Update on Predicting Harvest Time for Alfalfa

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Abstract

Knowing the chemical composition of alfalfa in the field would help producers to harvest, store, and inventory the feed resource based on its potential value in dairy rations. Use of conventional laboratory analyses to obtain forage quality status of individual fields for making harvesting decisions is impractical because of the time, labor, and expense required. Three methods of predicting or estimating alfalfa quality are currently generating significant interest: 1) actual forage sample collection and quality analysis (scissors-cut programs), 2) predictive equations of alfalfa quality (PEAQ) based on stem length and maturity, and 3) predicting alfalfa fiber content from growing degree days (GDD). Scissors-cut programs can provide general guidelines on the timing of first harvest, but are too expensive to use routinely on individual fields. Based on research to date, GDD data from the start of the season may not by themselves produce a consistent, reasonably accurate estimation or prediction of alfalfa neutral detergent fiber (NDF) in the spring, and GDD do not relate to forage quality in summer regrowth. Research to date with PEAQ indicates that this method has the greatest potential to provide fast, simple, inexpensive, and reasonably accurate estimates of alfalfa NDF across environments and across all harvests during the growing season. It may be the most practical system for adoption on individual farms and to monitor forage quality in individual fields. When significant forward planning is needed or desired during the spring, an early spring sample analyzed for NDF content coupled with the historic GDD accumulation can be used to predict (into the future) an optimal date for the first cutting. The PEAQ method could then be used to estimate NDF content of a given field as the predicted optimal date approaches.

Introduction

Dairy producers understand the importance of forage quality to profitability. Poor quality forages increase feed costs and limit milk production in high producing cows. Unfortunately, harvest and storage management decisions are often made without knowledge of alfalfa chemical composition. Knowing the chemical composition of alfalfa in the field

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would help producers to harvest, store, and inventory the feed resource based on its potential value in dairy rations. Use of conventional laboratory analyses to obtain forage quality status of individual fields for making harvesting decisions is impractical because of the time, labor, and expense required. Instead, producers often rely on calendar date or maturity to make the best guess of when to harvest high quality alfalfa. But these indices are not reliable. For example, under certain environmental conditions morphological stage of alfalfa can remain nearly constant while quality continues to decline (Cherney, 1995). Chronological age of forage relates to quality in spring growth, but is inconsistently related to quality in regrowth. Harvesting by calendar date can give very disappointing results as well. The NDF content of spring harvested alfalfa has been shown to vary by as much as 10 percentage units when harvested on the same date from one year to the next (Allen et al., 1992). Clearly, there is a need for simple and reliable methods of predicting or estimating forage quality of alfalfa.

Cherney and Sulc (1997) described the ideal method of estimating alfalfa quality in the field as one providing reasonably accurate results while being easy, quick, inexpensive, and consistent across all harvests during the season and across a wide range of environments. The ideal method would also allow for predictions into the near future and would require alfalfa producers to visit and personally assess their fields for individual differences in characteristics affecting both quality and quantity of the forage produced. In the past few years, three methods of predicting or estimating alfalfa quality have generated the most interest: 1) actual forage sample collection and quality analysis (the scissors-cut program), 2) predictive equations of alfalfa quality (PEAQ) based on stem length and maturity, and 3) predicting alfalfa fiber content from GDD. In this paper we describe these methods and outline the pros and cons of each. We also discuss recent developments in the use of these methods in this region.

It is important to understand that any method used to predict or estimate forage quality will have some error in relation to wet chemistry analyses. We will discuss the relative accuracy of these different methods. When discussing the use of forage quality models as decision aids for harvest timing, it is also important to define the desired forage quality goal. In this discussion, our premise is that NDF is currently the best commercially available criterion for evaluating forage quality in alfalfa, and that alfalfa NDF of approximately 40% usually optimizes profitability in a 50% concentrate ration fed to dairy cows.

Scissors-Cut Method

Scissors-cut programs have been successfully used for a number of years in Wisconsin and Minnesota. In these programs, alfalfa samples are collected 1 to 3 times per week during the spring growth in randomly selected fields. Samples are usually analyzed via near infrared reflectance spectroscopy (NIRS), and the decline in forage quality is monitored. Results are quickly distributed to clientele through various channels to help them adjust timing of the first harvest on their farms. Scissors-cut programs are restricted to the spring growth period, since widely differing first-harvest dates on farms preclude any widespread use of scissors-cut results in subsequent growth cycles.

Pros – Scissors-cut

Through the publicity associated with these programs, forage quality is put on the front burner for alfalfa producers during the spring growth when forage quality is especially difficult to assess. This increased awareness of forage quality is significant because the spring growth typically produces more forage than any other growth cycle. The exact forage quality of a given field at the time of sampling is determined, and after several sampling dates, a trend in forage quality decline is established. This information helps producers judge how the current season is shaping up and when to consider initiation of spring harvest on their farms. Since sampling is real-time, the effect of current weather conditions on quality is accurately reflected in the results.

Cons – Scissors-cut

The accuracy of a forage quality sample is only as good as the sampler, and good sampling technique is imperative. If samples are not representative of the field, they will not accurately reflect the forage quality of the field. Results reflect only the actual field sampled. Elevation and slope aspect of the field can significantly affect alfalfa quality trends. For example, in New York alfalfa on a hill may mature over a week later than alfalfa in a nearby valley. The time and expense of NIRS analysis deters its use as a routine harvest decision aid on individual farms or specific fields on a farm. In addition, NIRS is subject to errors when compared with wet chemistry, and might be no more accurate than other predictive methods when used as a harvest decision aid. In a Wisconsin study comparing NIRS and PEAQ with wet chemistry, the NDF and acid detergent fiber (ADF) values obtained through a commercial NIRS lab were about as accurate as the PEAQ estimated values for the same sample set (Owens et al., 1995). Errors can occur with NIRS analysis of scissors-cut samples because equations for fresh alfalfa are not generally available.

PEAQ (<u>P</u>redictive <u>E</u>quations for <u>A</u>lfalfa <u>Q</u>uality)

Hintz and Albrecht (1991) evaluated fifteen maturity and morphological characteristics of plants in developing mathematical models to estimate fiber content of alfalfa. Among the models tested were simple equations (referred to as PEAQ) based on length of the tallest stem and stage of the most mature stem in the sample. These were considered the best compromise between accuracy and ease of use for routine estimation of alfalfa fiber composition.

The PEAQ equations for NDF and ADF were first validated with 308 samples collected from several locations in Wisconsin during hot and dry 1992 and cool and moist 1993 (Owens et al., 1995). The PEAQ equations were further validated with a total of 488 samples collected from production fields in New York, Pennsylvania, Ohio, Wisconsin, and California between 1994 and 1996 (Sulc et al., 1997). Those samples represented a wide range of environmental and management conditions and a diverse set of alfalfa varieties. The PEAQ method was found to be robust across the wide range of environments sampled, and the equations performed as well in states outside Wisconsin as they did in Wisconsin, where they were originally developed. The equations also performed well across spring and summer growth cycles. Estimated NDF using PEAQ was within ± 3 percentage units of the wet chemistry value in 72 to 81% of the samples collected, and within ± 4 percentage units in 84 to 89% of the samples (Sulc et al. (1997).

In 1998 additional samples were collected from all growth cycles (spring and summer) in Ohio, Wisconsin, and South Dakota to further validate the use of PEAQ in field settings and to compare it to other simpler equations. Subsamples were collected from five representative locations within each field on any given sampling date. The length of the tallest stem and stage of the most mature stem in each subsample were determined directly in the field before cutting the subsample. In the previous validation work (Owens et al., 1995; Sulc et al., 1997) these measurements were carefully made in the comfort of a lab after the sample had been cut and collected. In 1998, the five subsamples collected from each field on a given sampling date were composited, dried, and analyzed for NDF content via wet chemistry. Wet chemistry NDF was compared with the PEAQ estimate of NDF (average of the five subsample measurements). In addition, a simplified staging scale was evaluated for use in the PEAQ equation. This scale consisted of only three stages (late vegetative, bud stage, and flower stage) rather than the detailed staging system of Kalu and Fick (1981) used in previous PEAQ research. In the simplified system, the two bud stages are averaged into a single bud stage value, and the two flower stages are averaged into a single flower stage value. With this method, one does not need to differentiate between early and late bud stages, or between early and late flower stages. The sampling protocol and NDF values generated from the PEAQ equation with this simplified staging system are shown in Table 1. The NDF values listed in Table 1 are calculated assuming a 1.5-inch cutting height.

Typical statistics used to evaluate regression equations include the coefficient of determination (r^2), root mean square error (RMSE), the y-intercept, and the slope of the regression line. A good equation will give a high r^2 value ($r^2 = 1.0$ for a perfect 1:1 relationship), a low RMSE, a y-intercept not different from 0, and a slope not different from 1.0 (Fick and Onstad, 1988). In validating such models, the RMSE measures the error of the estimation, and is in the same units as the trait being estimated. If RMSE = 3 for an NDF equation, then more than half the estimates are within ±3 percentage units of NDF, and nearly all estimates are within ±6 units of NDF (2 x RMSE).

Results obtained from samples collected in 1998 are shown in Figure 1. The PEAQ estimates of NDF (Fig. 1, top panel) were calculated using the 3-stage scale and stem length measurements obtained directly in the field during sampling, only the stem length was corrected for an assumed constant 2-inch cutting height. Using the 3-stage scale in the PEAQ equations yielded NDF estimates that were just as accurate as those calculated using the more detailed staging scale (data not shown). The in-field PEAQ estimates were nearly always identical to the PEAQ estimates calculated from the measurements made on the cut samples in the lab (data not shown). Thus, PEAQ can be performed accurately and quickly right in the field. These data demonstrate once again that PEAQ performs well across spring and summer growth cycles. The PEAQ method (using the 3-stage scale) estimated NDF within ± 2 percentage units of the wet chemistry value in 63% of the samples collected, within ±3 percentage units in 75% of the samples, and within ± 4 percentage units in 93% of the samples. This agrees with previous data sets (Sulc et al., 1997).

In addition to the PEAQ equations based on maturity and stem length, Hintz and Albrecht (1991) also reported an NDF equation based only on length of the tallest stem, with no consideration given to the maturity stage. We used the 1998 data set to validate that equation. The data shows that the equation based only on stem length works quite well (Fig. 1, bottom panel); however, the error of estimation was slightly higher and the y-intercept deviated further from 0 than for the equation based on both stem length and maturity stage (Fig. 1, top panel). The equation based only on stem length estimated NDF within ± 2 percentage units of the wet chemistry NDF in 37% of the samples collected, within ±3 percentage units in 56% of the samples, and within ± 4 percentage units in 82% of the samples. Preliminary evaluation of this stem length equation for other data sets shows similar or even slightly better results. This method deserves more careful study. If it proves to be reliable, it would have the advantage of being even easier than the simplified PEAQ method described in Table 1. Below are summarized the pros and cons of the PEAQ method for estimating NDF.

Pros – PEAQ

The PEAQ method of estimating alfalfa quality is simple, fast, and inexpensive. Alfalfa quality has been estimated reasonably well in a number of different locations across the USA. Thus, the method is robust across a wide range of environments. It also performs well across all growth cycles during a season, not just in the first growth cycle (Owens et al., 1995; Sulc et al., 1997). The PEAQ sampling forces alfalfa producers out into their fields for a close inspection of alfalfa development. This encourages and facilitates scouting for other concerns, such as winter injury, disease development, insect damage, and weed encroachment. The PEAQ sampling is real-time, so the effect of current weather conditions on crop development is reflected in the results. This method requires no record keeping. Yardsticks with NDF markings based on stem length and maturity stage are being produced and distributed. These “Alfalfa Fiber Sticks” will eliminate the need to calculate NDF from the equation or to look it up in a chart (Table 1). Thus, the method will become even more streamlined and convenient.

Cons – PEAQ

As with scissors-cut sampling, results are highly dependent on good sampling technique. This includes careful attention to finding and measuring the length of the tallest stem in the sample and correctly identifying what is the most advanced maturity stage present in the sample. The equation is calibrated only for pure alfalfa stands, so estimates are less reliable for weedy fields and alfalfa-grass fields. It does not work well in fields with poor stands, or in alfalfa suffering from waterlogging stress. It does not provide reliable estimates of NDF in alfalfa that is very short (longest stem less than 16 inches) or very tall (longest stem more than 40 inches). Nevertheless, the 16- to 40-inch height limit represents a much broader range in growth than the normal harvest range for alfalfa.

GDD (Growing Degree-Days)

Growing degree-days are a temperature-derived index representing the amount of heat plants are exposed to. Growing degree-days have been used successfully with corn development, but have had mixed success with perennial forages. Accumulated GDD are related to NDF content in the spring growth of alfalfa (Allen et al., 1992; Allen and Beck, 1996; Cherney, 1995), but are inadequate in predicting alfalfa quality across cuttings (Fick and Onstad, 1988; Sanderson, 1992). As noted by Van Soest (1996), GDD relate reasonably well to forage quality in perennial forages when soil moisture is not limiting, but later in the season when moisture is typically limiting, GDD do not relate well to quality. This is presumably because forage growth is limited more by soil moisture than by heat units. Therefore, researchers have focused their efforts on using GDD to predict quality of alfalfa in the spring only.

For alfalfa, GDD are calculated by averaging the maximum and minimum temperature (^{o}F) for a given day (24-h period) and subtracting the base temperature of 41^{o}F. For example, if the maximum temperature is 65 ^{o}F and the minimum is 43 ^{o}F for a given day, then 13 GDD accumulated that day [(65+43)/2 –41]. For days with an average temperature of less than 41^{o}F, daily GDD are set equal to 0. The seasonal total is obtained by summing the daily GDD from a predetermined starting date. Different criteria have been used to determine the starting date for GDD accumulation in the spring. In New York, Cherney (1995) began GDD accumulation after air temperature during the day remained above 41^{0}F for five consecutive days. The actual date when this occurred varied from late March to early April, depending on the year and site. Allen and Beck (1996) used a constant starting date (March 1) for GDD accumulation in their six-state study.

The GDD method offers the advantage of using historical weather records to forecast the date when alfalfa will reach 40% NDF in the spring, or whatever the quality goal may be. Two recent reports indicate that alfalfa was near 40% NDF when about 700 to 750 GDD were accumulated in the spring (Allen and Beck, 1996; Cherney, 1995). Thus, historical weather records for a given location can be used to predict the date when 700 to 750 GDD will be accumulated. Actual GDD accumulation up to the date of prediction can be substituted for the long-term average values, thus improving the prediction for the current year (Cherney, 1995). This method could potentially allow producers to plan well in advance for the target date of spring harvest.

Although GDD and alfalfa NDF content are highly related within an environment, GDD prediction equations have not been consistently accurate across environments. Cherney (1995) demonstrated that the relationship between GDD and NDF content of alfalfa in Iowa (Sanderson, 1992) was quite different from that in New York State. A New York GDD equation was developed to predict the date of 40% NDF, but the equation gave variable results when tested on samples that were outside of the data set used to calibrate the equation. The predicted date for 40% NDF was 1 to 7 days earlier than the actual date of 40% NDF. Allen and Beck (1996) reported that prediction equations developed in one year resulted in biased predictions for another year (the equations were not stable across years). The bias was generally less for predicting across states than across years. It appears that GDD models must be developed for a relatively narrow range of environments and periodic re-calibration is probably required (Sanderson, 1992). Below are summarized pros and cons of the GDD method.

Pros – GDD

The GDD method eliminates the need to sample a field, and therefore eliminates the potential for alfalfa sampling error. It allows NDF estimation in a predictive mode, meaning we can predict NDF into the future by using a historic GDD database. Thus, it potentially enables more forward planning than the scissors-cut or PEAQ methods. It is inexpensive, fast, and easy assuming weather data are available for the site. As with PEAQ, the GDD equations were developed for pure stands of alfalfa, so weeds or grasses in the stands are not accounted for in the estimates.

Cons – GDD

Equations to predict NDF based on GDD can be developed, but it is unlikely that one GDD equation will work across all environments. Validation of GDD equations in the literature is limited. Based on analysis of large data sets across many environments (Allen and Beck, 1996; Cherney, 1995), predicted NDF may vary from actual NDF by over six percentage units, which is unacceptable. This method does not require alfalfa producers to go out and assess their fields. From an agronomist's perspective this is not always desirable, because other problems may not be discovered until it is too late to take corrective action. The utility of the GDD method is limited to the first (spring) growth cycle.

The GDD method requires a weather station near the site where NDF estimates will be made. Alternatively, producers will have to monitor and keep records of the maximum and minimum daily temperature, which has the advantage of reflecting conditions right on their farm. Inexpensive thermometers are available which record the daily minimum/maximum temperatures. It is imperative that these thermometers be placed 5 feet above the ground in an enclosure mounted in an open area (preferably near a field), providing good ventilation with free airflow around the sensors, and preventing direct sunlight from hitting the sensors. When using GDD equations to predict the date for a given NDF level, it is necessary to have long-term weather data (10+ years).

Possible Combinations of Methods

Since no single method will ever result in perfect predictions of alfalfa quality into the future, a combination of methods may be most acceptable. Allen and Beck (1996) suggested that GDD in combination with plant height and maturity stage might be more accurate for estimating alfalfa NDF than using GDD alone. In Michigan, spring harvest alert programs are being used which are based on the GDD method (R. Leep, personal communication, 1999). Accumulation of GDD (base 41^{o}F, beginning March 1) is reported through various channels twice each week. Samples are collected to compare NIRS results of scissors-cut samples with GDD and PEAQ estimates of NDF. Michigan producers are encouraged to begin cutting alfalfa at 750 GDD for upright silos and 680 GDD for horizontal silos. Harvest should begin even earlier if it takes longer than one week to complete the harvest.

Cherney (1995) found that GDD prediction equations developed for different data sets in New York had considerably different intercepts (-6.0 to 13.5), but the slopes of the equations were relatively consistent (18 to 27 GDD per unit change in NDF). Because the slopes of the equations were similar but the intercepts varied, he proposed that alfalfa could be sampled several weeks ahead of harvest and analyzed to obtain a known NDF baseline value. The slope of the prediction equation (average of 21 GDD/unit NDF in New York) and the historic GDD for a given site could then be used to predict the date for 40% NDF, starting from the date of field sampling. This could potentially reduce the error in GDD predictions of the optimal harvest date. This method has been evaluated with fairly good success in New York (Cherney, 1995; Cherney and Sulc, 1997) and needs to be evaluated in other environments. This technique is dependent on getting a good sample early in the spring, which is much more difficult than sampling taller alfalfa. It may be tempting to use PEAQ to estimate the early spring NDF baseline value, but the alfalfa must be at least 16 inches tall for greater reliability of the PEAQ estimate. One major disadvantage of building a prediction date for spring harvest on an estimated NDF foundation (such as using NIRS or PEAQ) is that the early estimate of NDF and GDD prediction could both err on the early or the late side, compounding the error to an unacceptable level. This combination method also requires historic GDD data for the site in question and adds labor, complexity, and the expense of laboratory analysis.

Practical Applications and Summary

Alfalfa forage quality estimates or predictions for harvest should be based on a defined forage quality goal. Alfalfa NDF of approximately 40% usually optimizes profitability in dairy rations containing 50% concentrate. Typical harvest and storage losses under good conditions can increase NDF content by 3 to 6 percentage units. We also know that NDF content increases about 4 or 5 percentage units in one week during the spring and early summer, but the change in fiber content is slower in mid to late summer. Based on this information and assuming good quality forage is desired, a reasonable goal is to begin mowing when the standing forage is approximately 35% NDF. Mowing should be completed by the time the standing forage is 40 to 41% NDF. The timing of harvest operations will depend on the desired quality, the amount of high quality forage needed, and the time required to cover all acres. Pre-harvest estimates of NDF content can be used to time harvests and to guide the order of fields to harvest. These estimates might influence the storage location of the forage and may provide an early estimation of purchased feed needs. But it must be understood that pre-harvest estimates of NDF content do not replace the need to test the quality of stored forage before balancing rations and feeding.

Any method for estimating or predicting quality must be fast, simple and reasonably accurate. Based on research to-date, GDD data from the start of the season may not by themselves produce a consistent, reasonably accurate estimation or prediction of alfalfa NDF. Scissors-cut programs can provide general guidelines on the timing of first harvest, but are too expensive to use routinely on individual fields. Research to date with PEAQ indicates that this method has the greatest potential to provide fast, simple, inexpensive and reasonably accurate estimates of alfalfa NDF for individual farms and fields. In addition, it is reliable across all harvests during the growing season. When forward planning is needed or desired during the spring, a combination of methods may provide the best prediction of the optimal first harvest date; however, this involves more complexity than regularly monitoring NDF content with PEAQ as the spring progresses. An early prediction system involves the following: 1) collect a scissors-cut sample early in the growing season to determine NDF content, preferably via wet chemistry, 2) use the early season NDF content and historic GDD accumulation to predict the optimal harvest date, and 3) use the PEAQ method to estimate NDF content as the predicted optimal harvest date approaches.

It is not always possible to harvest alfalfa at the optimal time because of inclement weather. But methods of predicting or estimating alfalfa quality in the field along with weather forecasts will help producers come closer to their desired forage quality goals. If performed correctly, these methods are certainly more reliable guides than visual appraisals or harvesting by calendar date, or by age, or by maturity alone.

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Table 1. Estimation of alfalfa NDF using PEAQ with a simplified staging scale.

Step 1: Choose a representative 2-square-foot area in the field.

Step 2: Determine the most mature stem in the 2-square-foot sampling area using the criteria shown in the table at right.

Step 3: Measure the length of the tallest stem in the 2-square-foot area. Measure it from the soil surface (next to plant crown) to the tip of the stem (NOT to the tip of the highest leaf blade). Straighten the stem for an accurate measure of its length. The tallest stem may not be the most mature stem.

Step 4: Based on the most mature stem and length of the tallest stem, use the chart at the right to determine estimated NDF content of the standing alfalfa forage.

Step 5: Repeat steps 1 to 4 in four or five representative areas across the field. Sample more times for fields larger than 30 acres.

NOTE: This procedure estimates alfalfa NDF content of the standing crop. It does not account for changes in quality due to wilting, harvesting, and storage. These factors may further raise NDF content by 3 to 6 units, assuming good wilting and harvesting conditions. This procedure is most accurate for good stands of pure alfalfa with healthy growth.

Length of Tallest Stem (from soil to stem tip)	Stage of Most Mature Stem		
	Late Vegetative no buds visible on stem	Bud Stage 1 or more nodes with buds visible	Flower Stage 1 or more nodes with 1 open flower
-- inches --	------------------ % NDF --------------------		
16	28.5	29.7	31.4
17	29.2	30.4	32.0
18	29.9	31.1	32.7
19	30.6	31.8	33.4
20	31.3	32.5	34.1
21	32.0	33.2	34.8
22	32.7	33.9	35.5
23	33.4	34.6	36.2
24	34.0	35.3	36.9
25	34.7	35.9	37.6
26	35.4	36.6	38.3
27	36.1	37.3	38.9
28	36.8	38.0	39.6
29	37.5	38.7	40.3
30	38.2	39.4	41.0
31	38.9	40.1	41.7
32	39.6	40.8	42.4
33	40.3	41.5	43.1
34	40.9	42.2	43.8
35	41.6	42.8	44.5
36	42.3	43.5	45.2
37	43.0	44.2	45.8
38	43.7	44.9	46.5
39	44.4	45.6	47.2
40	45.1	46.3	47.9

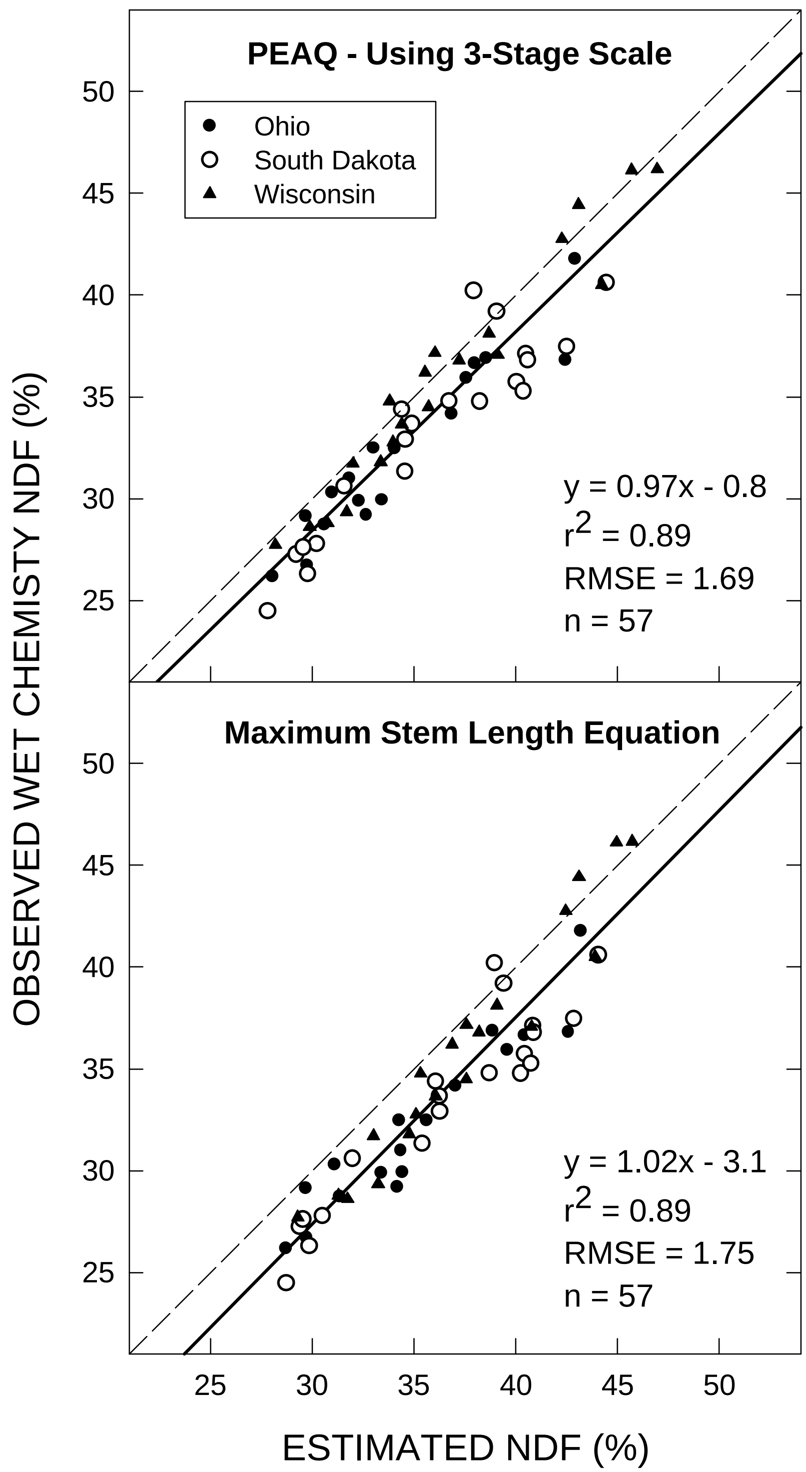

Figure 1. Estimated versus observed NDF of alfalfa. Estimates were calculated using predictive equations of alfalfa quality (PEAQ) with a 3-stage maturity scale (top panel) or using equations based solely on length of the tallest stem in the sample (bottom panel). Each point represents a composite sample from one field-sampling-date combination. The solid line is the observed regression and the dashed line represents a perfect 1:1 relationship (RMSE = root mean square error).