambliss, 2007; Tyler and Ensminger, 2006). Other recommendations include weighing a set volume of wet silage (*e.g.* 1 liter) on a regular basis to determine if a change has occurred (Anonymous, 2011); Mertens *et al* (2004) recommended using a food dehydrator, which would allow the sample to be safely left alone for several hours while drying.

Chapter 3: Methods

A. Overview

The research methodologies include a survey, on-farm DM and forage sample collection by Maryland dairy producers, and analysis of ration data collected from Maryland farms. Maryland farms were surveyed to examine relationships between current DM analysis implementation and milking herd size. Eight of the surveyed farms were asked to perform on-farm DM analysis for 21 days using a Farmex 1210 Electronic Silage Tester (electronic method; Farmex Inc, Streetsboro, OH) and provide corresponding forage samples for comparison to laboratory results.

Survey, farm, and laboratory data were graphed and visually inspected. Outliers and trends were noted for further inspection at the end of other analyses. JMP 4 Software (SAS Institute, Cary, NC) was used to conduct statistical analysis. In the analysis of ration data, ration formulation values were compared to ration analysis values, and the differences described.

B. Survey of on-farm dry matter practices in Maryland

A limited in-person survey of on-farm dry matter practices in Maryland was conducted. One operator from each farm was interviewed in-person using an interview form. Interviewees were found via unannounced farm visits and in-person meetings at public dairy-related events. A total of 31 dairy producers were interviewed on dairy farms in four Maryland counties (Washington County, Frederick County, Carroll County), at the 2008 Montgomery County Fair, or at the 2008 Maryland State Fair.

About two-thirds of the 31 farms surveyed were found through unannounced farm visits. Visited farms were randomly selected within the surveyed counties of Washington County, Frederick County, and Carroll County, in which there is a geographical concentration of dairy farms. Farm addresses were obtained from a list provided by the Maryland Dairy Industry Association for university extension work. Of the 35 farms visited, approximately 30% were not surveyed because no farm operators were available to interview. The remaining one-third of surveyed farms were found and interviewed at the Montgomery County Fair and at the Maryland State Fair; no farm operators approached at these events refused to be interviewed for the survey.

The survey served two functions: 1. a way to observe possible relationships between on-farm dry matter determination and other management parameters, and 2. a mechanism of finding dairy producers to participate in on-farm data collection.

The query objectives were as follows:

1. Frequency of forage DM analysis

2. Method of DM analysis (*e.g.,* microwave, Koster dryer, oven, electronic, laboratory)
3. Types of forages routinely fed
4. Feed delivery methods (*e.g.,* TMR, complete feed, pasture, top dressing)
5. Number of cows in the milking herd milk production
6. Approximate rolling herd average
7. Milk cooperative membership
8. Willingness to perform on-farm DM for 21 days if provided an electronic DM analysis device

The survey collected information on the current implementation of DM on 31 Maryland dairy operations, and the relationships of "number of cows" to implementation of DM analysis was assessed by Spearman correlation. The survey focused on the frequency of dry matter determination, methods of dry matter determination, types of forages fed, and the possibility of further collaboration in the study of on-farm dry matter. All information identifying each farm or producer remained confidential according to the will of the participants.

C. Silage samples from Maryland farms

Eight Maryland producers were asked to perform on-farm DM using a Farmex 1210 Electronic Silage Tester (Farmex Inc, Streetsboro, OH). These producers, based on survey responses, were interested in participating in an on-farm trial, fed a TMR, and used silage. The Farmex device was provided permanently to the producer as an incentive to participate. This electronic device has previously been evaluated against other methods (Oetzel 1993). Training and detailed instructions on the use of the electronic DM analysis device were provided. Pre-labeled sample bags were provided and work such as calculations were minimized to improve compliance.

For up to 21 days, each producer performed daily DM analysis using the electronic device, recorded observations on rain events, and recorded ration changes related to the daily DM analysis. Daily silage samples corresponding to each daily DM analysis were retained frozen or refrigerated in airtight, re-sealable bags, then transported to the lab, and remained frozen until they were dried and ground. Further laboratory analysis of samples for DM by oven and electronic DM device, neutral detergent fiber, and ash were then performed. Information on prevailing weather conditions were obtained from local weather stations operated by one of the following: the Maryland Department of Transportation, an airport, a city, or a hobbyist participating in a quality control program.

I. C.1. Sample collection and on-farm dry matter determination

Producers were given training on how to use the Farmex 1210 Electronic Silage Tester and were asked to follow a simple protocol for sample collection and data recording. For each day of up to 21 days, a sample of silage was collected and immediately analyzed for moisture content using the electronic device (hereafter referred to as “on-farm DM”). Analysis results were recorded on a data chart, along with observations about rain and whether DM analysis results influenced amount of silage used in the producer’s subsequent rations. The producers were asked to keep the samples in cold storage until they were moved to the laboratory freezer. Producers chose the day to start DM data and sample collection, and were asked to time the start day so that feed bunkers or bags would not be switched out during collection.

I. C.2. Laboratory sample processing

Samples were kept refrigerated or frozen on farms until they were picked up. Samples were picked up within one to two weeks of initial collection, were kept cold, and were kept frozen until dry matter analyses were performed.

Samples were weighed, dried in a forced-air oven at 55 C for at least 48 hours, weighed back cold to determine partial oven DM, ground using a Wiley Mill (1-mm screen; Arthur H. Thomas, Philadelphia, PA), and stored in sealed containers at room temperature for further analysis.

Total dry matter was determined by the two-step oven method (Undersander, Mertens, and Thiex, 1993). Partial DM was determined as described above. To determine Laboratory DM, 0.5g of ground sample were dried in ceramic crucibles at 100 C for 24 hours and weighed back hot. Total DM was determined by multiplying Partial DM by decimal percent Laboratory DM.

Each daily silage sample was analyzed using the Farmex 1210 device in the laboratory, in duplicate representative samples (hereafter referred to as "in-lab DM"). Performance this task was limited to one operator to reduce the contribution of operator bias between the samples.

NDF was determined by the Van Soest method (Van Soest and Wine, 1967) on each sample in duplicate. The samples were analyzed for ash using a muffle furnace at 500°C.

D. Ration evaluation: comparing rations with formulations

Data from a previous joint study with Dou *et al* (2003) were used to examine differences between offered Rations and Formulations from 2002-2005. During the study, ration information and TMR samples were collected every 3 months. Records from the 30 Maryland farms whose rations were collected and analyzed were mined for TMR formulations with corresponding TMR laboratory analysis (Cumberland Valley Analytical Services, Hagerstown, MD). For the 16 farms with appropriate records, the percentages of DM, NDF, CP, and Ca:P ratio predicted by formulated rations were compared to the corresponding laboratory measurements in TMR. The differences between formulation and measured ration (as-fed ration error) were summarized.

Chapter 4: Results

Survey of on-farm dry matter practices in Maryland

Of the 31 farms surveyed, most used TMR and most analyzed forage DM either on-farm or off-farm, sending samples to a laboratory through a dairy nutritionist. **Table 4** shows a summary of reported feeding practices and DM analysis practices.

Table 4. Dry matter analysis and feeding practices of 31 dairy farms.

Characteristic	**% "Yes"**	**Confidence interval** [1]
Analyze DM more than once per year (on- or off-farm)	84	13
Analyze On-Farm DM	39	17
Use Total Mixed Ration	71	16
Feeds used:		
Pasture	29	16
Corn silage	90	11
Alfalfa silage	39	17
Haylage	16	13
Small grain silage	10	11
Alfalfa hay	55	18
Grass hay	58	17
Balage	26	15
Sorghum	6	8
Other forage	35	17

[1] 95% Confidence interval for 31 farms.

Most (61%) of surveyed farms did not analyze forage DM themselves on-farm. As seen in **Figure 3**, of the 39% of surveyed farms who analyzed on-farm forage DM, none used any available electronic method. Those who analyzed DM used either a microwave oven or a Koster Moisture Tester, which is a forced-air drying device sold for the express purpose of forage DM analysis.

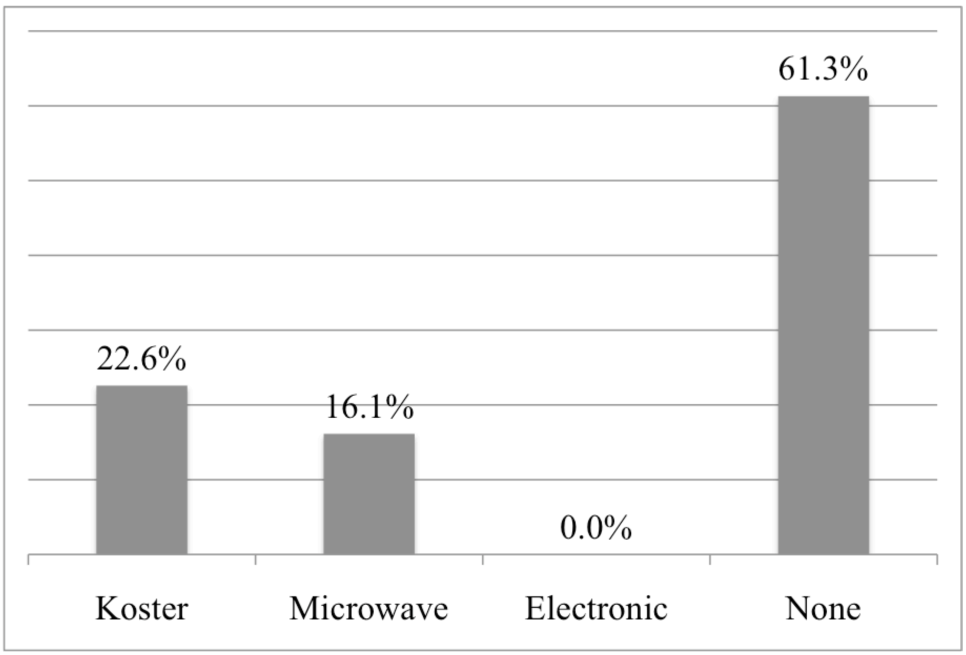

Figure 3. Methods of on-farm DM analysis used on 31 surveyed farms. Koster Moisture Tester, Koster Moisture Tester Inc, Brunswick, OH.

The reported mean rolling herd average (RHA) of milk production was 22,100 lb, and reported RHA ranged from 7,000 to 31,000 lb. Except for one farm, which reported keeping milk for cheese-making, each farm sent milk to one of five different cooperatives. The farms that did analyze DM on-farm had an average milking herd size of 146 cows, which was significantly larger (Welch's t-test for means with unequal variances, p=0.0423) than the average herd size, 76 cows, of those that did not perform on-farm DM analysis.

A test using Spearman's ranked correlation coefficient indicated that there was a positive correlation (p=0.0010) between milking herd size and frequency of DM analysis (on-farm or off-farm). The data is shown in **Figure 4**.

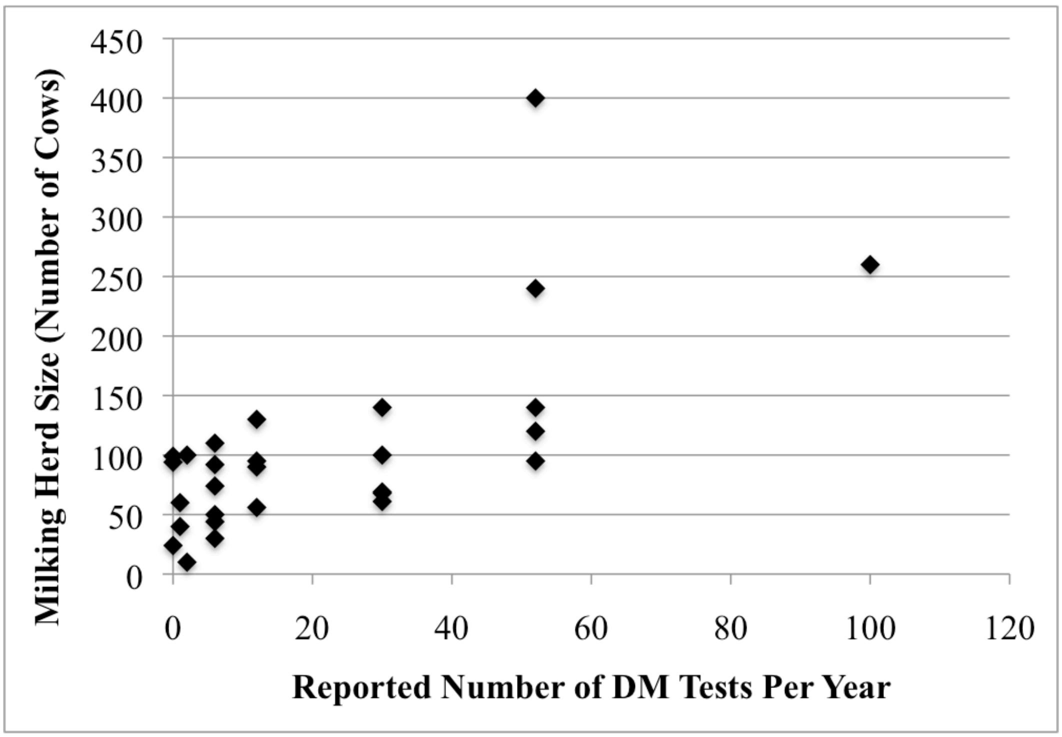

Figure 4. Frequency of DM analysis vs. milking herd size.

A. On-Farm DM Data Collection

Eight dairy producers participated in on-farm DM data collection; the DM analysis practices and dairy size information of each are shown in **Table 5**. All producers analyzed forage from bunker silos except for Farm C, which used a silage bag, and Farm F, which used balage (ensiling using bales of hay in airtight containment). All participants reported analyzing forage DM at least every two months, either off-farm or on-farm, but none had used an electronic DM device.

Table 5. Reported DM analysis practices and herd information for on-farm DM study participants.

Farm	DM analysis methods	DM analysis frequency	Milking herd (number cows)	Reported RHA (kg)
A	Off-farm analysis only	monthly	95	10,000
B	Koster & Off-farm analysis	weekly	95	11,000
C	Microwave, Nutritionist	monthly	90	500
D	Koster & Off-farm analysis	more than once per week	260	11,000
E	Off-farm analysis only	monthly	90	11,000
F	Microwave	weekly	240	9,000
G	Microwave	weekly	400	11,000
H	Koster	every two months	75	10,500

Sampling dates and silage types for each farm are shown in **Table 6**. All farms sampled at least 19 to 21 days except for Farm C, which only sampled on 13 days and stopped collection at day 18 upon emptying the silage bag that was being used during the trial.

Table 6. On-farm DM sampling dates and number of days sampled.

Farm	Silage type	Sampling start	Sampling end	Days sampled
A	Corn	15-Sep-2008	5-Oct-2008	21
B	Corn	15-Sep-2008	5-Oct-2008	19
C	Corn	16-Sep-2008	6-Oct-2008	13
D	Corn	21-Sep-2008	11-Oct-2008	21
E	Corn	22-Sep-2008	12-Oct-2008	20
F	Alfalfa	6-Oct-2008	26-Oct-2008	21
G	Corn and Alfalfa	15-Oct-2008	4-Nov-2008	19
H	Corn	17-Oct-2008	6-Nov-2008	21

The total percentage of DM depends on water content alone, while NDF may be independent of water content. The absence of a relationship between NDF and DM may indicate that changes in DM may be influenced by other factors than inherent properties in the silage. **Table 7** shows the mean and SD of DM and NDF during the trial for each farm.

Table 7. Mean and SD of DM (oven method) and NDF for each farm and silage type.

		DM %		NDF DM%	
Farm	**Silage Type**	**Mean**	**SD**	**Mean**	**SD**
A	Corn	37.30	0.72	40.19	1.58
B	Corn	33.13	3.00	37.24	2.09
C	Corn	33.38	2.90	43.60	3.88
D	Corn	31.96	2.02	39.24	3.02
E	Corn	36.57	2.48	40.94	1.43
F	Alfalfa	32.56	3.33	39.40	1.06
G	Alfalfa	35.82	3.20	38.89	1.06
G	Corn	35.19	1.55	33.61	1.46
H	Corn	29.72	1.83	42.11	2.33

Each farm showed a unique pattern in DM (standard method) and NDF over the course of 21 days (**Figure 5**). NDF values as a percentage of DM were regressed against standard DM values determined by the standard method. Over all farms and silage types, NDF decreased as DM increased ($p<0.001$). The overall significance of this relationship may have been disproportionally leveraged by Farm H ($p<0.0001$) Farm D ($p<0.0001$). Farm F showed a positive relationship between NDF and DM ($p= 0.0370$). No relationship (Spearman correlation) was found between the variability of the NDF and the variability of the DM values across farms and silage types.

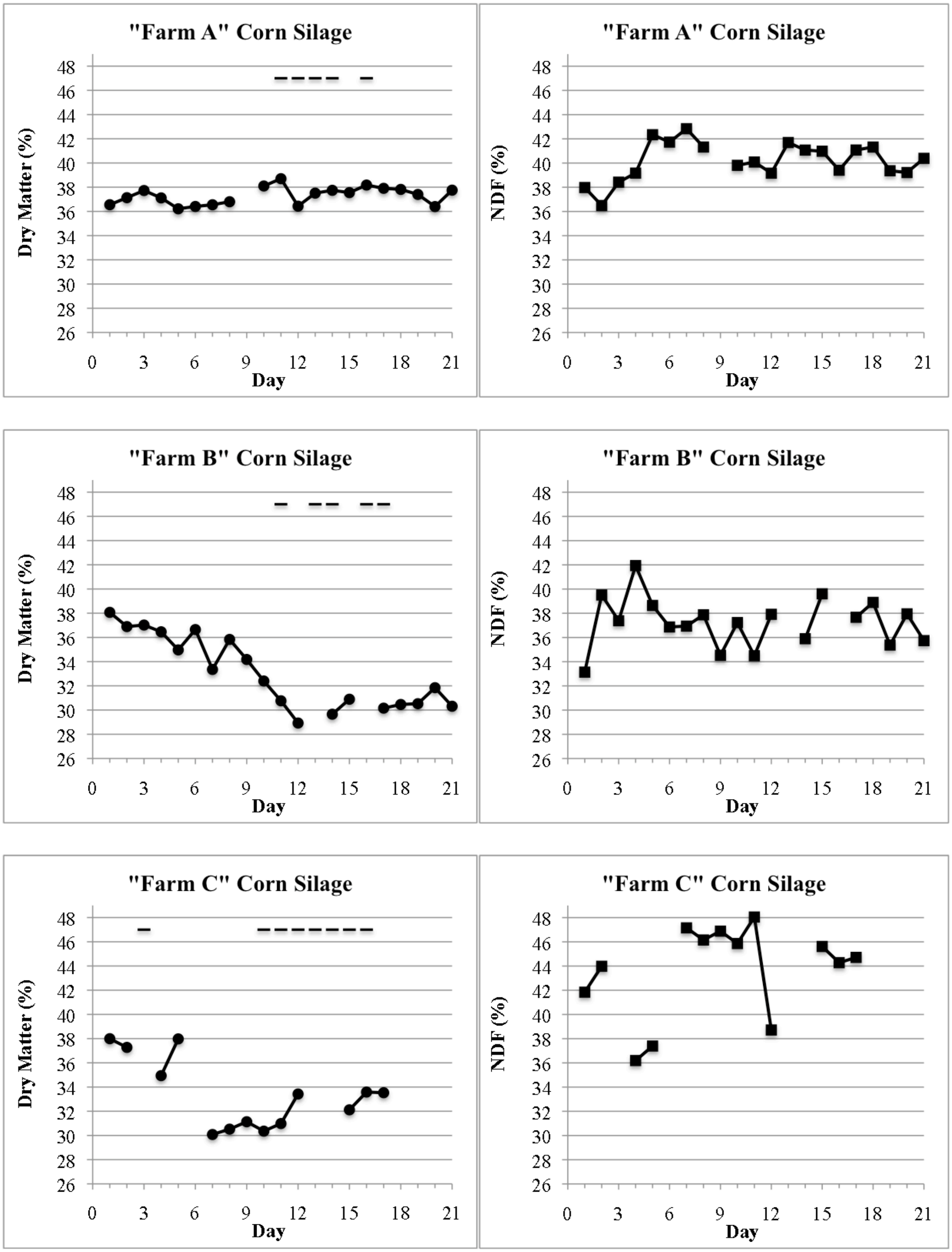

Figure 5 (Part 1). Dry matter (oven method) and NDF for each farm over 21 days. Dash marks indicated days on which measurable rain occurred.

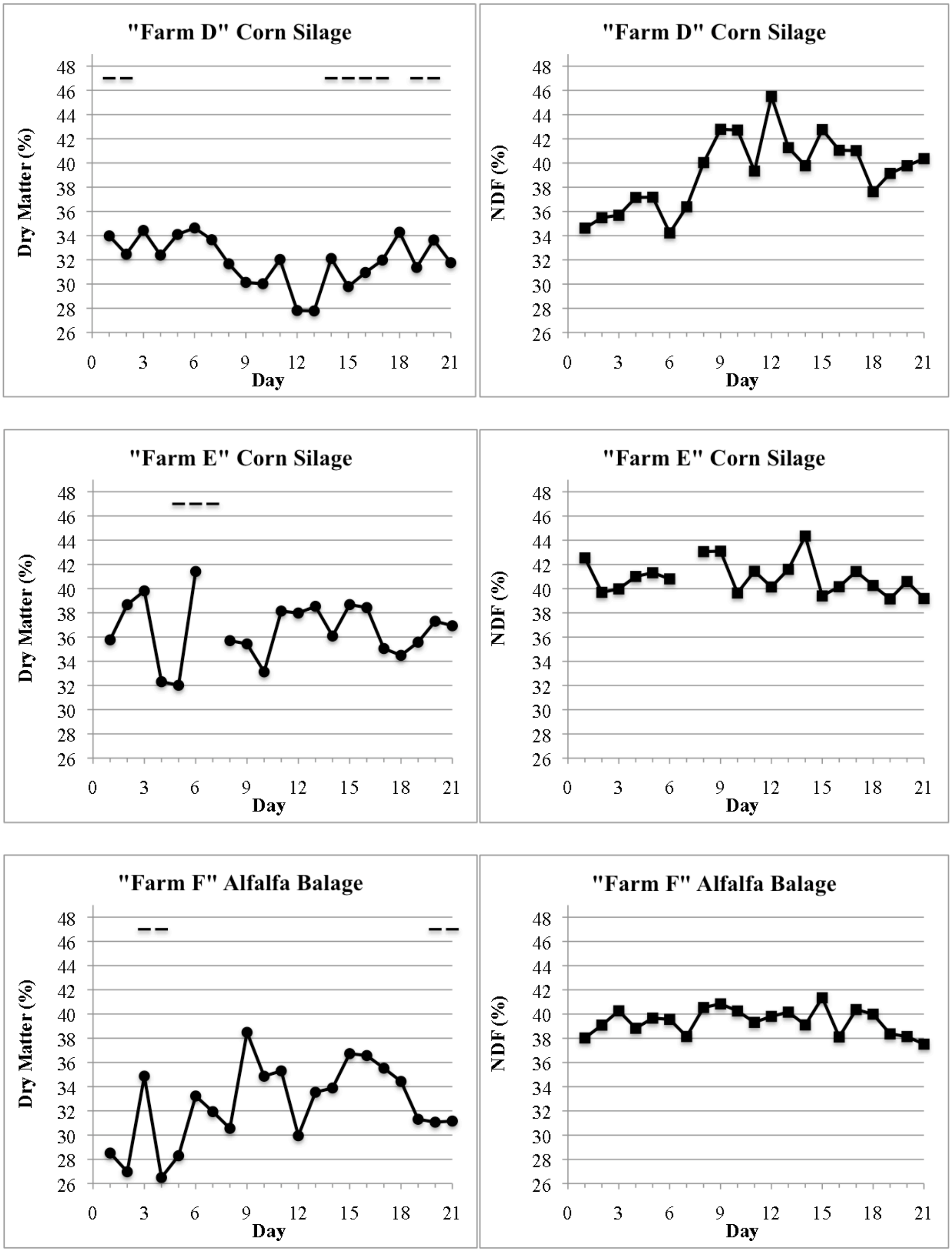

Figure 5 (Part 2). Dry matter (oven method) and NDF for each farm over 21 days. Dash marks indicated days on which measurable rain occurred.

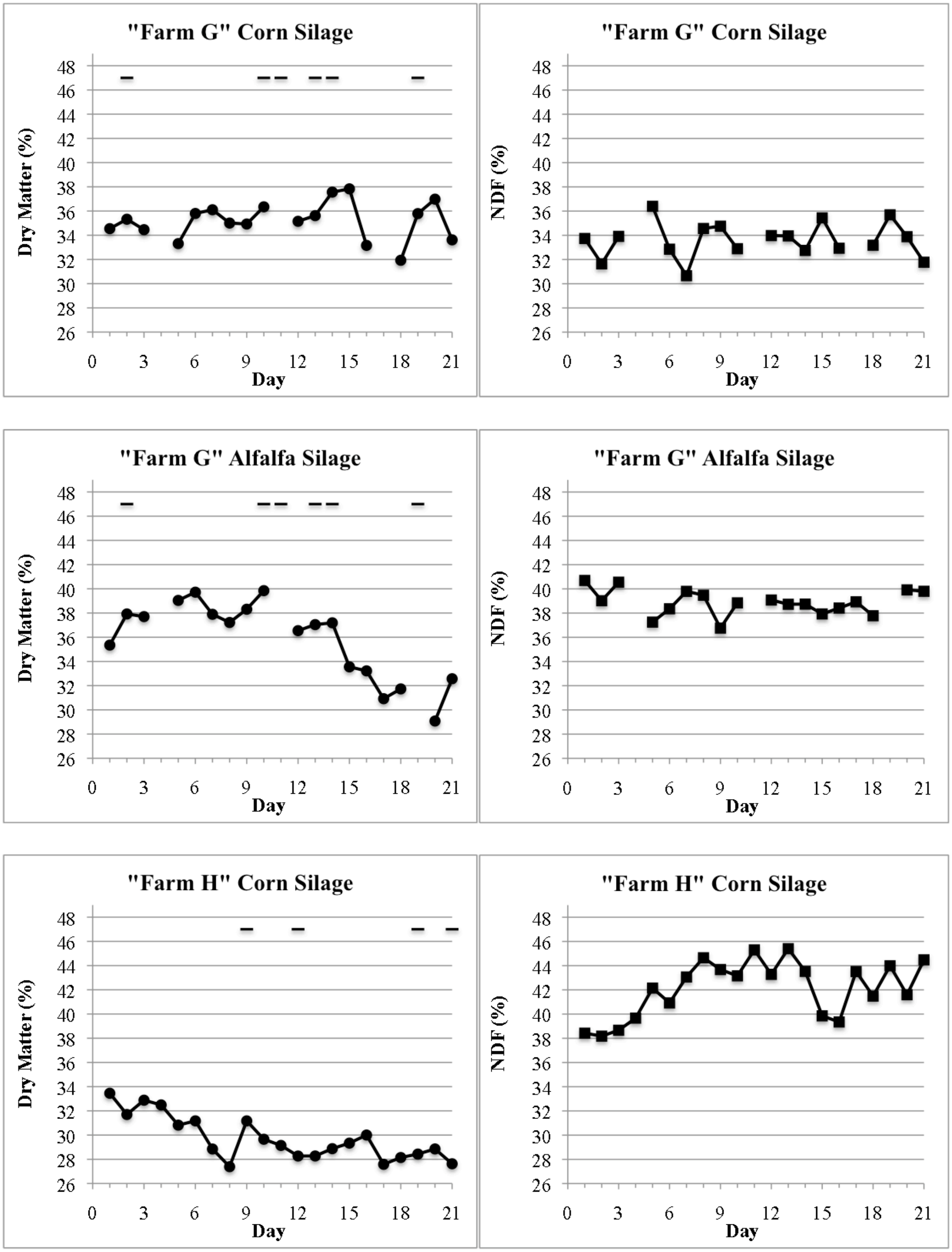

Figure 5. (Part 3). Dry matter (oven method) and NDF for each farm over 21 days. Dash marks indicated days on which measurable rain occurred.

Weather data were evaluated as a possible influence on changes in DM. Precipitation as rain averaged 1.91 inches for each farm over the course of 21 days, with an average of 4.9 days with rain, and prevailing temperature averaged 58.1°F (14.1 °C) as measured by weather stations within 4 miles of each farm. The effect of rain on changes in DM was evaluated using Students t-test to compare the mean DM change from the previous day when rain occurred to the mean DM change from the previous day when rain did not occur. The Shapiro-Wilk test was used to verify that the data within each silage type were not inconsistent with the normal distribution. Rain did not decrease DM across all farms and silage types. For each group with rain the previous day or no rain the previous day, rain did decrease DM by a very small amount (-0.13 change in % DM) from previous day for corn silage treatments. As a test, NDF was subjected to the same procedure and was not found to show any change due to rain the previous day. Prevailing temperature was not found to have an effect on DM changes.

B. Method comparisons

For evaluative purposes, the oven two-step method for total dry matter determination was assumed most accurate and was used as the standard to which measurements made using the electronic method were compared. The electronic DM device, using data gathered both on-farm and in-lab, was compared to the standard DM method. Two data points from the on-farm DM data set were removed as outliers, as they were outside the 95% confidence interval in the Grubbs test for outliers and appeared to be inconsistent with the rest of the data.

Because the electronic DM analysis equipment was not in use on any of the farms prior to this study, the possibility of a "learning curve" among farm operators of the electronic DM device was evaluated. A "learning curve" was defined as a decrease in the absolute value of residuals (on-farm DM minus standard DM) over the course of the trial. The residuals became significantly smaller over time for Farm H (p=0.0004) and Farm E (p=0.0271), indicating a possible learning curve for these farms, but the change was not significant over all farms and silage types.

As an indication of mean bias relative to the standard method, the differences between measurements made with the electronic method and the standard method were calculated, and the means and standard deviations of the differences are shown in **Table 8**. Reporting the limits of agreement (the mean difference plus or minus 1.96 SD) when comparing two methods was recommended by Bland and Altman (1995) to indicate "how far apart measurements by the two methods were likely to be for most individuals." The limits of agreement indicate the expectation that 95% of samples by the electronic method would be greater than the standard value plus the lower limit and less than the standard value plus the upper limit (Bland and Altman, 1995). For example, if DM were 40% by the standard method, 95% of the results found by the electronic method on-farm could be expected to fall within 32.03% and 51.60%.

Table 8. Dry matter (DM %) measured two ways by the electronic method minus DM measured by the standard method.

Method	Mean difference	SD	Lower limit of agreement	Upper limit of agreement
Electronic, In-Lab	0.65	4.25	-7.68	8.97
Electronic, On-Farm	1.82	4.99	-7.97	11.60

For 95% of samples, the measurement by the indicated method will be greater than the lower limit (reference value minus value indicated) and less than the higher limit (reference value plus the value indicated) relative to a measurement by the standard method; Limits = 1.96 (SD) ± mean difference (Bland and Altman, 1995).

As an indication of linear bias, the differences between the electronic method and standard method were regressed against the mean of the observed DM by each method for each sample (Bland and Altman, 1995). As seen in **Figure 6** and **Figure 7**, the electronic method tended to underestimate lower values of DM and overestimate higher values of DM, with the inflection falling around 32%. Regression against the mean of methods, rather than against the value from the reference method alone, is thought to reduce the potential for variance in the reference measurements to skew the estimate of linear bias (Altman and Bland 1983).

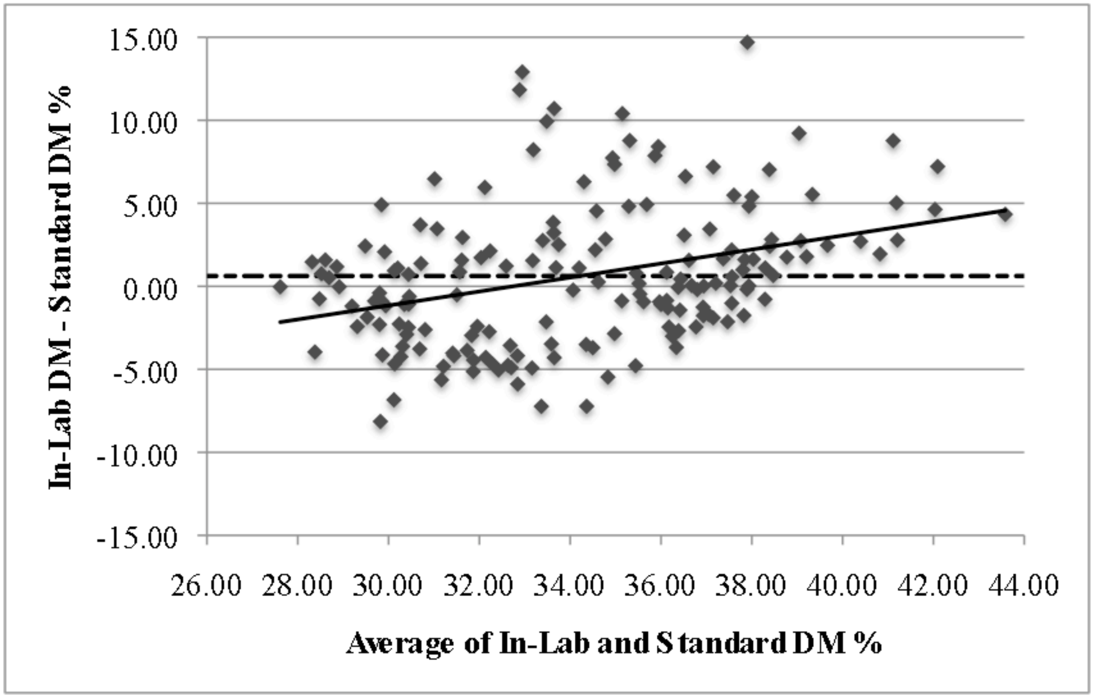

Figure 6. In-lab electronic method minus standard method DM values versus their average. Dotted line denotes the mean of the absolute values of the residuals at 0.65%. Solid line denotes linear fit: y = -13.84 + 0.42x.

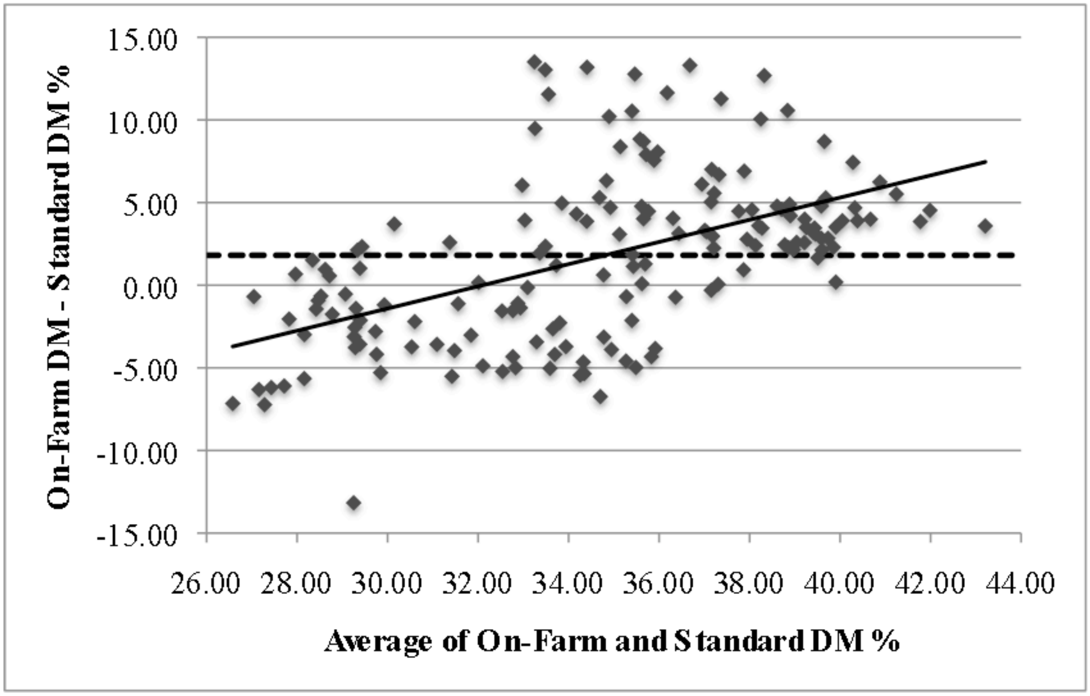

Figure 7. On-farm electronic method minus standard method DM values versus their average. Dotted line denotes the mean of the absolute values of the residuals at 1.82%. Solid line denotes linear fit: y = -21.40 + 0.67x.

The mean differences of farm DM value minus standard DM value were different for each farm, as can be seen in **Table 9**.

Table 9. Mean of differences between on-farm DM and standard DM values and the mean of the averages of on-farm DM and standard DM for each farm.

Farm	Silage Type	Mean Difference	Mean of averages of on-farm and standard DM
Farm A	Corn	3.57	39.08
Farm B	Corn	- 4.95	30.65
Farm C	Corn	- 0.12	33.32
Farm D	Corn	7.57	35.63
Farm E	Corn	2.49	37.82
Farm F	Alfalfa	5.59	35.35
Farm G	Corn	- 3.10	38.77
Farm G	Alfalfa	5.67	33.64
Farm H	Corn	- 1.18	29.13

The percentage of root mean square prediction error due to mean bias and slope bias were calculated, and are reported in **Table 10**.

Table 10. Sources of variation by method, when compared to standard (oven) method.

			Variation due to:		
Method	**Mean**	**SD**	**Mean bias**	**Slope bias**	**Error**
Electronic, In-Lab	34.53	4.63	2.3%	11.6%	86.1%
Electronic, On-Farm	35.78	5.70	11.7%	24.6%	63.7%

C. Ration evaluation study (data from Dou *et al*, 2003)

Information from the ration evaluation study provides a wider perspective on the variation seen in TMR DM and the potential for variation of the fed ration from the formulated ration. For the 16 farms whose TMR formulations and corresponding analyses were compared, the number of samples ranged from 2 to 15. The number of lactating cows on each farm ranged from 45 to 800, and averaged 169 cows. Number of days from ration formulation to Dou study analysis ranged from 0 to 150 days and averaged 24 days. The mean and SD of analyzed TMR DM, NDF, CP, and Ca:P ratio are shown in **Table 11** and **Table 12**. When NDF values were regressed against DM, NDF was found to decrease as DM increased ($p<0.001$).

Table 11. TMR DM and NDF values and number of samples for each ration evaluation study farm.

		DM %		NDF %	
Farm	**Samples**	**Mean**	**SD**	**Mean**	**SD**
1	7	42.79	4.85	32.57	1.86
2	5	46.06	5.15	34.16	2.69
3	15	47.31	5.17	33.29	3.96
4	9	45.80	5.31	31.41	3.60
5	4	49.88	2.35	32.45	2.35
6	4	39.28	4.69	36.20	2.71
7	2	37.95	2.47	37.40	0.14
8	8	43.44	4.91	31.20	2.80
9	2	49.10	10.32	31.20	2.26
10	4	43.30	5.56	34.88	6.26
11	2	45.70	1.41	32.55	1.63
12	6	47.55	5.14	27.58	3.04
13	7	43.43	3.77	31.30	1.71
14	9	40.17	3.49	33.69	3.33
15	7	42.17	5.44	32.74	3.51
16	12	45.06	4.97	31.93	2.88

Data from Dou *et al*, 2003.

Table 12. TMR crude protein values and Ca:P Ratio and number of samples for each ration evaluation study farm.

		CP %		Ca:P Ratio	
Farm	**Samples**	**Mean**	**SD**	**Mean**	**SD**
1	7	17.30	0.84	1.86	0.34
2	5	17.38	1.15	2.37	0.69
3	15	17.98	1.73	2.56	0.50
4	9	17.16	1.67	1.91	0.43
5	4	17.50	0.43	2.01	0.37
6	4	17.88	1.42	2.07	0.31
7	2	16.35	4.74	1.17	0.18
8	8	18.05	0.69	2.27	0.29
9	2	17.10	0.28	2.50	0.38
10	4	18.38	1.08	1.42	0.66
11	2	16.45	1.06	1.34	0.07
12	6	17.15	0.68	2.54	0.71
13	7	17.44	1.04	1.76	0.21
14	9	17.47	1.08	1.98	0.36
15	7	16.10	1.24	2.11	0.23
16	12	17.60	0.93	2.67	0.31

Data from Dou *et al*, 2003.

Analysis of DM is a tool to reduce the differences between the formulated ration and the fed ration (as-fed ration error). The magnitude of as-fed ration errors seen on the ration evaluation study farms for DM, NDF, CP, and Ca:P ratio are listed in **Table 13** and **Table 14**.

Table 13. Differences between formulated ration and analysis for DM and NDF for each ration evaluation study farm.

		DM difference		NDF difference	
Farm	Samples	Mean	SD	Mean	SD
1	7	-5.97	5.61	2.62	2.91
2	5	-3.33	6.16	0.49	3.17
3	15	-2.50	4.90	0.83	4.11
4	9	-8.22	7.45	0.84	5.21
5	4	-5.46	1.17	0.12	3.25
6	4	-11.90	11.47	-0.86	2.98
7	2	-17.84	13.94	4.95	5.10
8	8	-6.00	3.48	*	*
9	2	-3.55	0.49	-1.00	4.67
10	4	-3.78	4.81	1.26	4.68
11	2	-6.50	0.71	-0.20	2.04
12	6	-4.23	8.02	-2.18	2.27
13	7	-2.33	2.82	0.30	2.18
14	9	-5.70	3.05	-1.71	4.20
15	7	-7.37	3.95	-0.55	3.26
16	12	-3.20	3.38	-0.79	2.93

* NDF was not specified in the ration formulations for Farm 8.

Data from Dou *et al*, 2003.

Table 14. Differences between formulated ration and analysis for crude protein values and Ca:P ratio for each ration evaluation study farm.

		CP difference		Ca:P Ratio difference	
Farm	**Samples**	**Mean**	**SD**	**Mean**	**SD**
1	7	0.36	0.47	-0.25	0.23
2	5	-0.16	1.06	-0.05	0.60
3	15	0.05	1.93	0.01	0.32
4	9	-0.27	1.61	-0.06	0.49
5	4	0.34	0.42	0.09	0.28
6	4	0.41	1.36	0.02	0.27
7	2	-0.28	4.92	-0.96	0.52
8	8	0.15	0.73	0.10	0.38
9	2	0.00	0.28	0.41	0.18
10	4	0.68	0.99	-0.71	0.62
11	2	-1.16	1.12	-0.43	0.06
12	6	-0.38	1.00	0.35	0.68
13	7	-0.36	1.05	-0.30	0.19
14	9	0.29	0.98	-0.14	0.37
15	7	-1.12	0.85	-0.09	0.17
16	12	-0.33	0.89	0.21	0.37

Data from Dou *et al*, 2003.

The differences between fed and formulated rations were examined for relationships using a test of Spearman's rank correlation coefficient, listed in **Table 15**. Changes in NDF were found to have an inverse relationship to DM, CP, and Ca:P ratio. Changes in DM were found to have a positive statistical relationship to Ca:P ratio.

Table 15. Correlation between changes in ration DM, NDF, CP, and Ca:P (n=103 TMR samples).

Variables	Correlation coefficient	Prob. > |Spearman's Rho|
DM, NDF	-0.1292	0.0366
DM, Ca:P ratio	0.2781	0.0290
NDF, CP	-0.2407	0.0313
NDF, Ca:P ratio	-0.2157	0.0154

Data from Dou *et al*, 2003.

Time intervals between formulation and ration evaluation study ranged from 0 to 149 days; the distribution of time intervals, as measured in "number of days since formulation," is shown in **Figure 8**. No relationship was found between number of days since formulation and magnitude of as-fed ration error for values of DM, NDF, crude protein, or Ca:P ratio; absolute values and squares of the differences were also tested.

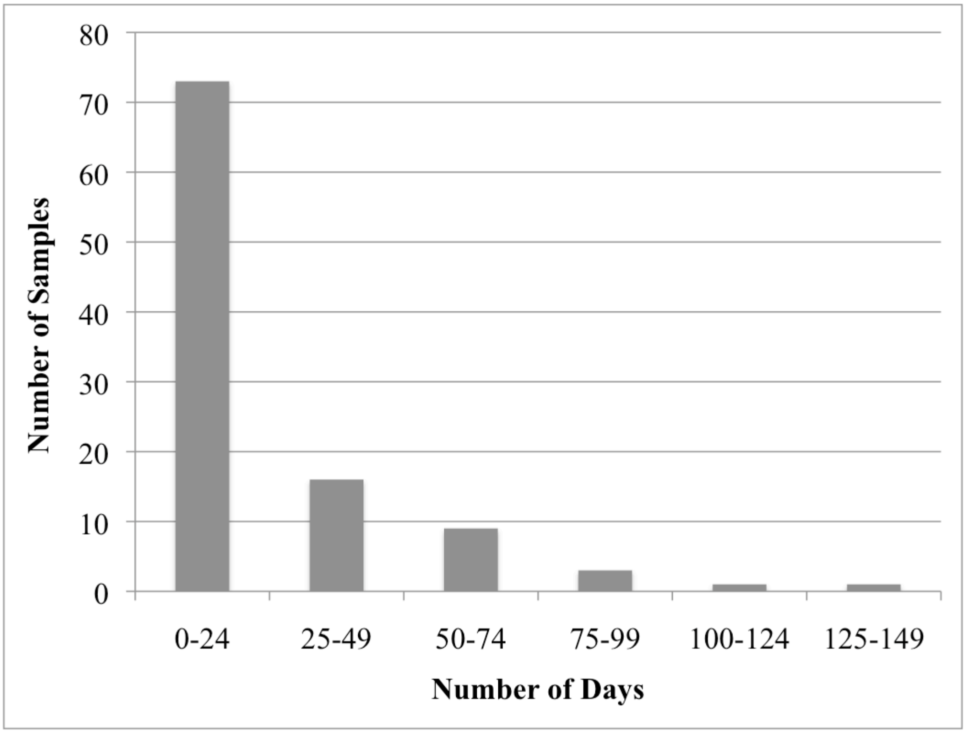

Figure 8. Frequency distribution of samples by number of days between TMR formulation and ration evaluation analysis.

Chapter 5: Discussion

A. Utility of on-farm DM analysis

By enabling the producer to account for changes in forage moisture weight, on-farm forage DM analysis can improve efficiency of the feeding regimen on dairy farms that weigh out forage (usually silage) for use in TMRs. Adjusting for changes in DM to find the correct weight of feed can prevent underfeeding, which may cause production losses, and overfeeding, which may increase wasted nutrients. Monitoring and adjusting for changes in forage DM, especially when there are multiple forages to be analyzed per farm, needs to have a pay-off that exceeds the cost in time and resources needed to perform the analysis required to enable adjustments. Recommendations that encourage on-farm DM analysis may be improved by including caveats about when usage may have a net benefit. For less frequent uses of on-farm DM analysis, such as checking forage moisture prior to ensiling, the same caveats would not necessarily apply.

The on-farm DM data collection demonstrated that a variety of patterns exist for silage DM over time; such patterns may not be predictable. For example, Farm A and Farm B milked 95 cows each, primarily fed corn silage, and reported 22,000 lb and 25,000 lb for RHA milk production, respectively. However, Farm A appeared to have very consistent silage DM over 21 days (37.30 ± 0.72%), while Farm B silage DM fell from approximately 37% to 31% over the course of 21 days. Similarly, the NDF of silage on Farm A appeared to vary less (40.19 ± 1.58%) than that of Farm B (37.24

± 2.09%). Changes in NDF may indicate changes in other properties of the feed, such as protein and mineral content.

In the case of Farm A, on-farm analysis may not have a net benefit simply because, if the DM and NDF patterns remain consistent beyond the trial, the silage does not change much. In the case of Farm B, a net benefit of on-farm DM analysis may be seen if silage DM changes more than silage NDF over time. If both DM and NDF are fluctuating greatly, DM analysis may still be beneficial; adjusting for changes in DM does not account for changes in NDF, but variation in DM may compound variation in NDF or other properties of the forage.

A third case is demonstrated by Farm F, which milked 240 cows, reported 20,000 lb for RHA milk production, and fed alfalfa balage at the time of the trial. The DM of the forage appeared to fluctuate daily (32.56 ± 3.33%), and an upward trend from approximately 28% to 35% was seen over the course of the trial. Meanwhile, NDF remained consistent at 39.40 ± 1.06% over 21 days. Assuming a negligible sampling error, Farm F may see a net benefit from routine on-farm DM analysis. From the data shown in **Figure 9**, alfalfa balage was formulated at 38% DM, and Farm F was underfeeding alfalfa balage by about 1.5 lb DM per cow per day on average.

For farms from the ration evaluation study, there were differences between expected (formulated) and observed (analyzed) DM for TMR samples; the lowest SD of DM was 1.41% and the highest was 10.32%, but observed SD was less than 5.56% for most of the 16 farms. This variation is slightly larger (1-2%) than the variation seen in the eight farms that participated in the on-farm DM trial. It is possible that this difference is due to the fact that TMR contains ingredients of varying moisture content, in addition to silage. Interestingly, no correlation was found between the time between formulation and analysis and the size of the difference between DM values, when looking at the ration evaluation study farms as a group.

One of the more conspicuous factors suspected of affecting forage DM is precipitation. In the on-farm DM trial, precipitation as was found to increase moisture by a small amount (-0.13% in DM) from one day to the next for corn silage. However, it is unknown whether this effect was due to moisture on the silage face or a more substantial change. Covering the silage face and ensuring that rainwater does not drain into the silo may be ways to prevent any changes due to precipitation. The practice of analyzing DM after rain may also help ensure that DM is known.

Farm A, 95 lactating cows

Component: Corn silage, actual DM = 37.30 ± 0.72%

	DM%	As-Fed lb per cow	DM lb per cow	Percent of TMR DM
Formulated	37.20	33.93	12.62	26.29
Actual (mean)	37.30	33.93	12.66	26.35
Actual +SD	38.02	33.93	12.90	26.82
Actual - SD	36.58	33.93	12.41	26.07
Adjusted	37.30	33.84	12.62	26.29

Difference in adjusted component weight for whole herd: -8.64 lb

Farm F, 240 lactating cows

Component: Alfalfa balage, actual DM = 32.56 ± 3.33%

	DM%	As-Fed lb per cow	DM lb per cow	Percent of TMR DM
Formulated	38	29.23	11.11	22.05
Actual (mean)	32.56	29.23	9.52	18.89
Actual +SD	35.89	29.23	10.49	20.82
Actual - SD	29.23	29.23	8.54	16.95
Adjusted	32.56	34.12	11.11	22.05

Difference in adjusted component weight for whole herd: 1,173.99 lb

Figure 9. Two cases: differences in adjusted and unadjusted ration for measured component of TMR.

B. Farm Size and Existing On-Farm DM Practices

The survey supported the hypothesis that despite recommendations for use, smaller dairy farms (as determined by milking herd size) tend to use this tool far less frequently than larger farms, which agreed with previous a previous finding by Dou *et al* (2003). This could be explained in part by the fact that smaller farms do not benefit from economies of scale, and have limited economic resources and limited manpower available for nonessential tasks.

The survey results were more skewed toward larger farms than the latest census data (2007) indicated for the population of farms in Maryland. This skew, visible in **Figure 10**, may reflect the fact that the survey was not designed to be truly representative and may have overrepresented farms that were in "higher producing" dairy counties and farms that were members of Maryland Dairy Industry Association (from which addresses were obtained). However, a possibility exists that these data reflect the continuation of the modern historical trend toward larger farms.

For those farms that did analyze forage DM on-farm, the Koster Moisture Tester and microwave oven methods were used, but not any kind of electronic DM analysis device. This could have been due to cost and perceived reliability. Microwave ovens are very common in home and workplace settings, and are likely to have been purchased primarily for uses other than DM analysis, thus incurring no extra cost other than electricity. At the time of the survey, the price of a Koster unit was approximately $350, compared to $200 for the Farmex 1210 Electronic Silage Tester, which was the least expensive electronic silage DM analysis device found.

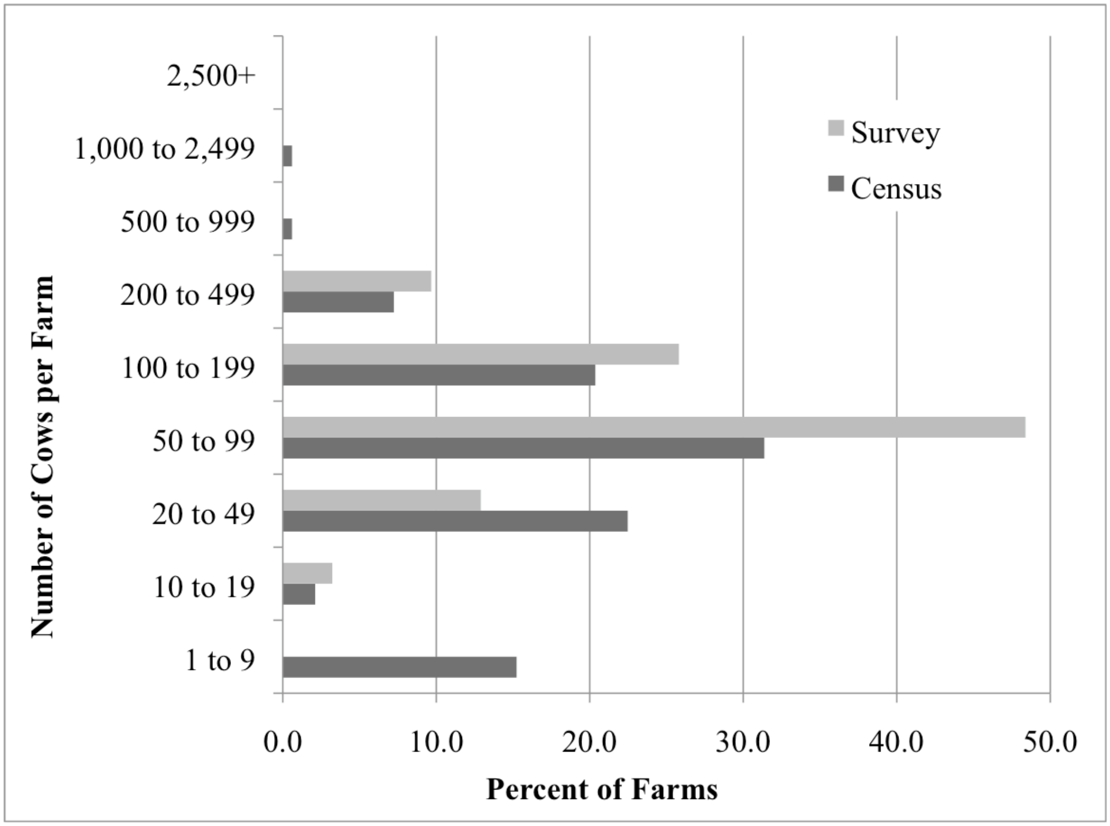

Figure 10. Distribution of 31 surveyed farms versus distribution of 663 dairy farms in Maryland from the 2007 Census of Agriculture, USDA Agriculture Statistics Service.

Though microwave ovens can vary in heating power and interface complexity, most operators can be assumed to be familiar with the procedure of using microwave ovens. Similarly, the Koster method is straightforward and intuitive, as it simply uses hot air to dry the sample. While the Farmex 1210 electronic device was less expensive than a Koster unit and requires less time to operate (15-20 minutes vs. 40-90 minutes), most operators would find that the electronic device has both an unfamiliar procedure and an unclear mechanism of action, which would work against purchase of the of the electronic device. Additionally, feedback from operators indicates that compressing the sample in the Farmex 1210 device is physically strenuous.

The eight farms that participated in on-farm DM data collection were heterogeneous according to their survey statistics, representing several herd sizes, two common silage types, and all three on-farm DM analysis behaviors (use of Koster Moisture Tester, microwave, or no on-farm analysis). Although heterogeneity can make interpretation more challenging, heterogeneity also increases the robustness of statistical trends found, and helps to ensure that the scope of the study results is not limited to these specific farms. Results may be most readily applicable to farms of the north-eastern US type, which tend to grow their own feed, tend to have small herds, and exist in a climate with four distinct seasons.

C. Utility of Farmex 1210 Portable Electronic Silage Tester

For a DM measurement to be meaningful, the uncertainty in the measurement would need to be less than the uncertainty in the silage. The Farmex 1210 device seemed promising as an affordable, efficient tool. Farmex product literature claims that the device is accurate within “2% (average) for silage under 50% moisture” and within “3% (average) for silage over 50% moisture.” For the Farmex 1210 electronic devices used in the trial, the uncertainty around the measurements exceeded variation in the silage even for farms with the greatest variation (*e.g.* Farm F, with a standard deviation of 3.33% for alfalfa balage DM).

The Farmex 1210 silage DM analysis device did not compare well to the standard method (two-step oven method). The limits of agreement (Results **Table 8**) with the standard method were very broad. If a DM measurement was 40% by the standard method, 95% of the results found by the electronic method could be expected to fall somewhere 32.32% and 48.97% in-lab or 32.03% and 51.60% on-farm. Although the device may present some advantage in price and the brevity of its procedure, the device does not appear to be useful for the purpose of analyzing silage DM on farms like the ones in the trial. As could be expected, the in-lab measurements showed a slightly smaller difference (0.65 ± 4.25%) from standard DM than the on-farm measurements (1.82 ± 4.99%).

Despite unfamiliarity with the procedure, there was no observable "learning curve" for on-farm operators using the Farmex 1210 device on six of the eight farms that performed DM data collection. Two explanations for this outcome could be: 1) the device is easy enough to use that there was no need for "learning" or 2) the device was difficult to use, and therefore "learning" was too difficult over 21 days. The fact that two operators seemed to demonstrate "learning" over the course of the trial would seem to be evidence for the second explanation. The smaller SD exhibited in the in-lab DM results could also support the second possibility, as the lab operator had more thorough training and more experience using the device in general. However, there is no way to truly distinguish whether either of the explanations is true from the data gathered. If it were necessary, such information might be gleaned from a longer trial than 21 days. A third possibility may be that the device itself changed with use over time, or the forage changed, causing the two farms (Farm E and Farm H) to exhibit a false "learning curve."

A possible flaw in the design of the on-farm DM trial was failure to pre-test all of the individual devices used in the lab and in the field to make sure that they were all fully operational and acted in a similar way to each other. It is possible that the accuracy of each device varies. However, except for Farm G (corn silage), the mean difference between on-farm DM and standard DM for each farm does tend to tend increase as the mean of the averages of the values increases, suggesting that the devices did exhibit similar behavior.

D. Relationship Between NDF and DM

Changes in DM reflect changes in water or moisture content only, while changes in NDF tend to reflect changes in the nutrient content of the DM itself. The inverse relationship between DM and NDF, seen in both the on-farm DM trial and the ration evaluation study, makes sense biologically; NDF tends to decrease as a percentage of total DM as corn plants age. However, the statistical analysis on data from the ration evaluation study and from the on-farm DM trial suggested that the amount of variability of DM was not necessarily related to amount of variability of NDF. Therefore, measuring them independently may be necessary for each farm.

Some farms in the on-farm DM trial had far greater variation in DM than others. The alfalfa silage (Farm F and Farm G) in particular exhibited the greatest variation in DM, but had the lowest variation in NDF. The alfalfa balage from Farm F showed a positive correlation between DM and NDF, likely because the alfalfa was cut and baled while in the young vegetative stage when NDF comprises a larger portion of DM. The lack of a positive correlation of DM and NDF for alfalfa could also result from the fact that alfalfa may be pre-wilted before ensiling, unlike whole-plant corn.

Because of its relatively small initial size, alfalfa may be less likely to be chopped into small pieces prior to ensiling, as was true with the alfalfa balage. This may cause a larger variety of particle sizes and greater difficulty in truly representative sampling. Alfalfa particles may also simply be less absorbent than corn particles, leading to a pooling effect of moisture, which would increase the necessity of taking a larger initial sample and subsampling correctly for these silages.

For farms in the on-farm DM trial, corn silage seemed to be more even in moisture than alfalfa, but more likely to vary in NDF. It is possible that this is due to the difference in size and age between corn and alfalfa plants; individual corn plants in a crop may vary from each other more than individual alfalfa plants.

E. Future Directions

Because patterns of DM and NDF variation differ from farm to farm, or from silo to silo, it may be beneficial for farms to analyze silage to establish what pattern is specifically applicable. More research is needed to determine whether these patterns hold over extended periods of time. For example, do bunker silos, which may contain several months' feed tend to show the same pattern of DM and NDF variability all the way through? Additionally, would variability depend on silage type or some other identifiable silage management practice?

Some farms in the on-farm DM trial had silage DM that varied from day to day or sample to sample while the mean DM did not change from week to week. More research is needed to determine the effect of this kind of day-to-day variability on nutrient utilization efficiency and milk production. Some research has shown that when crude protein is changed from "high" to "low" around a target mean every 48 hours, nitrogen utilization efficiency increases in growing lambs and finishing cattle (Archibeque *et al*, 2007; Doranalli *et al*, 2011). Additional research is needed to determine the effects of such variation on dairy cattle, especially fully grown animals. If day-to-day variability does not cause adverse changes to health, milk production, or nutrient utilization efficiency, adjusting DM daily should not be recommended. Instead, the goal of on-farm DM analysis would be to ensure that the mean DM is on target over the course of several days.

For those farms that stand to benefit from routine on-farm DM measurement, an accurate method is necessary. Repeating the current on-farm DM study using the Koster Silage Moisture Tester, microwave, or other similar device could be useful. Oetzel *et al.* found that the microwave method to be “most repeatable” and “most accurate” compared the 100°C oven when the microwave, Koster, and electronic silage DM devices were tested in the laboratory; research is needed to replicate such results and determine whether they would remain valid in a field setting.

Different forages show different variability in DM and in other measurements of nutrient content. Currently, there are no models available to accurately predict variability in forages. Development of such models for different forages (*e.g.* legumes, grasses, and corn) would provide guidance in discerning when on-farm DM measurement of specific forages may be beneficial. Before models can be developed, however, research is needed to determine the extent to which different forages vary.

Silage consistency may be improved with better silage management and special care during the ensiling process. Feed that is ensiled at an appropriate maturity and DM and that is packed consistently well may be more consistent in DM throughout the store. Using the appropriate techniques for the type of silo (*e.g.* bunker, bag, bale, or upright) can also be important. Intuitively, improved silage management should improve consistency of silage, and increase the certainty of DM and other properties of the silage. More data needs to be collected regarding consistency of silage throughout the silo, regardless of the quality of management factors.

For farms where silage consistency in DM, but not in other silage properties, is a significant problem, measuring by volume may be a better solution than continually measuring silage DM. More research would be needed establish recommendations for this solution, if appropriate.

F. Conclusion

The DM of forages was observed to vary from day to day and week to week on farms of the size seen in Maryland. This variation differs among individual farms and forage types. The magnitude of variation in TMR DM in the ration evaluation study was not dissimilar to the magnitude of variation in DM of silage in the on-farm DM study. In order for recommendations regarding on-farm DM analysis to be worth following, they must address specific farm circumstances and feeding regimens, and proper sampling must be stressed. Further research is needed regarding the variability of specific forages, which can inform recommendations. When on-farm DM analysis is appropriate, the Farmex 1210 Portable Electronic Silage Tester was not found to be a suitable tool.

Appendices

Appendix A

Field Survey Question Sheet

On-Farm Dry Matter Testing
University of Maryland Cooperative Extension

________________________________ Farm Manager	________________________________ Business Phone
________________________________ Farm Name	________________________________ Cell Phone (if used for business)
________________________________ Street Address	________________________________ E-mail (if used for business)
________________________________ City, ZIP code	

Survey of Farm Practices

We are looking at the use of forage dry matter testing on Maryland dairy farms. We are interested in learning how often dry matter is tested, and whether dry matter testing makes rations more consistent. We're starting by doing a short 5-minute phone survey to Maryland farms. Participants will get the results as soon as the survey is done, and all names and farms will be kept confidential.

Could you please help us by answering a few questions about what you do on your farm?

1. Do you ever determine your forage dry matter on the farm?

   Yes: How often? Daily / Weekly / When it rains / Other:

   Do you keep records? How far back?

   No: Have you ever? Do you think it would make a difference if you did?

2. What kind of equipment do you use for dry matter testing?

   a. microwave
   b. Koster tester - Does it have an electronic scale?
   c. oven
   d. electronic tester – Do you know the brand?
   e. nutritionist or lab analysis – How often?

3. Do routinely feed:
    a. Silage: Alfalfa / Corn / Small grain crops
    b. Hay: Alfalfa / Grass
    c. Pasture: Alfalfa / Grass
    d. Balage
    e. Sorghum
    f. Other forages:
4. Can you describe how you feed? For example: TMR, complete feed, pasture, top dressing.
5. How many cows are in your milking herd? What breed?
6. What is your approximate rolling herd average?
7. Do you belong to a co-op? Which?
8. If you could tell us your co-op herd ID number, we could get milk component information from your co-op that would be helpful to us. Can you give your herd ID number? If you don't know it, may we contact you later to get it?

<u>Further Study on Maryland farms</u>

We're also going to look at actual on-farm forage dry matters on volunteer farms. We would be looking at how much the forage dry matter varies, and whether it might be affecting the nutritional content of rations. If we were to provide you with an electronic silage tester, which you could keep, do you think you would be willing to do some dry matter tests on your farm, for a period of about 3 weeks?

Additional comments/issues/questions:

Appendix B

On-farm DM data collection instruction sheet

Thank you for helping us by testing your silage. By performing these tests, we will find out more about the usefulness of dry matter testing. With the forage samples you provide us, we will compare the results you found in a real farm setting to results we get in a laboratory, and perform additional tests for NDF and protein.

Below are the instructions for each day. Once you learn the procedure, testing should take no more than ten minutes.

1. Take a sample of forage and put it in that day's gallon-sized Ziploc bag.
    a. For the first day, please write down the date.
    b. If you happen to miss a day, please leave the bag for that day empty.

2. Put some of the forage sample into 3 of the small bags. Pack them gently. Aim for each bag to be about 3/4 inch thick. Clear excess material from the opening and seal it closed.

3. Press the battery button on the tester to check that the reading is above 75, which ensures that there is enough power to conduct tests. In the event that there is not enough power, the battery can be accessed by opening the bottom of the tester (requires a Philips screwdriver).

4. To take the measurement, place the bag in the slot in the middle of the tester.
    a. Start with the pressure knob unwound as far as it will easily go.
    b. Tighten the knob and count by half turns until the yellow ring in the middle of the tester appears. This may take some extra physical effort to achieve. A work glove may be helpful for gripping the knob.
    c. To get a reading that can be interpreted, this should take 4 to 5 1/2 turns.
        i. Fewer than 4: add some material to the bag.
        ii. Greater than 5 1/2: remove some material from the bag.
    d. Press the test button, and record the log reading and number of turns for each bag on the data chart.

5. Use the thermometer to take the approximate temperature of each bag after testing. Please use the Celsius scale on the thermometer (it is easier to read), and record the temperature on the data chart.

6. Use the laminated chart to determine the percent of dry matter. First, check the temperature part to see if you need to add or subtract anything from the log reading. Then, find the log reading and number of pressure turns to determine the percent of dry matter. Please record the dry matter result in the data chart. The average of the three tests is the final percent dry matter (but you don't need to record the average).

7. Please keep the gallon bag of sample in a fridge or freezer until we can pick it up.

Note: The start day is up to the producer. Time the start day so that feed bunkers/bags will not be switched out during testing.

Appendix C

On-farm DM data collection worksheet for Week 1 of trial

WEEK 1 of 3. The **start date** (day 1) was: ____________

Day	Tester Readout	Turns (4 to 5 ½)	Temp (Celsius)	Dry Matter %	Rain between yesterday's test and today's test	We changed the ration because of this test result
1					none ☐	yes ☐
					less than 1 inch ☐	no ☐
					more than 1 inch ☐	
2					none ☐	yes ☐
					less than 1 inch ☐	no ☐
					more than 1 inch ☐	
3					none ☐	yes ☐
					less than 1 inch ☐	no ☐
					more than 1 inch ☐	
4					none ☐	yes ☐
					less than 1 inch ☐	no ☐
					more than 1 inch ☐	
5					none ☐	yes ☐
					less than 1 inch ☐	no ☐
					more than 1 inch ☐	
6					none ☐	yes ☐
					less than 1 inch ☐	no ☐
					more than 1 inch ☐	
7					none ☐	yes ☐
					less than 1 inch ☐	no ☐
					more than 1 inch ☐	

Glossary

capacitance
the ratio of an impressed electrical charge on a conductor (*e.g.* water) to the corresponding change in electrical potential

Ca:P ratio
the total ratio of calcium to phosphorus

crude protein (CP)
percentage of dry mater consisting of protein, estimated by nitrogen content

dry matter (DM)
non-water content of a feed or forage

> ***on-farm analysis of*** -
> analysis of dry matter content performed on the premises of the farm, usually by farm personnel, with results immediately available for use.
>
> ***off-farm analysis of*** -
> analysis of dry matter content performed by an outside agency (*e.g.* dairy nutritionist, forage laboratory) not on the premises of the farm, with results available upon communication with the laboratory or outside agent

forage
cut plant matter, such as hay or silage, fed to grazing animals

neutral detergent fiber (NDF)
percentage of dry matter comprised by insoluble fiber, assumed to be composed primarily of cellulose, hemicellulose, and lignin from the plant cell wall, as determined by the Van Soest method

Rolling Herd Average (RHA)
a 365-day trailing average of milk produced per year per cow in a herd

silage
forage preserved by anaerobic fermentation in a silo (i.e. made by ensiling)

balage
silage made by sheathing bales of plant matter with airtight plastic

haylage
silage made with grass or legume plant matter that has been cut and partially desiccated, *e.g.* alfalfa hay

total mixed ration (TMR)
a method of feeding in which all components of a nutritionally complete diet are fed as a relatively uniform mixture

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