Predicting Forage Nutritive Value from Height and Maturity of Alfalfa in Saskatchewan, Canada

A Thesis Submitted to the College of
Graduate Studies and Research
In Partial Fulfillment of the Requirements
For the Degree of Master of Science
In the Department of Animal and Poultry Science
University of Saskatchewan
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Abstract

Several authors have shown that fiber levels can be predicted from plant height and maximum maturity in alfalfa (*Medicago satvia* L.). These estimates have been used to predict animal performance without any reference to error terms. This study evaluates the equations for predicting chemical characteristics from field measurements of plant morphology, and some equations for predicting animal performance from chemical characteristics. Finally, predicting forage utilization directly from field measurements of plant morphology was evaluated. Six sites were chosen from irrigated alfalfa fields in southwestern Saskatchewan. The chemical characteristics measured were neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), acid detergent lignin (ADL), ash, acid detergent insoluble nitrogen (ADIN), neutral detergent insoluble nitrogen (NDIN), and ether extract (EE). Only ADF and NDF showed predictive value from height and maximum maturity ($R^2 = 0.86$, and $R^2 = 0.90$, respectively). Weiss developed a theoretical model for estimating net energy based on summing the true digestibility of each of the components. This model did not predict digestibility well ($R^2 = 0.23$). A model was developed to predict in-vitro dry matter digestibility directly from height and maximum maturity, however this model only performed moderately well ($R^2 = 0.61$). This shows that in-vitro digestibility is predictable directly from height and maturity, although not without significant increases in error compared to prediction of ADF and NDF. Caution would be advised when using these estimates for further prediction.

Key Words: alfalfa, fiber, ADF, NDF, Prediction

Acknowledgments

I would like to acknowledge and thank several persons who contributed to my studies and the completion of this work.

First of all, I wish to thank the One who created this intriguing planet, for allowing the privilege of exploring the inner workings of it, and for granting us the mind to do it. Furthermore, I would like to thank Him for the comfort and encouragement of His daily Presence, and, more importantly, for sending His Son to provide payment for my mistakes.

I would also like to especially thank Dr. D.A. Christensen for his patience and encouragement. His guidance and attention to this project made it a valuable learning experience. Appreciation is also expressed to the members of my advisory Committee, Dr. B. Laarveld, Dr. A Iwaasa, Dr. B. Coulman, Mr. L. Bohrson and Dr. Peter Jeranyama. Their suggestions and constructive criticism has made my academic career challenging and rewarding.

I would like to extend my appreciation for the financial support to Sask Water and the Irrigation Crop Diversification Corporation. I would like to particularly acknowledge John Linsley and Carl Siemens for their support and their commitment to improving irrigation throughout the province. I am grateful for the assistance of Chad Lawley and Catherine Chubak for the long hours of counting alfalfa stems in the hot sun.

I would like to extend thanks to Elayna Bowie and Enviro-Test Labs, for their technical assistance and openness.

A special thanks goes to my parents, Mr. and Mrs. Art and Wanda Olfert, to my brothers and sisters for their love and support. An extra special thanks goes to my wife Tara, for her love, encouragement, and for putting up with my repeated absences to complete this project.

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Abbreviations

ADF	Acid Detergent Fiber
ADIN	Acid Detergent Insoluble Nitrogen
ADL	Acid Detergent Lignin
AOAC	Association of Official Analytical Chemists
CP	Crude Protein
EE	Ether Extract
FA	Fatty Acids
IVDDM	In-vitro Digestible Dry Matter
IVTD	In-vitro True Digestibility
MSC	Mean Stage by Count
MSW	Mean Stage by Weight
N	Sample Size
NDF	Neutral Detergent Fiber
NDIN	Neutral Detergent Insoluble Nitrogen
NFC	Non Fiber Carbohydrates
NIRS	Near Infra Red Spectrometry
NRC	National Research Council
OMD	Organic Matter Digestibility
P	Coefficient for multiples of Maintenance
PAF	Processing Adjustment Factor (1 for forages)
PEAQ	Prediction Equations of Alfalfa Quality
R^2	Adjusted Coefficient of Determination
r^2	Coefficient of Determination
RMSE	Root Mean Square Error
SAS	Statistical Analysis Systems
SAFRR	Saskatchewan Agriculture, Food and Rural Revitalization
TdCP	True Digestibility of CP
TdFA	True Digestibility of FA
$TDN_{1,f}$	Total Digestible Nutrients for 1x maintenance and forages
TDN_p	Total Digestible Nutrients for P x maintenance
TdNDF	True Digestibility of NDF
TdNFC	True Digestibility of NFC
TMR	Total Mixed Ration

List of Equations Evaluated to Estimate Compositional and Nutritional Value based on Field Measurements

Equation 1: $MSW = 0.456 + 1.153\ MSC$

$n = 596$, $r^2 = 0.982$, RMSE = 0.311, (Mueller and Fick 1989)

Authors attempted and succeeded in showing that MSC can be converted to MSW accurately.

Equation 2: $IVTD = 92.93 - 3.98\ MSW$

$n = 11$, $r^2 = 0.984$, RMSE = N/a, New York, (Kalu and Fick 1981)

Authors defined stages of maturity, MSC, MSW and correlated to IVTD to show usefulness.

Equation 3: $CP = 40.89 - 7.38\ MSW + 0.57\ MSW^2$

$n = 11$, $r^2 = 0.982$, RMSE = N/a, New York, (Kalu and Fick 1981)

Authors defined stages of maturity, MSC, MSW, and correlated to CP to show usefulness.

Equation 4: $CP = 36.15 - 6.09\ MSW + 0.48\ MSW^2$

$n = 35$, $R^2 = 0.883$, RMSE = 2.4, New York, (Kalu and Fick 1983)

Authors evaluated maturity definition and correlated to CP to show usefulness.

Equation 5: $IVTD = 93.67 - 4.29\ MSW$

$n =35$, $r^2 = 0.957$, RMSE = 1.9 New York, (Kalu and Fick 1983)

Authors evaluated maturity definition and correlated to IVTD to show usefulness.

Equation 6: $NDF = 20.62 + 8.03\ MSW - 0.59\ MSW^2$

$n = 24$, $R^2 = 0.946$, RMSE = 2.2, New York, (Kalu and Fick 1983)

Authors evaluated maturity definition and correlated to NDF to show usefulness.

Equation 7: $ADF = 17.05 + 3.85\ MSW$

$n = 24$, $r^2 = 0.899$, RMSE = 2.5, New York, (Kalu and Fick 1983)

Authors evaluated maturity definition and correlated to ADF to show usefulness.

Equation 8: $ADL = 2.77 + 1.01\ MSW$

$n = 24$, $r^2 = 0.841$, RMSE = 0.8, New York, (Kalu and Fick 1983)

Authors evaluated maturity definition and correlated to ADL to show usefulness.

Equation 9: $CP = 37.1 - 7.58\ MSW + 0.76\ MSW^2$

$n = 43$, $r^2 = 0.64$, RMSE = 2.74, National, (Fick and Onstad 1988)

Authors evaluated predictive equations from New York data across six states (CA, GA, KY, NM, NY, WI) and found morphological characteristics to give better correlations than weather data.

Equation 10: $IVTD = 100 - 16.3 \ln(MSW + 1)$

$n = 42$, $r^2 = 0.70$, RMSE = 3.15, National, (Fick and Onstad 1988)

Authors evaluated predictive equations from New York data across six states (CA, GA, WI, NM, NY, and KY) and found morphological characteristics to give better fits than weather data.

Equation 11: $NDF = 13.4 + 17.7 \ln(MSW + 1)$

$n = 43$, $r^2 = 0.70$, RMSE = 3.66, National, (Fick and Onstad 1988)

Authors evaluated predictive equations from New York data across six states (CA, GA, WI, NM, NY, and KY) and found morphological characteristics to give better fits than weather data.

Equation 12: $ADF = 12.5 + 13.1 \ln(MSW +1)$

$n = 44$, $r^2 = 0.70$, RMSE = 2.91, National, (Fick and Onstad 1988)

Authors evaluated predictive equations from New York data across six states (CA, GA, WI, NM, NY, and KY) and found morphological characteristics to give better fits than weather data.

Equation 13: $ADL = 1.91 + 3.23 \ln(MSW + 1)$

$n = 44$, $r^2 = 0.59$, RMSE = 0.91, National, (Fick and Onstad 1988)

Authors evaluated predictive equations from New York data across six states (CA, GA, WI, NM, NY, and KY) and found morphological characteristics to give better fits than weather data.

Equation 14: $NDF = 21.2 +14.9\ MSW - 1.15\ MSW^2$

$n = 79$, $r^2 = 0.88$, RMSE = 4.3, Iowa, (Sanderson and Wedin 1988)

Authors found that hemi cellulose was not related to maturity, however cell wall concentration was related to maturity.

Equation 15: $Lignin = 10.6 + 2.9\ MSW - 0.24\ MSW^2$

$n = 79$, $r^2 = 0.72$, RMSE = 1.3, Iowa, (Sanderson and Wedin 1988)

Authors found no correlation between hemi cellulose and maturity, however lignin and maturity showed a correlation.

Equation 16: $NDF = 15.0 + 9.8\ MSW - 0.6\ MSW^2$

$n = 16$, $r^2 = 0.98$, RMSE = 1.6, Iowa, (Sanderson and Wedin 1989)

Authors correlated NDF to phenological development in alfalfa, red clover, timothy, and smooth brome grass.

Equation 17: IVTD = 83.3 – 4.3 MSW

n = 16, r^2 = 0.98, RMSE = 1.3, Iowa, (Sanderson and Wedin 1989)

Authors correlated IVDDM to phenological development in alfalfa, red clover, timothy, and smooth brome grass.

Equation 18: NDF = 16.89 + 0.27 height + 0.81 maturity

n = 540, r^2 = 0.89, RMSE = 2.62, Wisconsin, (Hintz and Albrecht 1991)

Authors examined 15 plant characteristics to develop a fast, simple method of quality estimation. Other characteristics provided slightly better correlations, however, they suggested height and maximum maturity provide the best compromise between prediction accuracy and ease of use.

Equation 19: ADF = 11.57 + 0.21 height + 0.79 maturity

n = 540, r^2 = 0.88, RMSE = 2.20, Wisconsin, (Hintz and Albrecht 1991)

Authors examined 15 plant characteristics to develop a fast simple method of quality estimation. Other characteristics provided slightly better correlations, however, they suggested height and maximum maturity provide the best compromise between prediction accuracy and ease of use.

Equation 20: CP= 30.71 – 0.09 height – 0.89 maturity

n = 540, r^2 = 0.74, RMSE = 2.17, Wisconsin, (Hintz and Albrecht 1991)

Authors examined 15 plant characteristics to develop a fast simple method of quality estimation. Other characteristics provided slightly better correlations, however, they suggested height and maximum maturity provide the best compromise between prediction accuracy and ease of use.

Equation 21: ADL = 1.58 + 0.05 height + 0.25 maturity

n = 540, r^2 = 0.84, RMSE = 0.65, Wisconsin, (Hintz and Albrecht 1991)

Authors examined 15 plant characteristics to develop a fast simple method of quality estimation. Other characteristics provided slightly better correlations, however, they suggested height and maximum maturity provide the best compromise between prediction accuracy and ease of use.

Equation 22: NDF = 18.19 + 0.21 height + 1.44 maturity

n = 150, r^2 = 0.83, RMSE = 2.45, Wisconsin, First Cut (Owens, Hintz, and Albrecht 1995)

Authors separated data into first cut and subsequent cuts in an attempt to increase accuracy of prediction equations. They found accuracy did not improve.

Equation 23: ADF = 11.92 + 0.18 height + 1.11 maturity

n = 150, r^2 = 0.78, RMSE = 2.30, Wisconsin, First Cut (Owens, Hintz, and Albrecht 1995)

Authors separated data into first cut and subsequent cuts in an attempt to increase accuracy of prediction equations. They found accuracy did not improve.

Equation 24: CP = 29.63 – 0.09 height – 0.87 maturity

n = 150, r^2 = 0.37, RMSE = 2.27, Wisconsin, First Cut (Owens, Hintz, and Albrecht 1995)

Authors separated data into first cut and subsequent cuts in an attempt to increase accuracy of prediction equations. They found that accuracy did not improve and CP predictions inaccurate.

Equation 25: NDF = 16.53 + 0.34 height + 0.25 maturity

n = 158, r^2 = 0.66, RMSE = 3.06, Wisconsin, Second+ Cuts (Owens, Hintz, and Albrecht 1995)

Authors separated data into first cut and subsequent cuts in an attempt to increase accuracy of prediction equations. They found accuracy did not improve.

Equation 26: ADF = 12.08 + 0.28 height + 0.11 maturity

n = 158, r^2 = 0.75, RMSE = 2.11, Wisconsin, Second+ Cuts (Owens, Hintz, and Albrecht 1995)

Authors separated data into first cut and subsequent cuts in an attempt to increase accuracy of prediction equations. They found accuracy did not improve.

Equation 27: CP = 29.51 – 0.04 height – 1.07 maturity

n = 158, r^2 = 0.35, RMSE = 1.66, Wisconsin, Second+ Cuts (Owens, Hintz, and Albrecht 1995)

Authors separated data into first cut and subsequent cuts in an attempt to increase accuracy of prediction equations. They found that accuracy did not improve and CP predictions inaccurate.

Equation 28: NDF = 23.67 + 0.21 height + 0.41 maturity

n = 159, r^2 = 0.74, RMSE = 2.04, Ohio, Wisconsin, (Sulc, et al. 1997)

Authors evaluated performance of PEAQ across five states (NY, PA, OH, CA, WI) and concluded that they were robust across a wide range of environments.

Equation 29: ADF = 16.90 + 0.17 height + 0.32 maturity

n = 159, r^2 = 0.73, RMSE = 1.69, Ohio, Wisconsin, (Sulc, et al. 1997)

Authors evaluated performance of PEAQ across five states (NY, PA, OH, CA, WI) and concluded that they were robust across a wide range of environments.

Equation 30: $TDN_{1,f} = TdNFC + TdCP_f + TdFA(2.25) + TdNDF - fecal\ TDN$
(Weiss, et al, 1992)
Authors provided a theoretically based model for predicting TDN of forages and concentrates. It was determined to be as accurate as in vivo digestion.

Equation 31: $Td\ NFC = 0.98\ ((100 - (NDF - NDIN) - CP - EE - Ash) \times PAF)$
(Weiss, et al, 1992)

Equation 32: $TdCP_f = CP \times 2.71828^{(-1.2 * (ADIN / CP))}$
(Weiss, et al, 1992)

Equation 33: $TdFA = EE - 1\%$
(Allen, 2000)

Equation 34: $TdNDF = 0.75\ (NDFn - ADL) * ((1 - (ADL / NDFn)^{0.667}))$
(Weiss, et al, 1992)

Equation 35: $NDFn = NDF - NDIN$
(Weiss, et al, 1992)

Equation 36: $Fecal\ TDN = 7\%$
(Weiss, et al, 1992)

Equation 37: $TDN_p = TDN_{1,f} \times discount$
(Weiss, et al, 1992)

Equation 38: $Discount = (100 - ((ration\ TDN * 0.18 - 10.3) / (ration\ TDN / 100) \times (p - 1))) / 100$
(Weiss, et al, 1992)

Equation 39: $NDF = 18.09 + 0.97\ maturity + 0.24\ height$
$n = 95$, $r^2 = 0.84$, $RMSE = 2.31$
This equation was created from data in SW Saskatchewan and found accurate and useful for preharvest prediction of NDF.

Equation 40: $ADF = 12.57 + 1.24\ maturity + 0.21\ height$
$n = 95$, $r^2 = 0.87$, $RMSE = 1.92$
This equation was created from data in SW Saskatchewan and found accurate and useful for preharvest prediction of ADF.

Equation 41: $CP = 29.09 - 0.22\ maturity - 0.08\ height$
$n = 95$, $r^2 = 0.22$, $RMSE = 3.17$

This equation was created from data in SW Saskatchewan and found inaccurate and not useful.

Equation 42: ADL = 3.91 + 0.05 height

$n = 31$, $r^2 = 0.34$, RMSE = 1.22

This equation was created from data in SW Saskatchewan and found inaccurate and not useful.

Equation 43: Ash = 14.51 - 0.08 maturity

$n = 31$, $r^2 = 0.56$, RMSE = 0.76

This equation was created from data in SW Saskatchewan and found slightly accurate and not very useful.

Equation 44: ADIN = 0.16 - 0.01 maturity + 0.01 height

$n = 31$, $r^2 = 0.01$, RMSE = 0.03

This equation was created from data in SW Saskatchewan and found inaccurate and not useful.

Equation 45: NDIN = 0.26 - 0.01 maturity + 0.01 height

$n = 31$, $r^2 = 0.03$, RMSE = 0.05

This equation was created from data in SW Saskatchewan and found inaccurate and not useful.

Equation 46: EE = 2.38 + 0.08 maturity - 0.01 height

$n = 31$, $r^2 = 0.03$, RMSE = 0.37

This equation was created from data in SW Saskatchewan and found inaccurate and not useful.

Equation 47: IVTD = 21.08 + 13.15 maturity

$n = 72$, $r^2 = 0.61$, RMSE = 11.38

This equation was created from data in SW Saskatchewan and found slightly accurate and moderately useful.

1.0 INTRODUCTION

In 2002 Saskatchewan had over 330,000 acres under irrigation. Eighty three percent of irrigated acres in the Southwest Development Area (defined by Sask Water as the approximate area south of Kindersley and west of Moose Jaw) produce forages as feed for livestock. The majority of the non-intensive acres, and some of the intensive acres, produces low yields of low quality forage. Non-intensive irrigation is also known as back flood irrigation. The average long term annual hay yields from dry land is 1.1 tons/acre or 2466 kg/ha. (personal communication, Terry Karwondy, SAFRR). Well managed intensive irrigation can consistently produce yearly yields approaching six tons/acre or 13450 kg/ha. To increase the economic value of irrigation in the near future two things need to be accomplished: increase yields and increase quality of the forages harvested. Poor soil quality greatly limits yield. Reallocation of water rights to more productive land would remove soil quality limitations. This paper will provide an estimate of forage utilization, based on infield characteristics, as a method of improving forage quality. Knowledge of potential animal performance will aid in the proper management of alfalfa.

Proper economic management of alfalfa (*Medicago sativa* L.) requires knowledge of a number of factors including forage quality. When comparing alfalfa to other forage species it usually has higher crude protein and lower fiber levels than grasses. Alfalfa generally yields more under an irrigated two cut system. The quality of the standing forage will deteriorate during harvest, storage, and feeding. Many producers’ harvest management decisions are based on little or no knowledge of chemical composition due to the time and expense of obtaining this information prior to harvest. In many cases the economic value of alfalfa depends on its contribution to animal production rather than its market price due to direct feeding on the farm. Knowledge of animal performance prior to harvest, would allow the producer to harvest, store, and inventory the feed based on its potential value in the ration. The objective of this paper is to evaluate the usefulness of animal performance predictors prior to the harvest of alfalfa.

2.0 LITERATURE REVIEW

2.1 Plant Growth

Mankind has always sought to know the future. From the beginning of intelligence, humans noted cycles, remembered, and used them to predict the future. Our modern day modeling simply represents a more specific and complex method of predicting the future, yet that desire for knowledge of the future still drives us.

The growth cycle of alfalfa, precisely documented by Kalu and Fick (1981), in Table 2.1, contains ten different stages through which an alfalfa plant progresses. Even before alfalfa reaches the first stage it must germinate. Several factors influence germination, including water supply, soil salt concentration, temperature and light. Upon germination the hypocotyl elongates, pushing the hypocotyledonary hook upward, pulling the cotyledons to the soil surface. When exposed to the surface, the light activates the enzymatic destruction of the elongation-stimulating auxin. This causes growth on the light side of the hypocotyledonary hook to cease, while the dark side continues to grow. The net effect turns the cotyledons upward. Once the seedling has emerged it enters the first of the vegetative stages.

Table 2.1. Definition of morphological stages of development for individual alfalfa stems (Kalu and Fick 1981).

Number	Stage Name	Stage Definition
Stage 0	Early Vegetative	Stem length < 15cm; no buds, flowers, or seed pods
Stage 1	Mid Vegetative	Stem length16 to 30cm; no buds, flowers, or seed pods
Stage 2	Late Vegetative	Stem length >31cm; no buds, flowers, or seed pods
Stage 3	Early Bud	1 to 2 nodes with buds; no flowers or seed pods
Stage 4	Late Bud	3 or more nodes with buds; no flowers or seed pods
Stage 5	Early Flower	One node with one open flower; no seed pods
Stage 6	Late Flower	2 or more nodes with open flowers; no seed pods
Stage 7	Early Seed Pod	1 to 3 nodes with green seed pods
Stage 8	Late Seed Pod	4 or more nodes with green seed pods
Stage 9	Ripe Seed Pod	Nodes with mostly brown mature seed pods

The first three stages (stage 0, stage 1, and stage 2), are vegetative stages, that differ only by height. In the vegetative stages the plant simply increases its ability to access resources. This includes increasing the photosynthetic area, initiating new shoots and growth of existing ones, as well as increasing the root mass. Reserves begin to accumulate in the crown and roots.

The next two stages (stage 3 and stage 4) occur when the plant initiates the reproductive phase. The first step of reproduction, formation of buds at the nodes, will later turn to flowers (stage 5 and stage 6) and eventually, with fertilization, become seed pods (stage 7, stage 8, and stage 9). Once the shoot enters the reproductive stages, growth slows as the energy directs away from growth and to both reproduction and replenishing reserves. As the alfalfa matures from vegetative stages through reproductive stages the fibers and lignin increases to strengthen the stem and hold up the increasing mass against the wind.

Even though unstressed alfalfa will always go through these stages, considerable annual differences are observable. In some years, the plants may remain small and progress rapidly through the growth cycle, while in other years the alfalfa may lodge while still in the vegetative stages due to the extreme growth. If a producer intends to use it for feed, these variations may cause significant adversity (poor animal performance) or opportunity (excellent animal performance). Obviously, knowledge (and eventually control) of quality would aid the producer in accomplishing goals. The creation of mathematical models to predict growth is the first step to gain control. In order to create accurate models, one must know the correct parameters to include.

2.2 Weather Models

The first models to predict alfalfa growth and chemical characteristics included weather data (Fick and Janson 1990; Onstad and Fick 1983; Fick and Onstad 1988). Some of the variables studied were heat sums (with a 5^{o}C base temperature), day length sums, age of the canopy, leaf proportion of the canopy, and Mean Stage by Weight (MSW). With these variables, they attempted to predict chemical composition characteristics such as crude protein (CP), in vitro true digestibility (IVTD), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and leaf percentage. These models were not very accurate and required measurements that were difficult to obtain, often more work than direct sampling. The present study did not evaluate these models.

2.3 Mean Stage by Weight (MSW) models

Fick and Onstad (1988) found that stage of maturity, as defined by Mean Stage by Weight (MSW), was the single factor that most closely correlated alfalfa quality. Kalu and Fick (1981) presented a classification system (Table 2.1) for alfalfa with 10 stages and two alternative methods of determining mean stage – MSW and Mean Stage by Count (MSC). The MSC procedure estimated the mean as the average of observed stages weighted for the number of stems per stage.

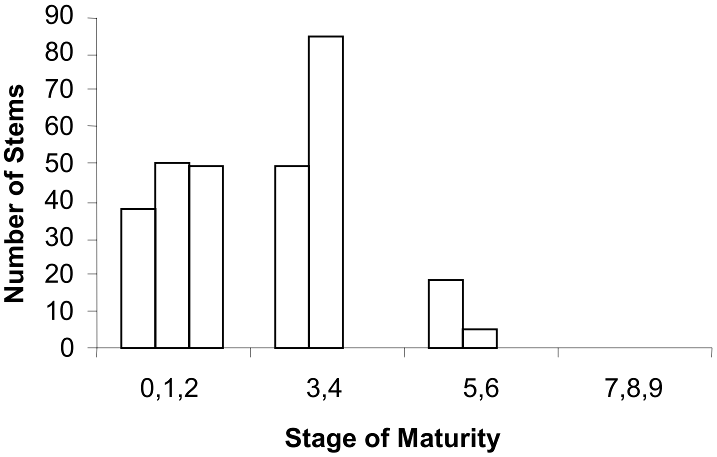

Figure 2.3. Sample Maturity Distribution for a MSC of 2.57 (data from 00LH13 in Appendix B and calculation in Table 2.3)

Table 2.3. Sample Calculation of MSC

Stage Number	Number of Stems	Stage N x N of Stems
0	38	0
1	51	51
2	46	92
3	49	147
4	85	340
5	18	90
6	5	30
Total	292	750

MSC = 750 / 292 = 2.57

The Mean Stage by Weight (MSW) procedure weighted the average of the observed stages by the dry mass of herbage in each stage. MSW required more labor due to weighing of the separated herbage sub samples. A conversion has been developed (Mueller and Fick 1989).

$$\text{MSW} = 0.456 + 1.153\ \text{MSC} \qquad \text{eq.1}$$

$$(n = 596,\ r^2 = 0.982,\ \text{RMSE} = 0.311)$$

MSC cannot be directly converted to MSW if there are young shoots regrowing from the crown. The presence of young growth combined with older previous growth actually cause MSC to peak and even start to lower so that canopies of different maturities could not be distinguished. Where as in the same situation, the small mass of the young shoots would not affect MSW as much and the MSW will continue to increase or plateau. Even though MSW required more labor, time and equipment, Mueller and Fick (1989) found MSW superior because it can be applied to even the very mature stages. However, MSC appeared appropriate up to the time that new basal shoots started to grow into an older canopy (approximately 8 weeks) and seemed as accurate as direct measurements of MSW.

Sanderson (1992) validated the conversion of MSC to MSW with combined datasets from Iowa and Texas ($n = 1129$, $r^2 = 0.95$, $RMSE = 0.288$). From this, he found the conversion equation accurate and applicable over a wide range of geographic and environmental locations.

Many equations have been published to predict CP, IVTD, NDF, ADF and ADL from MSW. The first was Kalu and Fick (1981), when they developed the staging procedure. They noted that several quality characteristics may depend on the stages. They reported equations for IVTD and CP based on data taken from New York State.

Original MSW Equations (Kalu and Fick 1981)

Samples were taken from the Caldwell Field Agronomy Research Farm in New York State on an alfalfa stand in its third year of full production. Samples were taken from random locations in a replicated field at weekly intervals during the summer of 1975 with subsequent cuts being taken after 10 weeks. The method of Goering and Van Soest (1970) was used to determine IVTD and conventional Kjehdahl digestion was used to determine CP. Unless otherwise noted, all equations are in percent dry matter.

$IVTD = 92.93 – 3.98\ MSW$ eq.2

(n = 11, r^2 = 0.984, RMSE = N/a)

$CP = 40.89 – 7.38\ MSW + 0.57\ MSW^2$ eq.3

(n = 11, r^2 = 0.995, RMSE = N/a)

Two years later they released more equations including changes to the IVTD and CP equations, still based only on data collected in New York state. They also published ADL prediction equations for 1975, 1980 and 1981 individually.

New York State Equations (Kalu and Fick 1983)

Samples included those from 1981 as well as from two additional sites at the Barrett Agronomy Research Farm, which were taken in a similar fashion. One stand was in its first full year of production, and the other was in its seeding year. The new samples had a larger sample size to permit the measurement of fibers and lignin. Lignin, NDF, ADF and IVTD were determined by the methods of Goering and Van Soest (1970), and CP determined by conventional Kjeldahl with a boric acid modification.

$CP = 36.15 – 6.09\ MSW + 0.48\ MSW^2$ eq.4

(n = 35, R^2 = 0.883, RMSE = 0.41)

$IVTD = 93.67 – 4.29\ MSW$ eq.5

(n =35, r^2 = 0.957, RMSE = 0.32)

$$\text{NDF} = 20.62 + 8.03\ \text{MSW} - 0.59\ \text{MSW}^2 \qquad \text{eq.6}$$

$(n = 24, R^2 = 0.946, \text{RMSE} = 0.45)$

$$\text{ADF} = 17.05 + 3.85\ \text{MSW} \qquad \text{eq.7}$$

$(n = 24, r^2 = 0.899, \text{RMSE} = 0.51)$

$$\text{ADL} = 2.77 + 1.01\ \text{MSW} \qquad \text{eq.8}$$

$(n = 24, r^2 = 0.841, \text{RMSE} = 0.17)$

Fick and Onstad (1988) set out to validate these equations with a USA national data set (CA, GA, WI, NM, NY, and KY), which also produced a new set of prediction equations. When tested nationally the New York States indicated no bias in the predictions (slope was equal to 1, intercept was equal to 0) but the prediction errors averaged 1.37 times the calibration errors (variation during equation creation), which suggested the need for regional equations.

National MSW Equations (Fick and Onstad 1988)

Samples were taken from five sites in 1982 from across the USA (NM, GA, GA, KY, NY, WI) to represent a wide range of environmental conditions with respect to latitude and weather. The sixth site was from New York state and was sampled in 1980 and used by Kalu and Fick (1983) in the development of their equations. ADF, NDF, ADL, and IVTD were determined by the methods of Goering and Van Soest (1970), and CP determined by conventional Kjeldahl with the boric acid modification (AOAC 1976).

$$CP = 37.1 - 7.58\ MSW + 0.76\ MSW^2 \qquad \text{eq.9}$$

$(n = 43, r^2 = 0.64, RMSE = 2.74)$

$$IVTD = 100 - 16.3 \ln(MSW + 1) \qquad \text{eq.10}$$

$(n = 42, r^2 = 0.70, RMSE = 3.15)$

$$NDF = 13.4 + 17.7 \ln(MSW + 1) \qquad \text{eq.11}$$

$(n = 43, r^2 = 0.70, RMSE = 3.66)$

$$ADF = 12.5 + 13.1 \ln(MSW +1) \qquad \text{eq.12}$$

$(n = 44, r^2 = 0.70, RMSE = 2.91)$

$$ADL = 1.91 + 3.23 \ln(MSW + 1) \qquad \text{eq.13}$$

$(n = 44, r^2 = 0.59, RMSE = 0.91)$

Sanderson and Wedin (1988), examined the change of cell wall components with maturity, and published several other equations predicting NDF, lignin and cellulose for the Iowa region. Samples were taken from two sites at the Agronomy and Agricultural Engineering Research Center near Ames, Iowa. The two sites were seeded May 6, 1983 and one was used for sampling in 1984 and the other in 1985. Sampling began in spring when the alfalfa was about 10 cm tall and was continued every ten days until the end of the spring harvest (June 10, 1984 and June 21, 1985). The entire site was then cut and the fall harvest was collected in a similar fashion. NDF, ADF, and ADL were determined according to the methods of Van Soest and Robertson (1980).

$$\mathrm{NDF} = 212 + 149\ \mathrm{MSW} - 11.5\ \mathrm{MSW}^2 \qquad \text{eq.14}$$

$(n = 79, r^2 = 0.88, \mathrm{RMSE} = 43)$

$$\mathrm{Lignin} = 106 + 29\ \mathrm{MSW} - 2.4\ \mathrm{MSW}^2 \qquad \text{eq.15}$$

$(n = 79, r^2 = 0.72, \mathrm{RMSE} = 13)$

In 1989 they republished an NDF equation as well as an IVTD equation using data from samples collected from another study. They were examining the phenological stage and herbage quality relationships of alfalfa, red clover, smooth brome grass and timothy. Two plots were established, one in 1983 and the other in 1984 with samples taken from the year after seeding (1984 and 1985). IVDDM was determined via the NC-64 direct-acidification method (Marten and Barnes 1980) and NDF according to Van Soest and Robertson (1980).

$$\mathrm{NDF} = 150 + 98\ \mathrm{MSW} - 6\mathrm{MSW}^2 \qquad \text{eq.16}$$

$(n = 16, r^2 = 0.98, \mathrm{RMSE} = 16)$

$$\mathrm{IVDDM} = 833 - 43\ \mathrm{MSW} \qquad \text{eq.17}$$

$(n = 16, r^2 = 0.98, \mathrm{RMSE} = 13)$

Fick and Janson (1990) revalidated both the New York States (eq. 4 to 8) and the national equations (eq. 9 to 13) in growth chamber trials. They found most of the equations were biased (slope not one and intercept not zero) although robust across several environments. They also found that the size of the prediction error appeared to correlate with the variability in the test data set, and they recommended that the calibration data and predictive domain overlap as much as possible.

Allan and Fick (1990) also found some difficulties with the prediction equations when evaluating the equations in production fields. They used MSC as the main predictor of ADF and NDF and found bias and prediction errors exceeded 40g/kg for samples collected from producer managed fields in four northeastern states.

Sanderson (1992) again tested the national dataset equations (eq. 9 to 13) against several previously published datasets from Texas and Iowa. He found that in most cases the intercepts and slopes deviated from zero and one respectively, indicating bias. He recommended the development of equations for a narrower range of environments and use of the equations within similar environments.

Predicting fiber levels from Mean Stage By Weight involves cutting, counting, drying and weighing each stem. It is not a procedure utilized by many producers. To be more practical an easier and quicker method must be developed.

2.4 Prediction Equations for Alfalfa Quality (PEAQ) Models

Measuring MSW is a labor intensive procedure that requires cutting, staging, and weighing each stem from a sample. A much simpler method would be needed for producer exploitation. Hintz and Albrecht (1991) evaluated 15 maturity and morphological characteristics to predict CP, NDF, ADF and ADL in Wisconsin. They found that equations based on height of the tallest stem and maturity of the most mature stem (on a scale of 0 to 9, Kalu and Fick, 1981) gave calibration errors similar to those found by other researchers using MSW. The time required for measuring the height of the tallest stem and the maturity of the most mature stem (PEAQ) was significantly less than clipping, drying and weighing a large number of stems (MSW). The ease and low cost of this method (PEAQ) made it particularly attractive for estimating pre-harvest chemical composition. It cannot substitute for chemical analysis of plant material once stored, although it did allow an estimate of initial quality.

When using the PEAQ method, the height was measured in cm starting from 4.0cm above the soil surface. The maturity was the integer of the stage number, as defined by Kalu and Fick (1981) of the most mature stem (Table 2.1).

Original Equations (Hintz and Albrecht 1991)

Three sites were established for sampling. One was established at the University of Wisconsin Arlington Experimental Farm in Arlington, WI in 1987 and sampled twice in 1988. These plots were not irrigated and displayed signs of severe moisture stress. Another site was also established at Arlington in 1988 and sampled four times in 1989. This site was irrigated three times during the growing season. The final site was established at the U.S. Dairy Forage Research Center Field Facility at Prairie du Sac, Wisconsin in 1988 and sampled four times in 1989. This site was not irrigated but did not show signs of moisture deficit. NDF, ADF and ADL was by sequential analysis procedure of Robertson and Van Soest (1981) with some modifications. Sodium sulfite was included and the samples were treated with α-amylase during NDF refluxing and filtration. Total Kjeldahl nitrogen was determined by the procedure of Bremner and Breitenbeck (1983).

$$\text{NDF} = 168.9 + 2.7\ \text{height} + 8.1\ \text{maturity} \qquad \text{eq.18}$$

$$(n = 540,\ R^2 = 0.89,\ \text{RMSE} = 26.2)$$

$$\text{ADF} = 115.7 + 2.1\ \text{height} + 7.9\ \text{maturity} \qquad \text{eq.19}$$

$$(n = 540,\ R^2 = 0.88,\ \text{RMSE} = 22.0)$$

$$\text{CP} = 307.1 - 0.9\ \text{height} - 8.9\ \text{maturity} \qquad \text{eq.20}$$

$$(n = 540,\ R^2 = 0.74,\ \text{RMSE} = 21.7)$$

$$\text{ADL} = 15.8 + 0.5\ \text{height} + 2.5\ \text{maturity} \qquad \text{eq.21}$$

$$(n = 540,\ R^2 = 0.84,\ \text{RMSE} = 6.5)$$

In 1995, Owens, Hintz, and Albrecht, split this dataset to separate the first cut from the remaining cuts and developed equations for each. This was done to see if separating the harvests improved the accuracy. These three sets of equations were then compared to new data collected for evaluation. They found that separating the cuts did not improve the accuracy, and they recommended the use of the original equations, which had less bias. Their RMSE values compared favorably to those that Fick and Janson (1990) reported for MSW equations (eq. 9 to 13). Their RMSE values were lower than those reported by Fick and Onstad (1988) for their MSW equations (eq. 9 to 13). Although they found statistically significant bias in the majority of the equations, they argued that even a small difference could become statically different with the large sample sizes they obtained and that it may not represent biological significance. Additionally, they found similar accuracy with the PEAQ equations as they did with commercial Near Infra Red Spectroscopy (NIRS). They also withdrew the previous recommendation that CP was predictable. Neither the first nor subsequent cuts showed r^2 above 0.4 for CP.

In the first cut, maturity was the most influential of the two parameters in raising both ADF and NDF levels as indicated by the larger coefficients in equations 22 and 23. In the second and subsequent cuts, height became more influential than maturity as indicated by larger coefficients in equations 25 and 26.

Split Original Dataset grouped by Cut

(Owens et al. 1995 using data from Hintz and Albrecht 1991)

First Cut

NDF = 18.19 + 0.54 height + 1.44 maturity eq.22

($n = 150$, $r^2 = 0.83$, RMSE = 2.45)

ADF = 11.92 + 0.46 height + 1.11 maturity eq.23

($n = 150$, $r^2 = 0.78$, RMSE = 2.30)

$CP = 29.63 - 0.23\ \text{height} - 0.87\ \text{maturity}$ eq.24

($n = 150$, $r^2 = 0.37$, $RMSE = 2.27$)

Second and third cuts

$NDF = 16.53 + 0.86\ \text{height} + 0.25\ \text{maturity}$ eq.25

($n = 158$, $r^2 = 0.66$, $RMSE = 3.06$)

$ADF = 12.08 + 0.71\ \text{height} + 0.11\ \text{maturity}$ eq.26

($n = 158$, $r^2 = 0.75$, $RMSE = 2.11$)

$CP = 29.51 - 0.11\ \text{height} - 1.07\ \text{maturity}$ eq.27

($n = 158$, $r^2 = 0.35$, $RMSE = 1.66$)

Cherney (1995) tested several of the equations for accuracy of estimating NDF in New York and found significant deviation in all equations, particularly in very immature and mature alfalfa. Orloff (1996), in the intermountain region of California, found PEAQ predicted forage quality more accurately than MSC for one year, although further evaluation revealed the necessary recalibration of these equations within California.

Sulc et al. (1997), evaluated the original PEAQ equations (eq. 18, 19) created in Wisconsin with data collected from a more diverse region (NY, PA, OH, WI, CA – termed the National Dataset) to determine their validity over a broad area. They also collected data from Ohio and Wisconsin to determine their validity over a more local area. From this more local Ohio/Wisconsin dataset, they developed two more of their own equations to predict NDF and ADF.

$$NDF = 236.7 + 2.1\ height + 4.1\ maturity \qquad eq.28$$

$(n = 159, r^2 = 0.74, RMSE = 2.04)$

$$ADF = 169.0 + 1.7\ height + 3.2\ maturity \qquad eq.29$$

$(n = 159, r^2 = 0.73, RMSE = 1.69)$

Sulc et al. (1997) evaluated the original PEAQ equations (eq. 18, 19) against the entire National Dataset, and evaluated their new OH/WI equations (eq. 28, 29) against only the 48 Ohio samples from this same National Dataset. This would determine if an Ohio specific calibration could improve performance. Due to the under estimation of the fiber of the samples less than 30 cm and the overestimation of fiber in those samples over 100 cm they recommendation that PEAQ be limited to samples with maximum heights of more than 30 cm and less than 100 cm. This may indicate a nonlinear accumulation of fibre with respect to height, particularly at the tall and short extremes. They also found that the equations performed as well in other states as they did in Wisconsin where they originated. They reported RMSE values lower than those previously reported and equal to or lower than those for commercial NIRS estimates of fiber. They also found that multiple sub samplings within a field gave better performance than an individual sample and recommended at least five sub samples for fields of 8 ha or less. However, producers must consider total field size, topography and other conditions that may affect variation of alfalfa within the field when determining the number of sub samples required. The Ohio specific calibration of the equations did not improve performance in Ohio.

2.5 Weiss Equations

The real value of estimating NDF and ADF is their practical application in predicting or improving animal performance. However there is an intermediate step in estimating available energy and intake. Lab analysis of field material provides fiber levels, which are used to estimate available energy. Available energy then can be used to estimate animal performance. The next step after the PEAQ equations is to check the validity of net energy estimates from chemical analysis.

Recently, Weiss et al. (1992) developed a theoretical model for predicting total digestible nutrients (TDN). They described a method combining the truly digestible portions of individual fractions of the feed to determine the total digestible nutrients. These fractions include CP, Fatty acids (FA), NDF and Non Fiber Carbohydrates (NFC).

$$TDN_{1,f} = TdNFC + TdCP_f + TdFA\ (2.25) + TdNDF - \text{fecal } TDN \qquad \text{eq. } 30$$

$(n = 247,\ r^2 = 0.78,\ RMSE = 7.8)$

The overall equation is equation 30, with each of the parameters calculated from the following equations (eq. 31 to 38).

$$Td\ NFC = 0.98 * ((100 - (NDF - NDIN) - CP - EE - Ash) * PAF) \qquad \text{eq. 31}$$

The digestibility of NFC is assumed to be high and constant among the feeds. At most it ranges from 85% to 120% (Van Soest 1982). To calculate the amount of NFC present, subtract the other known values from unity. Hence any error associated with measurements of those other values would be summed when calculating the NFC concentration.

$$TdCP_f = CP * 2.71828^{(-1.2 * (ADIN / CP))} \qquad \text{eq. 32}$$

With the concentration of ADIN expressed as a proportion of CP (ADIN / CP), it is possible to predict the true digestibility of the forage CP (Weiss et al. 1983).

$$TdFA = 1.0 \times EE - 1\% \qquad \text{(Allen 2000)} \qquad \text{eq. 33}$$

True digestibility of fatty acids, range from 1.0 in diets with 0.1% FA to 0.78 in diets with 0.8% FA. For most forage it is assumed to be 1.0. Non-fatty acid EE averages about 10g/kg DM and should be subtracted. (Weiss et al. 1992 quoted Palmquist personal communication). This fraction probably contains pigments and waxes, which contain almost no digestible energy. To equate lipid energy to carbohydrate energy, Atwater's constant of 2.25 was used.

TdNDF = 0.75 * (NDFn - ADL) * ((1 - (ADL / NDFn) $^{0.667}$)) eq. 34

NDFn = NDF – NDIN eq. 35

Weiss et al. (1992) modified the equation for TdNDF given by Conrad et al. (1984) to account for NDIN. They also derived a considerably lower coefficient of 0.75 than the 0.96 derived by Gerard and Dupuis (1988), who also failed to include NDIN.

Fecal TDN = 7% (Weiss et al.1992) eq. 36

Fecal TDN was not measured directly, but rather was calculated from assumed values of the digestible portions. Weiss, et al., used equations developed by Girard and Dupuis (1988).

TDN CP = %DM x average CP content x digestibility

= 130 x 0.3 x 0.7 = 27 g/kg

TDN EE = %DM x average EE content x %FA x 2.25

= 130 x 0.15 x 0.32 x 2.25 = 14 g/kg

TDN NFC = %DM x average NFC content x assumed digestibility

= 130 x 0.25 x 0.98 = 31 g/kg

Fecal TDN = 27 + 14 + 31 = 72 g/kg which was rounded to 7%

The %DM of fecal material was found to be 130 g/kg (Van Soest 1982). The major components of fecal material are CP, EE, and NFC with average amounts around 300g, 150 and 250g per kg DM respectively, (Jarrige 1965).

Crude protein has an apparent digestibility of 0.5, which corresponds to a true digestibility of 0.7 (Anthony 1970). The average forage EE contains 32% FA (Palmquist and Jenkins 1980; Palmquist 1991). The average NFC digestibility is assumed to be 0.98 (Van Soest 1982; Jarrige 1965).

The 2001 Dairy NRC Requirement publication suggests that feed TDN is dependent on intake, with a cow ingesting a larger amount of feed, digesting less. To account for this they applied a discount factor based on the TDN of the entire ration with a ration of high intakes receiving a more severe discount. This study will also compare these to the in vitro digestibilities for different levels of intake.

$$TDN_p = TDN_{1,f} \times \text{discount} \qquad \text{eq. 37}$$

$$\text{Discount} = (100 - ((\text{ration TDN} * 0.18 - 10.3) / (\text{ration TDN} / 100) * (p - 1))) / 100 \qquad \text{eq. 38}$$

2.6 Literature Review Summary

When trying to predict plant characteristics, the model must include the correct parameters to insure accuracy. The first models included weather information and did provide accurate results. However, they did indicate a parameter (maturity) that may increase accuracy. As the maturity models were developed they became more accurate and used parameters easier to measure. Finally, a model surfaced using only height and maximum maturity to predict fiber levels. Many of these models require local calibration, which has not been done in Saskatchewan. These models, which predict plant characteristics, have often been combined with other models to predict animal performance with no heed to error terms.

3.0 GENERAL OBJECTIVES

The goal of this research was to evaluate and develop a method to estimate in vitro dry matter digestibility of alfalfa from field measurements (height and maturity). To achieve this purpose requires the accomplishment of several sub goals.

The first sub goal was to determine if the prediction of chemical components from height and maturity are valid for Southwestern Saskatchewan.

The NRC net energy equations (Weiss equations, eq. 30-37) can estimate TDN of forages. The NRC equations use ADF, NDF, CP, ADL, EE, Ash, NDIN, and ADIN to predict TDN. The second sub goal determines the validity of these NRC equations of predicting TDN from the chemical components.

Finally, prediction models for IVTD directly from height and maturity were developed and evaluated.

Then, since the appropriate data was collected in accomplishing the previous sub goals, evaluation of the MSW equations was accomplished in a region significantly further north than where they were developed.

4.0 MATERIALS AND METHODS

4.1 Experiment 1 – Validation of Prediction Equations

4.1.1 Objectives

The goal of the first experiment was to develop a database to evaluate the existing Mean Stage by Weight (MSW) equations and Prediction Equations of Alfalfa Quality (PEAQ). In order to accomplish this goal, six characteristics were measured at various stages of growth. These included: height, MSC, maximum maturity, NDF, ADF, and CP.

4.1.2 Sample Collection

Six sites were chosen each year from a total of seven irrigation sites in southwestern Saskatchewan. The experimental design is a survey of the sites from 1998 to 2000. The sites were chosen to be representative of alfalfa production fields and contain a range of soils and alfalfa cultivars and are described in Appendix C. No cultivars were sampled which had quality enhancing traits such as multifoliate or reduced bloat characteristics. The major difference between the cultivars chosen was the rate of regrowth, which is measured in the stage of maturity.

Under irrigation in Saskatchewan, alfalfa is generally cut twice during the growing season. Each site was sampled at four different growth stages per cut. The testing spanned five cuts over three years, with a total sample size of 120. Each sample was to represent the maturity and height of the entire field at that date. To be representative, five sub samples were taken from random locations within the field. Each sub sample consisted of one quarter square meter clipped at 4 cm, and assigned a MSC, as defined by Kalu and Fick (1981). MSW was calculated for each sample using equation 1. The height of the tallest stem and maturity of the most mature stem was noted. The five sub samples were mixed and divided in half for duplicate chemical analysis. The samples were dried at 60°C (AOAC method 930.15) and ground to pass a 1mm screen. The parameters measured were NDF (Van Soest et al. (1991), without amylase and with sodium sulphite), ADF (AOAC method 973.18), and CP by Kjeldahl nitrogen (AOAC method 984.13) using a Tecator 1030 Titrator.

4.1.3 Statistics

The predicted values from the equations were regressed on the chemically measured values to evaluate equations. The linear regression package of Statistix Analytical Software (SAS, 2001) was used to make the test. In this test, a perfect prediction equation would have an intercept of 0.0 and a slope of 1.0, and a coefficient of determination (R^2) of 1.0 (Figure 4.1). For creating new prediction equations, the General Linear Models package of SAS was used. A stepwise regression was used to remove any site, year, or cut interactions based on the p value. An ideal equation would be able to remove site, year, and cut interactions, have a coefficient of determination (R^2) of 1.0 and root mean squared error (RMSE) of 0.0. Approximately 75% of the data were used in creating the equation, while the remaining 25% were randomly removed for validation. Validation procedures for the created equations were the same as described above, using the remaining 25% of the data.

The evaluation of the regression models is based on several statistics. The coefficient of determination (R^2) indicates a goodness of fit with better models having a higher R^2. The R^2 can be inflated by extreme values or by an increase in the number of independent variables in the equation. The RMSE is the standard deviation of the observations about the regression line and it gives an absolute measure of goodness of fit. The RMSE has the same units as the variable predicted. In validation, an ideal equation would have a RMSE of 0.0, a R^2 of 1.0, an intercept not significantly different from 0, and a slope not significantly different from 1. Several authors (Fick and Janson (1990), Fick and Onstad (1988), Onstad and Fick, (1983)), suggest that RMSE is the best overall test, due to the coefficient of determination being more susceptible to extreme values and also more dependent on the sample size than RMSE.

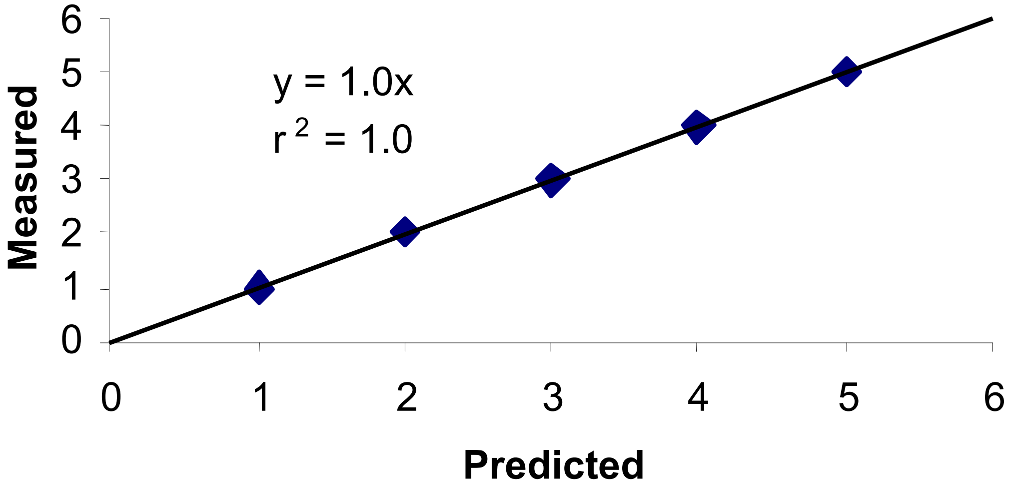

Figure 4.1. Example of Validation Technique on an Ideal Prediction Equation

When the T test shows that the slope is equal to 1.0 at a probability level of 10% or more ($p > 0.1$) no bias in the slope is indicated. If the probability of the slope being equal to one is between 1% and 10% ($0.01 > p > 0.1$) the slope is reported as moderately biased. Bias was reported if the probability of the slope being equal to one was less than 1% ($p < 0.01$). The same terminology is used to describe how closely the intercept comes zero.

4.2 Experiment 2 –Prediction of In Vitro Organic Matter Digestibility

4.2.1 Objectives

The purpose of the second experiment was to determine if in vitro digestibility could be predicted accurately directly from field information (height and maturity) and to evaluate the digestibility equations previously published.

4.2.2 Sample Collection

A subset of the data (n=72) from Experiment 1 was selected for determination of in vitro organic matter digestibility (Tilley and Terry 1963, modified by Troelsen 1971). The subset is from the last two years of data, which consisted of three cuts and seven different sites. Values from Experiment 1 were also included (Height, Maturity, ADF, NDF, CP).

4.2.3 Statistics

The predicted values were regressed on the measured values to evaluate equations. The linear regression package of SAS was used. In this test, a perfect prediction equation would have an intercept of 0.0, a slope of 1.0, and a coefficient of determination (R^2) approaching 1.0. For creating new prediction equations, the General Linear Models package of SAS was used. A stepwise regression was used to attempt to remove any site, year, or cut interactions. An ideal equation would be able to remove site, year and cut interactions, have a high coefficient of determination (R^2) and low root mean squared (RMSE). Approximately 75% of the data from this new dataset were used in creating the equation, while the remaining 25% were randomly set aside for validation. Validation procedures for the created equations were the same as described above, using the remaining 25% of the data.

4.3 Experiment 3 – Validation of Weiss equations

4.3.1 Objectives

The purpose of the third experiment was to evaluate the Weiss equations and also determine if any of the parameters (Ash, ADIN, NDIN, Fat, Lignin) used were predictable from field data (height and maturity). This was accomplished by comparing the TDN estimated from the Weiss equations using the analysis from Experiment 1, to the OMD measured by in-vitro analysis. TDN has a high correlation to OMD for forages due to the uniform low levels of lipids (avg. 2.6%, st. dev. 0.4 from this dataset).

4.3.2 Sample Collection

A subset of the previous data (n = 42) from Experiment 2 was selected for further analysis. The subset is from one year, both cuts and seven sites. Total Ash (AOAC method 942.05), Acid Detergent Insoluble Nitrogen (Kjeldahl Nitrogen performed on the ADF residue), Neutral Detergent Insoluble Nitrogen (Nitrogen (Kjeldahl Nitrogen performed on the NDF residue), Crude Fat (AOAC method 7.061), and Lignin (AOAC method 973.18) were the additional parameters examined. Values from Experiment 2 were also included (CP, ADF, NDF, Height, Maturity, OMD).

4.3.3 Statistics

The predicted energy values were regressed on the measured values to evaluate equations. The linear regression package of SAS was used to make the test. In this test, a perfect prediction equation would have an intercept of 0.0, a slope of 1.0, and a very high significant coefficient of determination (R^2). For creating new prediction equations, the General Linear Models package of SAS was used. A stepwise regression was used to attempt to remove any site, year or cut interactions. An ideal equation would be able to remove site, year and cut interactions, have a high coefficient of determination (R^2) and low root mean squared (RMSE). Approximately 75% of the data were used in creating the equation, while the remaining 25% were randomly set aside for validation. Validation procedures for the created equations were the same as described above, using the remaining 25% of the data.

5.0 RESULTS AND DISCUSSION

5.1 Comparison of Data Sets from Experiments 1, 2, and 3

For comparison of how the nutrient composition changed with maturity, the data were split into the maturity stages by MSC for display. Experiment 3 did not have any of the very young samples (MSC < 1). Table 5.1a shows the averages, standard deviation, maximum value, and minimum values for each parameter measured in each experiment. For evaluation purposes, the data was also organized by MSC to show trends in each of the parameters measured.

Table 5.1a. Variance of the Analyses from Experiment 1, 2, and 3

	Experiment 1					Exp. 2		Experiment 3					
MSC	Height[1]	ADF[2]	NDF[2]	CP[2]	N[3]	OMD[2]	N[3]	ADIN[2]	NDIN[2]	ADL[2]	EE[2]	Ash[2]	N[3]
0-1	32	21.2	27.6	27.9	5	68.7	3	N/a	N/a	N/a	N/a	N/a	0
1-2	49	26.4	33.2	24.6	42	65.6	29	0.23	0.36	5.63	2.56	11.68	15
2-3	67	32.1	39.5	22.6	34	62.1	22	0.16	0.29	7.15	2.62	10.18	14
3-4	79	35.3	42.7	21.6	29	58.1	15	0.17	0.29	7.95	2.52	8.98	11
4-5	88	36.5	44.6	22.1	10	60.3	2	0.16	0.35	7.73	2.99	9.15	2
Avg	64	30.8	38.0	23.2	120	62.9	72	0.19	0.32	6.85	2.59	10.35	42
St.Dv.	19	5.2	5.7	3.5	120	4.6	72	0.16	0.10	1.37	0.40	1.24	42
Max	126	43.9	51.5	33.0	120	79.1	72	1.17	0.67	11.15	3.60	12.68	42
Min	29	18.7	24.8	17.1	120	54.7	72	0.11	0.20	3.89	1.88	7.94	42

[1] in cm,
[2] in % of Dry Matter,
[3] the number of samples

The datasets from Sulc et al. (1997) and Hintz and Albrecht (1991) were chosen for comparison to the dataset collected in this study. Sulc et al. (1997), evaluated the PEAQ equations with data collected across five states (NY, PA, OH, CA, WI), and determined them robust across a wide range of environments.

Table 5.1b. Dataset Characteristics from Sulc et al. (1997) across 5 states

	Height[1]	ADF[2]	NDF[2]	CP[2]	N[3]
Average	63.8	28.3	36.9	N/a	192
St. Dev.	14.9	3.8	4.7	N/a	192
Max	100	38.5	48.8	N/a	192
Min	35.7	19.6	26.0	N/a	192

[1] in cm,
[2] in % of Dry Matter,
[3] the number of samples

The dataset from Sulc et al. (1997) had a slightly lower average ADF (28.3 vs. 30.8) and slightly lower average NDF (36.9 vs. 38.0) than the ADF and NDF from this study. The dataset from this study (Table 5.1a) included samples that had a maximum height of over 100 cm (126 cm tallest) and shorter than 35.7 cm (29 cm shortest) and as a result had slightly larger standard deviations.

Hintz and Albrecht (1991) used a very large dataset (n = 540) from Wisconsin to examined 15 morphological characteristics to develop a fast, simple method of quality estimation (estimating NDF and ADF). Other characteristics (such as mean stem height weighted for plant mass) provided slightly better correlations, however they suggested that maximum height and maximum maturity provide the best compromise between prediction, accuracy, and ease of use.

Table 5.1c. Dataset Characteristics from Hintz and Albrecht (1991) in Wisconsin

	Height[1]	ADF[2]	NDF[2]	CP[2]	N[3]
Average	51	25.4	33.9	22.4	540
St. Dev.	N/a	N/a	N/a	N/a	N/a
Max	120	37.7	49.7	32.2	540
Min	12	13.3	19.6	13.5	540

[1] in cm, [2] in % of Dry Matter, [3] the number of samples

The dataset from Hintz and Albrecht (1991) had a lower average ADF (25.4 vs. 30.8) and average NDF (33.9 vs. 38.0) than the ADF and NDF from this study. Maximum heights were very similar (120 vs. 126), however they included samples shorter (12 vs. 29) than the dataset included in this study (Table 5.1a). CP was also slightly lower (22.4 vs. 23.2).

5.2 Comparison of MSW Models

These equations use MSW as the main parameter to predict a variety of plant characteristics. Therefore the data presented here include results from all three experiments. In this study MSW was not measured. However, MSC converts to MSW using the equation presented by Kalu and Fick (1981), (eq. 1) and validated by Sanderson (1992). Kalu and Fick (1981) used data from Wisconsin to develop the conversion equation, while Sanderson (1992) used data from both Iowa and Texas. Sanderson (1992) concluded that the conversion equation was accurate and applicable over a wide range of geographic and environmental locations. However the conversion was never evaluated with data from growing conditions north of Wisconsin. As a result, if any of the MSW equations are declared inaccurate by this study it may be possible that the conversion equation is inaccurate rather than the MSW equation.

5.2.1 Validation of Original MSW Equations

When Kalu and Fick (1981) developed the alfalfa stage classification system they suggested that it might be used to predict some quality characteristics. They correlated the MSW to IVTD to show the usefulness of MSW (eq. 2). The first line of Table 5.2.1a shows parameters of the dataset used to create the IVTD equation. The final line shows how well the equation performed in SW Saskatchewan. The equation suggests that digestibility decreases as the plant matures which is consistent with conventional knowledge. This equation did not predict IVTD very well in SW Saskatchewan.

Table 5.2.1a. Validation of Equation 2

In Vitro True Digestibility, % of Dry Matter = 92.93 – 3.98 MSW

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
IVTD	Kalu & Fick (1981)	New York	11	0.984	N/a	N/a	N/a
IVTD	This study	SW Sask	72	0.496	0.322	Some Bias	No Bias

When Kalu and Fick (1981) developed the alfalfa stage classification system they suggested that it might be used to predict some quality characteristics by correlating the MSW to CP in an exponential relationship. This would suggest a leveling off rather than a continuous linear increase. The first line of Table 5.2.1b shows parameters of the dataset used to create the CP equation. The final line shows how well the equation performed in SW Saskatchewan. The equation suggests that crude protein increases, as the plant matures, however not in a linear fashion. This equation did not predict CP very well in SW Saskatchewan.

Table 5.2.1b. Validation of Equation 3

Crude Protein, % of Dry Matter = 40.89 – 7.38 MSW + 0.57 MSW^2

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
CP	Kalu & Fick (1981)	New York	11	0.982	N/a	N/a	N/a
CP	This study	SW Sask	120	0.207	0.312	Biased	Biased

5.2.2 Validation of New York State Equations

Two years later, Kalu and Fick (1983) published a more complete set of equations based on data collected from New York. The authors were attempting to show the usefulness of the alfalfa stage classification system they developed two years earlier by correlating the MSW to various quality characteristics. The first line of Table 5.2.2a shows parameters of the dataset used to create the CP New York State. The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study. The equation suggests that crude protein decreases initially then increases as the plant matures. This equation did not predict CP well in SW Saskatchewan.

Table 5.2.2a. Validation of Equation 4

Crude Protein, % of Dry Matter = 36.15 – 6.09 MSW + 0.48 MSW^2

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
CP	Kalu & Fick (1983)	New York	35	0.883	2.4	N/a	N/a
CP	Fick & Onstad (1988)	6 States	43	0.62	2.76	No Bias	No Bias
CP	Fick & Janson (1990)	Growth Chamber	33	0.61	2.16	Biased	Biased
CP	This Study	SW Sask	120	0.207	3.12	Biased	Biased

The first line of Table 5.2.2b shows parameters of the dataset used to create the IVTD New York State equation (eq.5). The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study. The equation suggests that digestibility decreases as the plant matures which is consistent with conventional knowledge. This equation did not predict IVTD well in SW Saskatchewan.

Table 5.2.2b. Validation of Equation 5

In Vitro True Digestibility, % of Dry Matter = 93.67 – 4.29 MSW

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
IVTD	Kalu & Fick (1983)	New York	35	0.957	1.9	N/a	N/a
IVTD	Fick & Onstad (1988)	6 States	42	0.67	3.31	No Bias	No Bias
IVTD	Fick & Janson (1990)	Growth Chamber	33	0.86	2.18	Biased	Biased
IVTD	This Study	SW Sask	72	0.496	3.22	Biased	No Bias

The first line of the Table 5.2.2c shows parameters of the dataset used to create the NDF New York State equation (eq. 6). The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study. The equation suggests that NDF decreases initially then increases as the plant matures. This equation did predict NDF well in SW Saskatchewan.

Table 5.2.2c. Validation of Equation 6

Neutral Detergent Fiber, % of Dry Matter = 20.62 + 8.03 MSW – 0.59 MSW^2

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
NDF	Kalu & Fick (1983)	New York	24	0.946	2.2	N/a	N/a
NDF	Fick & Onstad (1988)	6 States	43	0.71	3.64	No Bias	No Bias
NDF	Fick & Janson (1990)	Growth Chamber	30	0.63	3.83	Some Bias	No Bias
NDF	This Study	SW Sask	120	0.750	2.86	No Bias	No Bias

The first line of Table 5.2.2d shows parameters of the dataset used to create the ADF New York State equation (eq. 7). The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study.

The equation suggests that ADF increases as the plant matures which is consistent with conventional knowledge. This equation did predict ADF moderately well in SW Saskatchewan, although not as well as in New York.

Table 5.2.2d. Validation of Equation 7

Acid Detergent Fiber, % of Dry Matter = 17.05 + 3.85 MSW

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADF	Kalu & Fick (1983)	New York	24	0.899	2.5	N/a	N/a
ADF	Fick & Onstad (1988)	6 States	44	0.68	2.99	No Bias	No Bias
ADF	Fick & Janson (1990)	Growth Chamber	30	0.74	2.38	Some Bias	No Bias
ADF	This Study	SW Sask	120	0.689	2.93	No Bias	No Bias

The first line of Table 5.2.2e shows parameters of the dataset used to create the ADL New York State equation (eq.8). The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study. The equation suggests that lignin increases as the plant matures which is consistent with conventional knowledge. This equation did not predict ADL well in SW Saskatchewan.

Table 5.2.2e. Validation of Equation 8

Acid Detergent Lignin, % of Dry Matter = 2.77 + 1.01 MSW

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADL	Kalu & Fick (1983)	New York	24	0.841	0.8	N/a	N/a
ADL	Fick & Onstad (1988)	6 States	44	0.59	0.92	No Bias	No Bias
ADL	Fick & Janson (1990)	Growth Chamber	30	0.60	0.83	Some Bias	No Bias
ADL	This Study	SW Sask	42	0.437	1.03	No Bias	No Bias

5.2.3 Validation of National Dataset Equations

Fick and Onstad (1988) evaluated predictive equations from New York data across six states (CA, GA, KY, NM, NY, WI) and found morphological characteristics to give better fits than weather data. The dataset they developed, called the National Dataset, was used to validate the New York equations on a national basis.

The first line of Table 5.2.3a shows parameters of the dataset used to create the CP National equation (eq.9). The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study. The equation suggests that crude protein decreases initially then increases as the plant matures. This equation did not predict CP well in SW Saskatchewan or in any of the other locations.

Table 5.2.3a. Validation of Equation 9

Crude Protein, % of Dry Matter = 37.1 – 7.58 MSW + 0.76 MSW^2

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
CP	Fick & Onstad (1988)	6 States	43	0.64	2.74	N/a	N/a
CP	Fick & Janson (1990)	Growth Chamber	33	0.62	2.14	Biased	Biased
CP	Sanderson (1992)	Iowa	16	0.73	2.11	Biased	Biased
CP	This Study	SW Sask	120	0.21	3.11	Biased	Biased

The first line of Table 5.2.3b shows parameters of the dataset used to create the IVTD National equation (eq. 10). The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study. The equation suggests that digestibility decreases as the plant matures, however not in a linear fashion. This equation did not predict IVTD well in SW Saskatchewan.

Table 5.2.3b. Validation of Equation 10

In Vitro True Digestibility, % of Dry Matter = 100 – 16.3 ln(MSW + 1)

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
IVTD	Fick & Onstad (1988)	6 States	42	0.70	3.15	N/a	N/a
IVTD	Fick & Janson (1990)	Growth Chamber	33	0.89	1.97	Biased	Biased
IVTD	Sanderson (1992)	Texas	164	0.64	4.25	No Bias	No Bias
IVTD	Sanderson (1992)	Texas	830	0.49	4.69	Biased	Biased
IVTD	This Study	SW Sask	72	0.50	3.20	Biased	No Bias

The first line of Table 5.2.3c shows parameters of the dataset used to create the NDF National equation (eq.11). The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study. The equation suggests that NDF increases as the plant mature, however not in a linear fashion. This equation predicted NDF better in SW Saskatchewan than where it was developed, with the second highest R^2 (0.74).

Table 5.2.3c. Validation of Equation 11

Neutral Detergent Fiber, % of Dry Matter = 13.4 + 17.7 ln(MSW + 1)

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
NDF	Fick & Onstad (1988)	6 States	43	0.70	3.66	N/a	N/a
NDF	Fick & Janson (1990)	Growth Chamber	30	0.61	3.89	Biased	Biased
NDF	Sanderson (1992)	Iowa	16	0.94	1.84	Biased	Biased
NDF	Sanderson (1992)	Texas	164	0.74	3.95	Some Bias	Some Bias
NDF	Sanderson (1992)	Texas	829	0.60	4.51	Biased	Biased
NDF	This Study	SW Sask	120	0.74	2.89	No Bias	No Bias

The first line of Table 5.2.3d shows parameters of the dataset used to create the ADF National equation (eq. 12). The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study. The equation suggests that ADF increases as the plant matures, however not in a linear fashion. This equation did predict ADF moderately well in SW Saskatchewan, better than where it originated, although not as well as in other locations.

Table 5.2.3d. Validation of Equation 12

Acid Detergent Fiber, % of Dry Matter = 12.5 + 13.1 ln(MSW +1)

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADF	Fick & Onstad (1988)	6 States	44	0.70	2.91	N/a	N/a
ADF	Fick & Janson (1990)	Growth Chamber	30	0.78	2.18	Some Bias	No Bias
ADF	Sanderson (1992)	Iowa	16	0.94	1.32	No Bias	No Bias
ADF	This Study	SW Sask	120	0.73	2.73	Some Bias	Some Bias

The first line of Table 5.2.3e shows parameters of the dataset used to create the ADL National equation (eq. 13). The subsequent lines show various studies that attempted to validate the equation, with the final line showing the data from this study. The equation suggests that lignin increases as the plant matures, however not in a linear fashion. This equation did not predict ADL well in SW Saskatchewan or nationally.

Table 5.2.3e. Validation of Equation 13

Acid Detergent Lignin, % of Dry Matter = 1.91 + 3.23 ln(MSW + 1)

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADL	Fick & Onstad (1988)	6 States	44	0.59	0.91	N/a	N/a
ADL	Fick & Janson (1990)	Growth Chamber	30	0.67	0.76	No Bias	No Bias
ADL	This Study	SW Sask	42	0.46	1.00	No Bias	No Bias

5.2.4 Validation of Equations from the Iowa Dataset 1

Sanderson and Wedin (1988), compared cell wall composition at various stages of maturity using samples from Iowa, and found that hemi cellulose not related to maturity, with NDF and lignin dependent on maturity.

The first line of Table 5.2.4a shows parameters of the dataset used to create the NDF equation (eq. 14). The final line shows the data from this study evaluating the equation. The equation suggests NDF decreases initially then increases as the plant matures. This equation did predict NDF moderately well in SW Saskatchewan.

Table 5.2.4a. Validation of Equation 14

Neutral Detergent Fiber, % of Dry Matter = $21.2 + 14.9\ \mathrm{MSW} - 1.15\ \mathrm{MSW}^2$

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
NDF	Sanderson & Wedin (1988)	Iowa	79	0.88	4.3	N/a	N/a
NDF	This Study	SW Sask	120	0.75	2.9	Biased	Some Bias

The first line of Table 5.2.4b shows parameters of the dataset used to create the ADL equation (eq. 15). The final line shows the data from this study evaluating the equation. The equation suggests ADL decreases initially then increases as the plant matures. This equation did not predict ADL well in SW Saskatchewan.

Table 5.2.4b. Validation of Equation 15

Acid Detergent Lignin, % of Dry Matter = 10.6 + 2.9 MSW – 0.24 MSW^2

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADL	Sanderson & Wedin (1988)	Iowa	79	0.72	1.3	N/a	N/a
ADL	This Study	SW Sask	42	0.31	1.1	Biased	Biased

5.2.5 Validation of Equations from the Iowa Dataset 2

The following year, Sanderson and Wedin (1988), again using samples from Iowa, correlated NDF to phenological development in alfalfa, red clover, timothy and smooth brome grass. This second dataset produced equations predicting NDF and IVTD.

The first line of Table 5.2.5a shows parameters of the dataset used to create the alfalfa NDF equation (eq. 16). The final line shows the data from this study evaluating the equation. The equation suggests NDF decreases initially then increases as the plant matures. This equation did predict NDF moderately well in SW Saskatchewan, although was biased and not as well as in Iowa.

Table 5.2.5a. Validation of Equation 16

Neutral Detergent Fiber, % of Dry Matter = 15.0 + 9.8 MSW – 0.6MSW^2

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
NDF	Sanderson & Wedin (1989)	Iowa	16	0.98	1.6	N/a	N/a
NDF	This Study	SW Sask	120	0.74	2.9	Biased	Biased

The first line of Table 5.2.5b shows parameters of the dataset used to create the IVTD equation (eq. 17). The final line shows the data from this study evaluating the equation. The equation suggests that digestibility decreases as the plant matures which is consistent with conventional knowledge. This equation did not predict IVTD well in SW Saskatchewan.

Table 5.2.5b. Validation of Equation 17

In Vitro True Digestibility, % of Dry Matter = 83.3 – 4.3 MSW

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
IVTD	Sanderson & Wedin (1989)	Iowa	16	0.98	1.3	N/a	N/a
IVTD	This Study	SW Sask	72	0.50	3.2	Biased	Some Bias

While there are several of the MSW equations that showed promise (eq. 6, 7, 11, 12, 14, and 16), most notably the NDF and ADF prediction equations, there remains the issue of producer usefulness. To be widely accepted and utilized, a simpler and quicker method must be developed.

5.3 Comparison of PEAQ Equations

Several of the MSW equations did show promise, however the procedure for measuring MSW is laborious. A simpler and easier method is preferable. These equations use height and maturity to predict a variety of plant characteristics. The data presented here include results from all three experiments.

5.3.1 Validation of Original PEAQ

Hintz and Albrecht (1991) examined 15 plant characteristics to develop a fast simple method of quality estimation. They used a large sample size (540) from two sites in Wisconsin measuring these 15 characteristics for each. Other more difficult to measure characteristics (such as mean stem height weighted for plant mass, and mean node number weighted for plant mass) provided slightly better correlations, however they suggested height of the tallest stem and maturity of the most mature stem would provide the best compromise between prediction accuracy and ease of use. They published equations predicting NDF, ADF, CP, and ADL from these two parameters.

The first line of Table 5.3.1a shows parameters of the dataset used to create the NDF PEAQ equation (eq. 18). The subsequent lines show various attempts at validating the equation with the final line showing data from this study. The equation suggests that NDF increases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did predict NDF well in SW Saskatchewan, and almost as well as in Wisconsin where it was developed, with some bias in both the slope and intercept.

Table 5.3.1a. Validation of Equation 18

Neutral Detergent Fiber, % of Dry Matter = 16.89 + 0.27 height + 0.81 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
NDF	Hintz & Albrecht (1991)	Wisconsin	540	0.89	2.62	N/a	N/a
NDF	Owens et al. (1995)	Wisconsin	308	0.72	3.02	Biased	Biased
NDF	Sulc et al. (1997)	5 States	192	0.71	2.53	Biased	Biased
NDF	This Study	SW Sask	120	0.82	2.43	Some Bias	Some Bias

The first line of Table 5.3.1b shows parameters of the dataset used to create the ADF PEAQ equation (eq. 19). The subsequent lines show various attempts at validating the equation with the final line showing data from this study. The equation suggests that ADF increases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did predict ADF well in SW Saskatchewan, and almost as well as in Wisconsin where it was developed, although with some bias.

Table 5.3.1b. Validation of Equation 19

Acid Detergent Fiber, % of Dry Matter = 11.57 + 0.21 height + 0.79 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADF	Hintz & Albrecht (1991)	Wisconsin	540	0.88	2.20	N/a	N/a
ADF	Owens et al. (1995)	Wisconsin	308	0.72	2.47	Some Bias	No Bias
ADF	Sulc et al. (1997)	5 States	192	0.73	1.94	Biased	Biased
ADF	This Study	SW Sask	120	0.81	2.28	Biased	Biased

The first line of Table 5.3.1c shows parameters of the dataset used to create the CP PEAQ equation (eq. 20). The subsequent lines show various attempts at validating the equation with the final line showing data from this study. The equation suggests that crude protein decreases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did not predict CP well in SW Saskatchewan nor when it was rechecked in Wisconsin.

Table 5.3.1c. Validation of Equation 20

Crude Protein, % of Dry Matter = 30.71 – 0.09 height – 0.89 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
CP	Hintz & Albrecht (1991)	Wisconsin	540	0.74	2.17	N/a	N/a
CP	Owens et al. (1995)	Wisconsin	308	0.37	2.12	Biased	Biased
CP	This Study	SW Sask	120	0.16	3.20	Biased	Biased

The first line of Table 5.3.1d shows parameters of the dataset used to create the ADL PEAQ equation (eq. 21). The subsequent lines show various attempts at validating the equation with the final line showing data from this study. The equation suggests that lignin increases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did not predict ADL well in SW Saskatchewan.

Table 5.3.1d. Validation of Equation 21

Acid Detergent Lignin, % of Dry Matter = 1.58 + 0.05 height + 0.25 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADL	Hintz & Albrecht (1991)	Wisconsin	540	0.84	0.65	N/a	N/a
ADL	This Study	SW Sask	42	0.41	1.06	No Bias	Some Bias

5.3.2 Validation of First Cut Equations

Owens et al. (1995) separated data from Hintz and Albrecht (1991) into first cut and subsequent cuts in an attempt to increase accuracy of prediction equations. They found accuracy did not improve, however they did provide equations to predict NDF, ADF, and CP for each cut.

The first line of Table 5.3.2a shows parameters of the dataset used to create the NDF First Cut PEAQ equation (eq. 22). The second line shows data from this study. The equation suggests that NDF increases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did predict NDF well in SW Saskatchewan, slightly better than in Wisconsin where it was developed. This equation predicted NDF the best of all the previously developed equations.

Table 5.3.2a. Validation of Equation 22

Neutral Detergent Fiber, % of Dry Matter = 18.19 + 0.21 height + 1.44 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
NDF	Owens et al. (1995)	Wisconsin	150	0.83	2.45	Some Bias	Some Bias
NDF	This Study	SW Sask	120	0.82	2.40	No Bias	No Bias

The first line of Table 5.3.2b shows parameters of the dataset used to create the ADF First Cut PEAQ equation (eq. 23). The final line shows data from this study. The equation suggests that ADF increases as the plant matures and grows taller which is consistent with conventional knowledge. This equation predicted ADF better in SW Saskatchewan than in Wisconsin where it was developed. This equation predicted ADF the best of all the previously developed equations. The bias in the slope was associated with an unusually low standard error and may not be biologically significant.

Table 5.3.2b. Validation of Equation 23

Acid Detergent Fiber, % of Dry Matter = 11.92 + 0.18 height + 1.11 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADF	Owens et al. (1995)	Wisconsin	150	0.78	2.30	No Bias	No Bias
ADF	This Study	SW Sask	120	0.83	2.17	Biased	No Bias

The first line of Table 5.3.2c shows parameters of the dataset used to create the CP First Cut PEAQ equation (eq. 24). The final line shows data from this study. The equation suggests that crude protein decreases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did not predict CP well in SW Saskatchewan or in Wisconsin.

Table 5.3.2c. Validation of Equation 24

Crude Protein, % of Dry Matter = 29.63 – 0.09 height – 0.87 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
CP	Owens et al. (1995)	Wisconsin	150	0.37	2.27	Biased	Biased
CP	This Study	SW Sask	120	0.16	3.20	Biased	Biased

5.3.3 Validation of Second Cut equations

The first line of Table 5.3.3a shows parameters of the dataset used to create the NDF Second Cut PEAQ equation (eq. 25). The final line shows data from this study. The equation suggests that NDF increases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did predict NDF well in SW Saskatchewan, better than in Wisconsin where it was developed.

Table 5.3.3a. Validation of Equation 25

Neutral Detergent Fiber, % of Dry Matter = 16.53 + 0.34 height + 0.25 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
NDF	Owens et al. (1995)	Wisconsin	158	0.66	3.06	Biased	Some Bias
NDF	This Study	SW Sask	120	0.80	2.56	Biased	Biased

The first line of Table 5.3.3b shows parameters of the data set used to create the ADF Second Cut PEAQ equation (eq. 26). The final line shows data from this study. The equation suggests that ADF increases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did predict ADF well in SW Saskatchewan, similar to Wisconsin where it originated.

Table 5.3.3b. Validation of Equation 26

Acid Detergent Fiber, % of Dry Matter = 12.08 + 0.28 height + 0.11 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADF	Owens et al. (1995)	Wisconsin	158	0.75	2.11	Some Bias	No Bias
ADF	This Study	SW Sask	120	0.80	2.36	Biased	Biased

The first line of Table 5.3.3c shows parameters of the dataset used to create the CP Second Cut PEAQ equation (eq. 27). The final line shows data from this study. The equation suggests that crude protein decreases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did not predict CP well in SW Saskatchewan nor in Wisconsin.

Table 5.3.3c. Validation of Equation 27

Crude Protein, % of Dry Matter = 29.51 – 0.04 height – 1.07 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
CP	Owens et al. (1995)	Wisconsin	158	0.35	1.66	Biased	Biased
CP	This Study	SW Sask	120	0.19	3.16	No Bias	No Bias

5.3.4. Validation of Ohio/Wisconsin Equations

Sulc et al. (1997) developed another set of PEAQ equations from data collected in Ohio and Wisconsin, and evaluated their performance across five states (NY, PA, OH, CA, WI). They found these equations accurate across a wide range of environments.

The first line of Table 5.3.4a shows parameters of the dataset used to create the NDF OH/WI PEAQ equation (eq. 28). The subsequent line shows the validation of the equation with the final line showing the validation from this study. The equation suggests that NDF increases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did predict NDF well in SW Saskatchewan, as well as in Wisconsin where it originated with a slightly larger RMSE and R^2.

Table 5.3.4a. Validation of Equation 28

Neutral Detergent Fiber, % of Dry Matter = 23.67 + 0.21 height + 0.41 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
NDF	Sulc et al (1997)	Wisconsin	159	0.74	2.04	N/a	N/a
NDF	Sulc et al (1997)	Wisconsin	48	0.74	2.31	No Bias	Biased
NDF	This Study	SW Sask	120	0.81	2.48	Some Bias	Biased

The first line of Table 5.3.4b shows parameters of the dataset used to create the ADF OH/WI PEAQ equation (eq. 29). The subsequent line shows the validation of the equation with the final line showing the validation from this study. The equation suggests that ADF increases as the plant matures and grows taller which is consistent with conventional knowledge. This equation did predict ADF well in SW Saskatchewan, almost the same as in Wisconsin where it originated with an RMSE larger than previous studies. This may indicate that the samples taken from across 5 states did not fully represent the range of variability possible.

Table 5.3.4b. Validation of Equation 29

Acid Detergent Fiber, % of Dry Matter = 16.90 + 0.17 height + 0.32 maturity

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADF	Sulc et al. (1997)	Wisconsin	159	0.73	1.69	N/a	N/a
ADF	Sulc et al. (1997)	Wisconsin	48	0.73	1.83	No Bias	No Bias
ADF	This Study	SW Sask	120	0.78	2.48	Biased	No Bias

5.4 Evaluating Weiss Equation

The 2001 NRC Dairy Nutrient Requirements applies a discount factor to show the lower utilization of forage by a cow at a high dry matter intake level compared to a low intake. The choice of intake (multiples of maintenance) as well as the ration TDN affects the discount applied. Two different intake levels were evaluated (maintenance, and 3x maintenance). When evaluating the equation, this study used a ration TDN equal to the forage TDN, since the “in vitro diet” consisted of 100% forage. This was possible since the forage TDN was estimated first, and then the discount was calculated (using the forage TDN) and applied to the forage TDN. However, since the results were similar and only differed by the discount, the forage TDN was chosen to be compared to the in vitro analysis.

Also, in vitro methods are related more to true digestibility than to apparent digestibility because the in vitro methods are incapable of estimating fecal endogenous matter (Van Soest 1994). The Weiss equation is also related to true digestibility since the fecal TDN is subtracted.

The data used to evaluate this equation (Eq. 30) came from all three experiments. The samples that were analyzed in experiment three also included ADF and NDF from the first experiment and OMD from the second. The first line of Table 5.4a shows parameters of the dataset that the original authors used to validate the theoretical equations. The second line shows the validation from this study. The final line is an example of another method of estimating TDN only from ADF. (Adams et al. 1995; TDN = 4.898 + ((1.044 - (0.0119 * ADF)) * 89.796). The Weiss equations did not predict TDN well. When used to predict the data from this study, the standard error was lower, as well there was no bias in either the slope or intercept. However, the equation only explained 23% of the variation between the actual and predicted values. When using the alternate method to predict the measured data, it performed similar to the Weiss equations.

Table 5.4a. Validation of Weiss Equations

	N	R^2	RMSE	Slope	Intercept
Weiss (1992)	191	0.54	7.62	No Bias	No Bias
This Study	42	0.23	4.24	No Bias	No Bias
Adams et al. (1995)	72	0.52	3.16	Biased	Biased

Other equations (eq. 2, 5, 10, and 17) using MSW or height and maturity, also predict IVTD and TDN. For comparison to the Weiss equations, these other equations evaluated the same 42 samples (Table 5.4b). In order to convert OMD (measured in the lab) to IVTD the ash was subtracted out. To convert it to TDN the regression equation from Heaney and Pigden (1963) was used (TDN = -0.27 + 1.018 OMD). Also included in Table 5.4b is an additional TDN prediction equation (Adams et al. 1995), using ADF. The Weiss equation did not predict TDN very well. All of the MSW equations had similar error terms and coefficients of determination as the Weiss equation, while the Adams equation was better.

Table 5.4b. Comparison of Weiss Equation to other Predictive TDN Equations

Equation	N	Slope	Intercept	R^2	RMSE
Weiss (1992) (eq. 30)	42	No Bias	No Bias	0.23	4.29
Kalu & Fick (1981) (eq. 2)	42	No Bias	No Bias	0.39	3.20
Kalu & Fick (1983) (eq. 5)	42	No Bias	No Bias	0.39	3.20
Fick & Onstad (1988) (eq. 10)	42	No Bias	No Bias	0.39	3.19
Sanderson & Wedin (1989) (eq. 17)	42	No Bias	No Bias	0.39	3.20
Adams et al. 1995	42	Some Bias	No Bias	0.53	3.41

5.5 New PEAQ Equations for Southwestern Sask

Since there has been significant variation in the prediction equations from different geographic locations, it was hoped to increase accuracy by developing some local prediction equations. When developing the equations only 75% of the data was used, with the remaining 25% randomly selected and set aside for verification of the equations.

5.5.1 Developing NDF PEAQ

When developing the NDF PEAQ for SW Saskatchewan, the site, year and cut (as well as all possible interactions between them) were also put into the model to check if they were useful for prediction. The first terms that showed no significance were the site, year, cut and site by cut interaction (at the 0.1% level). With removal of these four, the remaining site by year and year by cut interactions still showed significance (at the 0.01% level). This equation had a R^2 of 0.92 and RMSE of 1.89. A decision was made to include these two unpredictable terms in the error term. With removal of the two interactions, the R^2 dropped slightly to 0.84 and the RMSE increased to 2.30. When running the model including only height and maximum maturity, both were significantly useful for prediction at the 0.01 probability level.

NDF = 18.0855 + 0.9677 maturity + 0.2370 height eq.39

SE 1.0503 0.2601 0.0163

(n = 95, R^2 = 0.8425, RMSE = 2.307)

When validating this equation the remaining 25% of the data was used. The predicted values were plotted against the measured values and the resulting regression showed a R^2 of 0.76, RMSE of 2.74, and no bias in either the slope nor intercept.

Table 5.5.1. Validation of Equation 39

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
NDF	Calibration	SW Sask	95	0.84	2.31	N/a	N/a
NDF	Validation	SW Sask	25	0.76	2.74	No Bias	No Bias

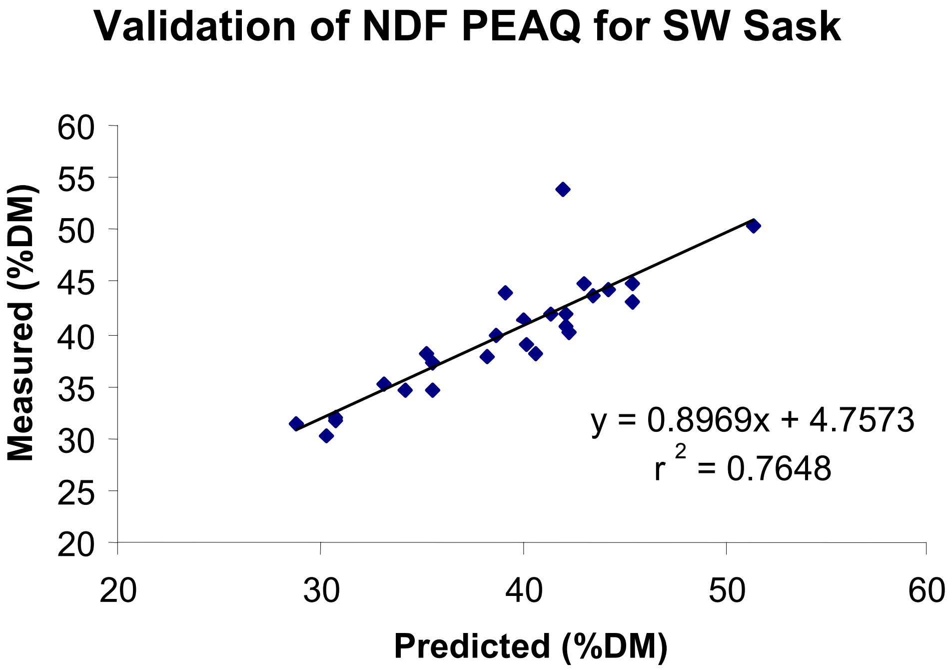

Figure 5.5.1. Plot of Predicted vs Measured for Equation 39

The probability that the intercept is equal to zero (p value) is 0.1986 (no bias), and the probability that the slope is equal to one is 0.1397 (no bias). The one point that was outlying was 99MG14. It is a very fast growing cultivar on a south facing sandy slope and this point was taken at the very end of first cut. As a result this stand had an unusually tall (long) height. With this outlier removed the R^2 increases to 0.9008 and the RMSE decreases to 1.77.

5.5.1a Comparison to NIRS

Fonseca et al. (1999), proposed Near Infra-Red Spectroscopy as another method of quickly estimating NDF for large numbers of samples and showed its usefulness in alfalfa breeding programs to select for low NDF. The alfalfa sample is dried and a spectrum of the entire infrared region of the sample is obtained and compared to a calibration spectrum. A spectrum can be obtained much more quickly than performing the wet chemistry. Representative calibration spectra are essential. Over three harvests they accumulated and analyzed 116 samples. The RMSE was 2.84 and a R^2 of 0.89. Predicting NDF from height and maximum maturity is of comparable accuracy to predicting NDF by NIRS.

5.5.2 Developing ADF PEAQ

When developing the ADF PEAQ for SW Saskatchewan, the site, year and cut (as well as all possible interactions between them) were also put into the model to check if they were useful for prediction. The first terms that showed no significance were site, year, cut, and the site by cut interaction. With removal of these four, the site by year and year by cut interactions both showed significance at the 0.05% level. The equation gave a R^2 of 0.91 and RMSE of 1.76. A decision was made to include these two unpredictable interactions in the error term. When running the model including only height and maximum maturity, both were significantly useful for prediction at the 0.01 probability level. The R^2 decreased to 0.86 and the RMSE increased to 1.92.

ADF = 12.5670 + 1.2438 maturity + 0.2128 height eq.40

SE 0.8717 0.2159 0.0136

(n = 95, R^2 = 0.8649, RMSE = 1.915)

When validating this equation the remaining 25% of the data was used. The predicted values were plotted against the measured values, and the resulting regression showed a R^2 of 0.71, a high RMSE of 3.02, and no bias in neither the slope nor intercept. With a lower R^2 and a higher RMSE, the ADF prediction equation is slightly less accurate than the NDF prediction equation.

Table 5.5.2. Validation of Equation 40

Equation	Source	Location	N	R^2	RMSE	Slope	Intercept
ADF	Calibration	SW Sask	95	0.86	1.92	N/a	N/a
ADF	Validation	SW Sask	25	0.72	3.02	No Bias	No Bias

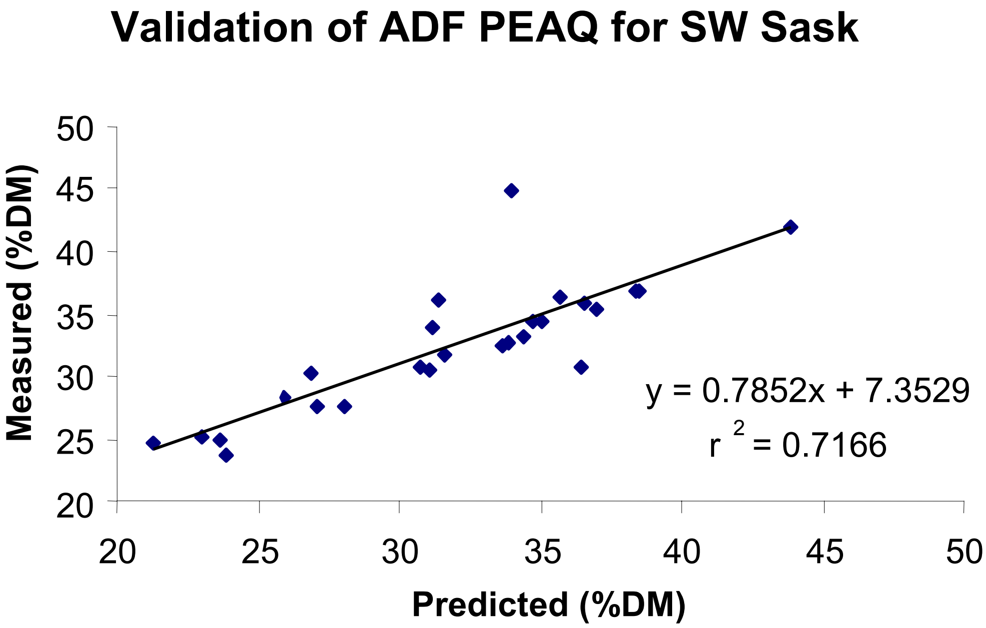

Figure 5.5.2. Plot of Predicted vs. Measured for Equation 40

The probability that the intercept is equal to zero (p value) is 0.55 (no bias), and the probability that the slope is equal to one is 0.4624 (no bias). The one point that is outlying is the same point as for the NDF validation (99MG14). It is a very fast growing cultivar on a south facing sandy slope and this point was taken at the very end of first cut. As a result this stand had an unusually tall (long) height. With this outlier removed the R^2 increases to 0.8626 and the RMSE decreases to 2.09.

5.5.3 Developing CP PEAQ

When developing the CP PEAQ for SW Saskatchewan, the site, year and cut (as well as all possible interactions between them) were also put into the model to check if they were useful for prediction. The first terms that showed no significance were site and the year by cut interaction. With removal of these two terms from the model, the site by year interaction showed significance (at the 0.1% level). When this term was removed the site by cut interaction showed significance (at the 0.1% level). With all the interactions removed, as well as site, both cut and year showed significance (at the 0.01% level), in addition to the maximum maturity and height. This model had an R^2 of 0.71 and RMSE of 8.53. When removing the year and cut from the model, the R^2 dropped to 0.22 with an RMSE of 3.16. This shows that year and cut explained a large portion of the variation and could not be removed from the model. However, if the year is included it makes the equation of no use for predictive purposes. This equation did not predict CP well and is not recommended for use.

$$\begin{array}{llll} CP = & 29.0890 & - 0.2217\ \text{maturity} & - 0.0792\ \text{height} \qquad \text{eq.41} \\ SE & 1.4413 & 0.3570 & 0.0224 \end{array}$$

(n = 95, $R^2 = 0.2223$, RMSE = 3.1669)

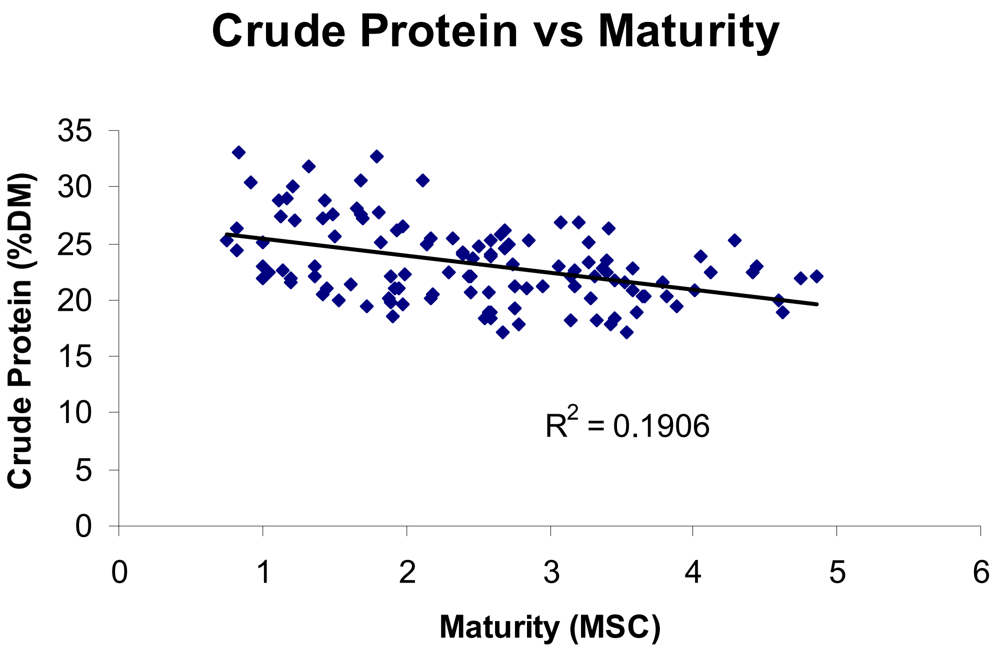

Figure 5.5.3. Plot of Crude Protein Data

The negative coefficients of the previous CP equations (Equations 3, 4, 9, 20, 24, and 27) suggest that CP decreases with maturity. Although the overall trend is visible in figure 5.5.3, there is no strong correlation between the two.

5.5.4 Developing ADL PEAQ

When developing the ADL PEAQ for SW Saskatchewan, the site, and cut (as well as the interaction between them) were also put into the model to check if they were useful for prediction. No year interactions were possible since the data was only taken for one year. When running this model, none of the predictors had any usefulness (including height and maturity). When removing site and cut (and the interaction) from the model, height showed usefulness at the 5% level of probability ($p = 0.0253$). When removing maturity from the model, the height became a very significant predictor ($p < 0.0001$), however the R^2 value was only 0.34. This seems to suggest that height does influence lignin. However, the height coefficient was equal to zero ($p = 0.70$). The ADL is not predictable from the characteristics studied here and this equation is not recommended for use.

ADL = 3.905 + 0.046 (height) eq. 42

SE 0.803 0.119

($n = 31$, $R^2 = 0.3389$, RMSE = 1.217)

5.5.5 Developing Ash PEAQ

When developing the Ash PEAQ for SW Saskatchewan, the site, and cut (as well as the interaction between them) were also put into the model to check if they were useful for prediction. No year interactions were possible since the data was only taken for one year. When running this model, the interaction and height showed no usefulness and were removed. The new model including site, cut and maximum maturity showed that all had some usefulness in predicting ash ($p = 0.065$, $p =0.012$, $p < 0.0001$ respectively). When removing site and cut from the model (including their prediction value in the error term), maximum maturity remained a useful predictor ($p < 0.0001$) however, the R^2 value fell from 0.72 to 0.56. This means that maturity alone can only explain 56% of the variation, while including site and cut can explain 72%.

The site effect is understandable since each site would differ with respect to the micronutrient availabilities. The higher mineral content in immature alfalfa could be an artifact of a higher leaf to stem ratio and the fact that most of the minerals are found in the leaf. It may also be soil contamination of the sample after a water application.

This equation did predict ash moderately well and has potential for further development. Accuracy could be improved by measuring the ash content over more cuts to determine the cut coefficient and including it in the model. This dataset only included information from two cuts.

$$\text{Ash} = 14.50802 - 0.08303\ \text{maturity} \qquad \text{eq. 43}$$

$$\text{SE} \qquad 0.73470 \qquad\qquad 0.13693$$

(n = 31, $R^2 = 0.5591$, RMSE = 0.7644)

5.5.6 Developing ADIN PEAQ

When developing the ADIN PEAQ for SW Saskatchewan, the site, and cut (as well as the interaction between them) were also put into the model to check if they were useful for prediction. No year interactions were possible since the data was only taken for one year. When running this model, site and cut did not have any usefulness. When removing site and cut from the model, the interaction, the maximum maturity and height all showed usefulness at the 5% level of probability ($p = 0.0206$, $p = 0.0339$, $p = 0.0374$ respectively). When the interaction was removed from the model, the height and maximum maturity became unuseful predictors ($p = 0.81$, $p = 0.59$

respectively), and the R^2 value dropped from 0.62 to 0.01. This suggests that the site by cut interaction explained a significant amount of the variation. However, when the model was run including only the interaction, it became of no value for prediction ($p = 0.169$). ADIN is not predictable from these characteristics and this equation is not recommended for use.

ADIN = 0.15878 – 0.00158 maturity + 0.00020 height eq.44

SE 0.02944 0.00675 0.00037

($n = 31$, $R^2 = 0.0104$, RMSE = 0.0305)

5.5.7 Developing NDIN PEAQ

When developing the NDIN PEAQ for SW Saskatchewan, the site, and cut (as well as the interaction between them) were also put into the model to check if they were useful for prediction. No year interactions were possible since the data was only taken for one year. When running this model, none of the predictors had any usefulness (including height and maturity). When removing site and cut (and the interaction) from the model, again neither height nor maturity showed any usefulness. NDIN is not predictable from these characteristics and this equation is not recommended for use.

NDIN = 0.26401 – 0.00340 maturity + 0.00063 height eq.45

SE 0.05220 0.01198 0.00066

(n = 31, R^2 = 0.0364, RMSE = 0.0540)

5.5.8 Developing EE PEAQ

When developing the EE PEAQ for SW Saskatchewan, the site, and cut (as well as the interaction between them) were also put into the model to check if they were useful for prediction. No year interactions were possible since the data was only taken for one year. When running this model, only the site showed usefulness at the 5% probability level (p = 0.075). When removing site and cut (and the interaction) from the model, still neither height nor maturity showed any usefulness. When running the model only with site, it became of no value. EE is not predictable from these characteristics and this equation is not recommended for use.

EE = 2.38055 + 0.07673 maturity – 0.00242 height eq.46

SE 0.35436 0.08130 0.0044

(n = 31, R^2 = 0.0308, RMSE = 0.3668)

5.5.9 Developing IVTD PEAQ

When developing the IVTD PEAQ for SW Saskatchewan, the site and cut (as well as the interactions between them) were also put into the model to check if they were useful for prediction. No year interactions were possible since the data was only taken for one and a half years (three cuts). Instead of a year interaction, the three cuts were each considered separate environments. When running this model, site and maximum maturity showed usefulness. With just these two in the model, the site and maximum maturity remained significant predictors. This equation showed an R^2 of 0.84 with a rather high RMSE of 7.48. However, to be useful across a range of sites, the model cannot include a site parameter. When including site in the error term, the R^2 dropped to 0.60 with an even higher RMSE of 11.37. This shows that site explained a significant portion of the variation. This equation does not predict IVTD very well from maturity and height. The other equations that use MSW to predict IVTD perform equally well if not better.

IVTD = 21.07514 + 13.14545 maturity eq.47

SE 4.17545 1.27886

(n = 72, $R^2 = 0.605$, RMSE = 11.377)

6.0 SUMMARY AND CONCLUSIONS

The purpose of this research was to determine if in-vitro digestibility used as an index of animal performance could be predicted from infield characteristics (height and maturity) in alfalfa. Typically, chemical characteristics of alfalfa have been estimated from the infield characteristics, and then the animal performance has been estimated from the chemical characteristics. In order to validate this procedure, first the estimation of the chemical characteristics must be proven accurate. If this is true then the second step, estimating animal performance from the chemical characteristics, must prove accurate. Perhaps it is possible to combine these two steps and estimate animal performance directly from infield characteristics.

First of all, is it possible to predict chemical characteristics from infield characteristics accurately? Tables 6.1 to 6.4 show summaries of the equation validations for NDF, ADF, CP and ADL. The NDF equation previously developed that was most accurate for SW Saskatchewan was equation 22. The ADF equation previously developed that was most accurate for SW Saskatchewan was equation 23. The equations developed to predict NDF (Eq. 39) and ADF (Eq. 40) were the most accurate. None of the CP or ADL equations were accurate for SW Saskatchewan.

Table 6.1. Summary of Equation Validations for NDF

Equation	Parameter	N	Slope	Intercept	R^2	RMSE
Kalu & Fick (1983) (eq. 6)	MSW	120	No Bias	No Bias	0.75	2.86
Fick & Onstad (1988) (eq. 11)	MSW	120	No Bias	No Bias	0.74	2.89
Sanderson & Wedin (1988) (eq. 14)	MSW	120	Biased	Some Bias	0.75	2.90
Sanderson & Wedin (1989) (eq. 16)	MSW	120	Biased	Biased	0.74	2.90
Hintz & Albrecht (1991) (eq. 18)	Hgt, Mat	120	Some Bias	Some Bias	0.82	2.43
Owens et al. (1995) (eq. 22)	Hgt, Mat	120	No Bias	No Bias	0.82	2.40
Owens et al. (1995) (eq. 25)	Hgt, Mat	120	Biased	Biased	0.80	2.56
Sulc et al. (1997) (eq. 28)	Hgt, Mat	120	Some Bias	Biased	0.81	2.48
This study (eq. 39)	Hgt, Mat	25	No Bias	No Bias	0.90	1.77

Table 6.2. Summary of Equation Validations for ADF

Equation	Parameter	N	Slope	Intercept	R^2	RMSE
Kalu & Fick (1983) (eq. 7)	MSW	120	No Bias	No Bias	0.69	2.93
Fick & Onstad (1988) (eq. 12)	MSW	120	Some Bias	Some Bias	0.73	2.73
Hintz & Albrecht (1991) (eq. 19)	Hgt, Mat	120	Biased	Biased	0.81	2.28
Owens et al. (1995) (eq. 23)	Hgt, Mat	120	Biased	No Bias	0.83	2.17
Owens et al. (1995) (eq. 26)	Hgt, Mat	120	Biased	Biased	0.80	2.36
Sulc et al. (1997) (eq. 29)	Hgt, Mat	120	Biased	No Bias	0.78	2.48
This study (eq. 40)	Hgt, Mat	25	No Bias	No Bias	0.86	2.09

Table 6.3. Summary of Equation Validations for CP

Equation	Parameter	N	Slope	Intercept	R^2	RMSE
Kalu & Fick (1981) (eq. 3)	MSW	120	Biased	Biased	0.21	3.12
Kalu & Fick (1983) (eq. 4)	MSW	120	Biased	Biased	0.21	3.12
Fick & Onstad (1988) (eq. 9)	MSW	120	Biased	Biased	0.21	3.11
Hintz & Albrecht (1991) (eq. 20)	Hgt, Mat	120	Biased	Biased	0.16	3.20
Owens et al. (1995) (eq. 24)	Hgt, Mat	120	Biased	Biased	0.16	3.20
Owens et al. (1995) (eq. 27)	Hgt, Mat	120	No Bias	No Bias	0.19	3.16

Table 6.4. Summary of Equation Validations for ADL

Equation	Parameter	N	Slope	Intercept	R^2	RMSE
Kalu & Fick (1983) (eq. 8)	MSW	42	No Bias	No Bias	0.44	1.03
Fick & Onstad (1988) (eq. 13)	MSW	42	No Bias	No Bias	0.46	1.00
Sanderson & Wedin (1988) (eq. 15)	MSW	42	Biased	Biased	0.31	1.10
Hintz & Albrecht (1991) (eq. 21)	Hgt, Mat	42	No Bias	Some Bias	0.41	1.06

The equations that were developed for Ash (eq. 43), ADIN (eq. 44), NDIN (eq. 45), and EE (eq. 46), were not validated due to their low prediction value. None of these were accurate for SW Saskatchewan.

Table 6.5. Summary of Equations 43 to 46

Equation	Parameter	N	Slope	Intercept	R^2	RMSE
Ash (eq. 43)	Mat	31	N/a	N/a	0.56	0.76
ADIN (eq. 44)	Hgt, Mat	31	N/a	N/a	0.01	0.03
NDIN (eq. 45)	Hgt, Mat	31	N/a	N/a	0.04	0.05
EE (eq. 46)	Hgt, Mat	31	N/a	N/a	0.03	3.67

Only ADF and NDF could be accurately predicted in SW Saskatchewan. All of the remaining characteristics were not estimable from the parameters studied.

The second step is to check to see if estimating animal utilization (OMD) and hence available energy (TDN), from chemical characteristics (CP, ADF, NDF, Ash, ADIN, NDIN, EE, ADL) is accurate. The method of choice was the Dairy NRC 2001, which used the equations developed by Weiss (1992). The first line in Table 5.4a shows parameters of the dataset used to develop the Weiss equations. The second line shows the Weiss equations predicting the data from this study. The final line shows the equation developed by Adams et al. (1995) to predict the data from this study. The Weiss equations did not accurately predict net energy.

Table 5.4a. Validation of Weiss Equations

	N	R^2	RMSE	Slope	Intercept
Weiss (1992)	191	0.54	7.62	No Bias	No Bias
This Study	42	0.23	4.24	No Bias	No Bias
Adams et al. (1995)	72	0.52	3.16	Biased	Biased

Finally, can one estimate animal utilization directly from infield characteristics? Table 6.6 shows a summary of the TDN prediction equations. The prediction equation created from the data in this study showed a slightly higher R^2, but a much higher RMSE. Still, none of the equations proved very useful in predicting TDN.

Table 6.6. Summary Comparison of TDN Equations

Equation	Parameter	N	Slope	Intercept	R^2	RMSE
Kalu, Fick (1981) (eq. 2)	MSW	72	Some Bias	No Bias	0.50	3.22
Kalu & Fick (1983) (eq. 5)	MSW	72	Biased	No Bias	0.50	3.22
Fick & Onstad (1988) (eq. 10)	MSW	72	Biased	No Bias	0.50	3.20
Sanderson & Wedin (1989) (eq. 17)	MSW	72	Biased	Some Bias	0.50	3.20
This Study, (eq. 47)	Mat	72	N/a	N/a	0.61	11.38

This data suggests that the practice of estimating one parameter, which is then used to estimate a second parameter, is not particularly useful. For example, estimating NDF or ADF, while standing in a field of alfalfa is accurate, however using that estimate to then predict TDN, while still standing in the field, shows a significant decrease in accuracy. However, there is educational value for using the TDN as a trend to highlight the decrease in quality as the alfalfa matures.

Finally, NDF and ADF can be accurately predicted while standing in the field, which then can be used to alter cutting date to target a particular quality. Using the same information to predict digestibility is less accurate.

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Appendix A. Analysis Procedures

Mean Stage by Count (Kalu and Fick 1981)

A one square foot sample was clipped at 4 cm. Each stem was staged and sorted according to stage. The MSC was calculated by dividing the sum of the Stem Stage numbers by the total number of stems in the sample. The Stem Stage number was calculated by multiplying the number of stems in that stage by the stage number.

Mean Stage by Weight (Kalu and Fick 1981)

A one square foot sample was clipped at 4 cm. Each stem was staged and sorted according to stage. The MSW was calculated by dividing the sum of the Weight Stage numbers by the total weight of all the stems in the sample. The Weight Stage number was calculated by multiplying the weight of the stems in that stage by the stage number.

Total Moisture Determination (AOAC method 930.15)

If the sample was more than 15% moisture, it was dried in a 60^{o}C oven until 15% was reached. Then the sample was placed in a 135^{o}C oven for two hours. The sample was weighted before and after drying to determine the total moisture. Once dried all samples were ground to pass a 1mm screen.

Neutral Detergent Fiber (Van Soest et al. 1991)

The NDF solution was made by adding 360g sodium lauryl sulfate and 120ml 2-ethoxyethanol to 2L distilled water to dissolve. 223g of EDTA and 81.5g sodium borate decahydrate were added to 1L distilled water and heat used to dissolve. 5.47g anhydrous disodium hydrogen phosphate was added to 1L distilled water and heat used to dissolve. When cool the three solutions were combined and made up to 12L volume, followed by mixing well.

Half a gram of sample was weighted into a beaker, with 0.5g sodium sulfite and 50ml of NDF solution added. It was refluxed for 10 minutes. The sides of the beaker were rinsed with a small amount of NDF solution and refluxed for an additional 60 minutes. The NDF solution was filtered off using a Fiber Frax porcelain mat in a Buchner funnel and vacuum. The sample was washed with 300ml of distilled water, and twice with acetone. The sample was transferred from the filter mat to ashing dishes and dried overnight at 105^{o}C. The sample was weighed and placed in a muffle furnace at 600^{o}C for 2 hours. After the sampled had cooled, it was reweighed. The difference in weights was the residual fiber and expressed as a percentage of original 0.5g sample.

Acid Detergent Fiber (AOAC method 973.18)

To mix ADF solution, 610ml of concentrated sulphuric acid was added to 10L distilled water and let cool. 440.0g of cetyl trimethylammonium bromide was added and made up to 22L volume, followed by mixing.

The filter bag was weighed, and 0.5g of sample was added into the bag. The bag was sealed, reweighed, and spread uniformly in the bag. It was placed in bag suspender basket adding an empty blank bag. Ambient temperature ADF solution was added until the bags are completely covered after which the agitator and heat was turned on. The solution reached 100^{o}C in 15 minutes and digested for an additional 45 minutes. The spent ADF solution was removed and refilled with boiling distilled water. It was agitated for an additional 5 minutes, the spent water removed, and repeated the rinse 4 more times. The filter bags were removed and squeezed to remove any excess moisture. The filter bags were dried by first soaking in acetone for 3 minutes, then let air dry, and finally, in an oven at 105^{o}C overnight. The sample bags were cooled in a desiccator and weighed. The residual inside the bag was the portion of interest. After subtracting off the weight of the bag and taking into account any changes in the blank bag, the results was expressed as a percentage of the original 0.5g sample.

Kjeldahl Digestion (AOAC method 984.13)

Half a gram of sample was weighted into a digestion tube with one packet of catalyst (15g potassium sulphate, 0.45g copper sulfate). 25ml of concentrated hydrosulfuric acid was added and swirled. The tube was placed on the digestion block and heated until the dense white fumes cleared and the solution has turned a blue-green color. It was digested for an additional 1.5 hours and cooled for 15-20 minutes. 50ml of distilled water was slowly added. The tube was titrated using an automatic Tecator 1030 Distiller/Titrator with 1M HCl as the titrant. The %N was determined by multiplying the mls of titrant used by the molarity of the acid and by 1.401 divided by the weight of the sample. The % protein was determined by multiplying the %N by 6.25.

Total Ash (AOAC 942.05)

2g of sample were weighed into a crucible and place in a muffle furnace at 600^{o}C for 2 hours. It was cooled in a dessicator for 1 hour and weighed. The remnant was the total ash and expressed as a percentage of the original 2g sample.

ADIN

The sample bags from the ADF procedure were used and the Kjeldahl method was performed on them.

NDIN

The sample bags from the NDF procedure (omitting the sodium sulfite step) were used and the Kjeldahl method was used on them.

Crude Fat (AOAC method 7.061)

This method used the Soxtec Avanti 2050 Auto Extraction Unit.The extraction cups were predried with boiling chips at 105°C for 2 hours. They were cooled in a dessicator. The extraction cup was weighed. 2g of sample was added to a #1 Whatman filter paper and reweighed. The filter paper was folded into a package and placed it in the corresponding thimble with the correct extraction cup beneath it. 80 ml of solvent (1:1 Dichloromethane & Hexane) was added to start the cycle. Once it was completed, the extraction cups were removed and placed into a 105°C oven for 30 minutes. They were cooled in a desiccator and weighed. The extra weight added to the empty cup, was fat. This was expressed as a percent of the original 2g sample.

Lignin (AOAC 973.18)

The residual filter bags from the ADF digestion were submerged in 72% cold sulfuric acid for 3 hours. They were dried at 105°C for 2 hours then cooled in a dessicator and reweighed. The bags were placed in preweighed porcelain crucibles and ashed at 550°C for 2 hours. They were cooled in a dessicator and reweighed. The lignin was the residual ADF filter bag weight minus the difference between before and after ashing. This was expressed as a percentage of the original 0.5g sample.

Organic Matter Digestibility (Tilley and Terry 1963)

Rumen fluid was collected from a 1yr old Hereford steer adjusted to a forage ration. The rumen fluid was strained and kept anaerobic. It was combined with McDougall's artificial sheep saliva (19.6g Sodium bicarbonate, 14g Sodium phosphate, 1.14g Potassium cloride, 0.94g Sodium chloride, 0.08g Calcium chloride, 0.24g Magnesium sulphate, 1.83g urea, 1.83g Glucose, make up to 2L) as 2 parts fluid to 3 parts saliva. Fifteen ml was added to each 0.5g sample and digested for 48 hours in a 39°C water bath with occasional stirring. Five ml of a 2% pepsin/HCl solution (17.24 ml conc. HCl in 2L distilled water) was added. The pH was adjusted to 1.2 using a 50/50 HCl/distilled water solution and the tubes were allowed to digest for an additional 24 hours. Each sample was then filtered into a crucible, dried overnight at 60°C, weighed, ashed for 2 hours at 600°C and reweighed. The OMD is the weight remaining after the digestion minus the ash, expressed as a percentage of the original 0.5g sample.

Experiment #1 Data (n=120)

Sample #	Site	Year	Cut	Maturity (MSC)	Maturity (max)	Height	ADF	NDF	CP
98BS11	1	98	1	2.45	5	56	29.40	37.32	22.02
98BS12	1	98	1	2.75	5	70	30.54	38.72	21.26
98BS21	1	98	2	1.68	5	57	28.16	35.64	27.59
98BS23	1	98	2	3.36	6	96	36.54	44.74	22.81
98BS24	1	98	2	3.29	6	120	40.73	50.09	20.11
98DG11	6	98	1	0.75	3	31	21.88	28.93	25.35
98DG12	6	98	1	1.95	4	51	24.41	32.44	21.01
98DG13	6	98	1	2.95	6	65	32.80	38.87	21.20
98DG21	6	98	2	0.83	4	29	18.72	25.52	33.02
98DG22	6	98	2	2.69	6	47	27.58	34.36	26.11
98DG23	6	98	2	3.20	6	57	31.72	36.46	26.81
98DN11	8	98	1	1.15	4	35	24.05	31.81	22.55
98DN12	8	98	1	1.89	4	44	28.72	36.24	19.88
98DN13	8	98	1	3.57	6	58	32.26	40.49	20.91
98DN21	8	98	2	1.42	5	43	25.67	33.35	27.16
98DN22	8	98	2	2.43	6	71	33.64	41.22	22.10
98DN23	8	98	2	3.15	6	84	39.62	45.16	22.13
98DN24	8	98	2	3.18	6	102	34.46	42.89	22.71
98KK11	5	98	1	1.19	3	38	23.63	30.97	21.96
98KK12	5	98	1	1.36	4	39	25.13	30.49	22.14
98KK13	5	98	1	2.59	6	56	30.94	39.97	18.88
98KK14	5	98	1	4.59	6	86	33.85	42.62	20.04
98KK21	5	98	2	1.21	4	47	25.78	32.96	30.05
98KK22	5	98	2	1.98	5	55	29.59	34.43	26.53
98MG11	4	98	1	1.90	4	55	27.69	34.98	22.15
98MG12	4	98	1	2.19	4	61	29.91	37.93	20.49
98MG13	4	98	1	3.45	6	86	38.58	47.11	18.43
98MG14	4	98	1	4.75	6	107	40.15	48.91	21.86
98MG21	4	98	2	1.70	5	53	26.73	33.81	27.28
98MG22	4	98	2	2.46	6	69	37.44	43.29	23.77
98MG23	4	98	2	3.07	6	79	38.51	43.91	23.00
98MG24	4	98	2	4.12	6	91	37.01	44.00	22.48
98RM11	3	98	1	1.62	3	51	25.01	33.33	21.37
98RM12	3	98	1	1.93	4	51	25.60	33.61	21.12
98RM13	3	98	1	3.17	6	73	30.33	36.61	21.26
98RM14	3	98	1	4.41	7	93	36.33	45.98	22.48
98RM21	3	98	2	2.40	6	69	31.19	36.96	24.17
98RM22	3	98	2	3.40	6	72	35.97	40.99	22.44
98RM23	3	98	2	3.66	6	81	37.49	43.76	20.34

99BS11	1	99	1	1.42	3	48	28.35	34.85	20.55
99BS12	1	99	1	1.82	3	67	28.55	34.65	25.10
99BS13	1	99	1	2.57	4	87	34.15	42.60	20.75
99BS14	1	99	1	3.43	6	82	38.77	48.01	17.87
99BS21	1	99	2	1.43	4	53	27.69	32.84	28.73
99BS23	1	99	2	2.74	6	75	35.05	42.11	23.11
99JC11	2	99	1	1.04	3	38	23.36	29.91	22.49
99JC12	2	99	1	1.51	3	48	24.69	30.53	25.57
99JC13	2	99	1	2.30	4	62	29.50	37.98	22.41
99JC14	2	99	1	3.15	6	68	34.27	43.78	18.28
99JC22	2	99	2	1.79	4	55	25.62	30.89	32.64
99JC23	2	99	2	2.69	6	66	28.42	34.85	24.63
99RM11	3	99	1	0.82	2	32	23.05	30.06	24.48
99RM12	3	99	1	1.00	3	34	21.69	28.47	25.16
99RM14	3	99	1	3.81	6	57	33.39	43.34	20.33
99RM21	3	99	2	1.12	4	36	22.74	24.80	27.40
99RM23	3	99	2	2.66	6	59	28.68	36.20	25.72
99RM24	3	99	2	3.27	6	68	31.91	38.98	23.34
99MG11	4	99	1	1.22	3	43	23.16	28.22	27.09
99MG12	4	99	1	1.82	4	68	30.89	36.09	27.74
99MG13	4	99	1	2.32	4	80	32.26	41.15	25.44
99MG21	4	99	2	1.11	4	46	28.29	32.67	28.87
99MG22	4	99	2	1.93	5	60	30.62	36.24	26.23
99MG24	4	99	2	3.39	6	89	36.44	42.52	23.48
99KK11	5	99	1	0.83	3	30	21.78	27.54	26.37
99KK13	5	99	1	2.59	5	61	31.73	38.19	23.87
99KK14	5	99	1	3.52	6	71	32.87	40.99	21.59
99KK21	5	99	2	1.18	4	37	24.88	30.50	28.99
99KK22	5	99	2	1.68	6	48	24.79	31.15	30.55
99KK23	5	99	2	2.17	6	54	30.22	36.79	25.43
99DG11	6	99	1	0.92	3	35	20.42	25.89	30.46
99DG14	6	99	1	3.79	6	83	35.05	43.79	21.49
99LH21	7	99	2	1.65	4	52	30.39	35.87	28.10
99LH22	7	99	2	2.40	6	59	29.84	36.33	24.10
99LH23	7	99	2	3.27	6	70	32.80	40.98	25.04
99LH24	7	99	2	4.05	6	75	35.46	41.65	23.85
00BS12	1	0	1	1.91	6	64	30.55	34.95	18.60
00BS13	1	0	1	2.67	6	80	34.15	43.40	17.20
00BS14	1	0	1	3.33	6	94	38.05	45.35	18.15
00DG11	6	0	1	1.37	4	54	27.80	35.65	23.00
00DG13	6	0	1	2.78	6	72	35.70	43.70	17.80

00DG14	6	0	1	3.54	6	77	36.40	43.85	17.10
00KK12	5	0	1	1.99	6	49	28.05	37.55	22.30
00KK13	5	0	1	2.45	6	55	29.30	36.85	20.70
00MG11	4	0	1	1.44	3	51	28.36	36.47	20.95
00MG12	4	0	1	2.17	4	72	34.95	44.00	20.15
00MG13	4	0	1	2.58	4	83	36.15	44.95	18.40
00MG14	4	0	1	2.75	5	97	39.85	46.85	19.20
00JC11	2	0	1	1.01	4	37	22.30	30.65	21.90
00JC12	2	0	1	1.88	4	51	26.15	35.70	20.20
00JC13	2	0	1	2.58	6	63	30.85	40.10	19.00
00JC14	2	0	1	3.61	6	67	34.05	41.65	18.95
00LH12	7	0	1	1.72	5	53	27.80	37.45	19.45
00LH13	7	0	1	2.54	6	65	32.15	42.30	18.40
00LH14	7	0	1	3.88	6	73	34.15	42.05	19.50

Randomly taken out for Validation

99RM13	3	99	1	2.59	6	57	26.88	35.47	24.12
98KK24	5	98	2	3.31	6	74	31.13	40.07	22.14
99DG12	6	99	1	1.68	4	54	28.12	34.20	27.64
99BS24	1	99	2	3.46	6	86	38.39	45.52	21.66
99KK12	5	99	1	1.49	3	39	23.84	30.26	27.66
99JC24	2	99	2	4.29	7	82	31.44	39.15	25.28
99MG23	4	99	2	2.71	6	84	36.59	43.50	24.89
00KK11	5	0	1	1.01	4	42	23.00	30.75	22.95
98BS22	1	98	2	2.85	6	89	38.43	43.09	25.37
00BS11	1	0	1	1.54	4	53	27.10	35.55	19.95
99MG14	4	99	1	3.41	6	126	34.00	42.03	26.27
99RM22	3	99	2	2.14	6	49	25.98	33.18	24.88
99DG13	6	99	1	2.59	5	70	31.61	40.13	25.25
98DG14	6	98	1	4.86	6	76	34.67	42.24	22.14
98BS14	1	98	1	4.00	6	85	35.78	44.34	20.80
98KK23	5	98	2	2.51	6	68	33.65	38.73	24.77
98BS13	1	98	1	3.65	6	76	35.04	41.43	20.39
99BS22	1	99	2	2.11	5	66	30.79	35.30	30.59
98DN14	8	98	1	4.44	6	81	36.92	45.37	23.03
99KK24	5	99	2	3.58	7	67	34.40	42.25	22.84
99JC21	2	99	2	1.32	3	44	23.63	30.78	31.79
98DG24	6	98	2	3.08	6	60	36.45	40.63	26.87
00KK14	5	0	1	2.85	6	59	31.05	38.30	20.95

00DG12	6	0	1	1.98	6	68	33.85	42.35	19.60
00LH11	7	0	1	1.19	4	40	21.30	28.85	21.55
98RM24	3	98	2	4.62	7	108	43.88	51.50	18.87

Experiment #2 Data (n=72)

Sample #	Site	Year	Cut	MSC	MSW	Max	Height	ADF	OMD
99BS11	1	1	1	1.42	2.10	3	48	28.35	64.45
99BS14	1	1	1	3.43	4.41	6	82	38.77	54.73
99BS23	1	1	2	2.74	3.62	6	75	35.05	59.54
99JC11	2	1	1	1.04	1.66	3	38	23.36	57.13
99JC12	2	1	1	1.51	2.19	3	48	24.69	64.48
99JC13	2	1	1	2.30	3.11	4	62	29.50	61.78
99JC14	2	1	1	3.15	4.09	6	68	34.27	56.11
99JC22	2	1	2	1.79	2.52	4	55	25.62	70.21
99JC23	2	1	2	2.69	3.56	6	66	28.42	63.57
99JC24	2	1	2	4.29	5.41	7	82	31.44	61.50
99RM12	3	1	1	1.00	1.60	3	34	21.69	67.67
99RM13	3	1	1	2.59	3.44	6	57	26.88	64.31
99RM14	3	1	1	3.81	4.85	6	57	33.39	58.89
99RM22	3	1	2	2.14	2.93	6	49	25.98	64.61
99RM24	3	1	2	3.27	4.23	6	68	31.91	59.96
99MG11	4	1	1	1.22	1.86	3	43	23.16	68.08
99MG12	4	1	1	1.82	2.55	4	68	30.89	64.43
99MG13	4	1	1	2.32	3.14	4	80	32.26	61.81
99MG14	4	1	1	3.41	4.39	6	126	34.00	60.96
99MG21	4	1	2	1.11	1.74	4	46	28.29	66.58
99MG22	4	1	2	1.93	2.68	5	60	30.62	64.68
99MG23	4	1	2	2.71	3.58	6	84	36.59	57.46
99MG24	4	1	2	3.39	4.37	6	89	36.44	57.12
99KK11	5	1	1	0.83	1.41	3	30	21.78	68.90
99KK14	5	1	1	3.52	4.51	6	71	32.87	57.81
99KK22	5	1	2	1.68	2.40	6	48	24.79	66.76
99KK23	5	1	2	2.17	2.96	6	54	30.22	61.72
99KK24	5	1	2	3.58	4.58	7	67	34.40	58.29
99DG11	6	1	1	0.92	1.52	3	35	20.42	68.72
99DG12	6	1	1	1.68	2.40	4	54	28.12	65.38
99DG13	6	1	1	2.59	3.44	5	70	31.61	63.41
99DG14	6	1	1	3.79	4.83	6	83	35.05	57.02
99LH21	7	1	2	1.65	2.36	4	52	30.39	68.03
99LH23	7	1	2	3.27	4.23	6	70	32.80	54.93
99LH24	7	1	2	4.05	5.13	6	75	35.46	59.08

00BS11	1	2	1	1.54	2.23	4	53	27.10	64.81
00BS14	1	2	1	3.33	4.29	6	94	38.05	61.54
00DG11	6	2	1	1.37	2.03	4	54	27.80	64.97
00DG12	6	2	1	1.98	2.74	6	68	33.85	60.18
00DG13	6	2	1	2.78	3.67	6	72	35.70	57.81
00DG14	6	2	1	3.54	4.53	6	77	36.40	55.46
00KK12	5	2	1	1.99	2.75	6	49	28.05	62.97
00KK13	5	2	1	2.45	3.28	6	55	29.30	62.68
00KK14	5	2	1	2.85	3.74	6	59	31.05	63.70
00MG11	4	2	1	1.44	2.12	3	51	28.36	63.84
00MG14	4	2	1	2.75	3.63	5	97	39.85	60.62
00JC11	2	2	1	1.01	1.62	4	37	22.30	68.04
00JC12	2	2	1	1.88	2.62	4	51	26.15	63.97
00JC13	2	2	1	2.58	3.43	6	63	30.85	59.55
00JC14	2	2	1	3.61	4.62	6	67	34.05	60.72
00LH11	7	2	1	1.19	1.83	4	40	21.30	70.20
00LH12	7	2	1	1.72	2.44	5	53	27.80	62.25
00LH13	7	2	1	2.54	3.39	6	65	32.15	56.82
00LH14	7	2	1	3.88	4.93	6	73	34.15	60.73

randomly taken out to use for validation

99KK12	5	1	1	1.49	2.17	3	39	23.84	66.41
99RM23	3	1	2	2.66	3.52	6	59	28.68	63.08
99BS12	1	1	1	1.82	2.56	3	67	28.55	63.32
99BS13	1	1	1	2.57	3.42	4	87	34.15	59.94
99JC21	2	1	2	1.32	1.97	3	44	23.63	70.21
00BS13	1	2	1	2.67	3.53	6	80	34.15	60.17
99RM21	3	1	2	1.12	1.75	4	36	22.74	69.13
00MG13	4	2	1	2.58	3.44	4	83	36.15	57.51
99RM11	3	1	1	0.82	1.40	2	32	23.05	68.38
99KK21	5	1	2	1.18	1.81	4	37	24.88	67.01
99BS24	1	1	2	3.46	4.44	6	86	38.39	57.45
99KK13	5	1	1	2.59	3.44	5	61	31.73	62.58
00KK11	5	2	1	1.01	1.62	4	42	23.00	67.98
00MG12	4	2	1	2.17	2.96	4	72	34.95	63.62
00BS12	1	2	1	1.91	2.65	6	64	30.55	61.46
99BS21	1	1	2	1.43	2.10	4	53	27.69	68.25
99BS22	1	1	2	2.11	2.89	5	66	30.79	79.11

Experiment #3 Data (n=42)

Sample #	Site	Year	Cut	MSC	MSW	Max	Height	NDF	ADIN	NDIN	ADL	EE	Ash
99BS14	1	1	1	3.43	4.41	6	82	48.01	0.15	0.24	8.23	2.20	7.94
99BS21	1	1	2	1.43	2.10	4	53	32.84	0.16	0.28	5.09	2.45	11.74
99BS22	1	1	2	2.11	2.89	5	66	35.30	0.16	0.39	11.15	2.01	10.30
99BS23	1	1	2	2.74	3.62	6	75	42.11	0.15	0.25	7.31	2.51	9.96
99BS24	1	1	2	3.46	4.44	6	86	45.52	0.19	0.36	8.24	2.30	9.28
99JC13	2	1	1	2.30	3.11	4	62	37.98	0.11	0.20	5.94	2.33	9.81
99JC14	2	1	1	3.15	4.09	6	68	43.78	0.12	0.22	7.74	2.18	8.17
99JC21	2	1	2	1.32	1.97	3	44	30.78	0.15	0.29	3.89	2.76	11.90
99JC23	2	1	2	2.69	3.56	6	66	34.85	0.16	0.26	5.86	2.49	9.88
99JC24	2	1	2	4.29	5.41	7	82	39.15	0.15	0.31	7.38	3.10	9.42
99RM13	3	1	1	2.59	3.44	6	57	35.47	0.15	0.28	6.15	2.55	10.38
99RM14	3	1	1	3.81	4.85	6	57	43.34	0.16	0.31	7.99	2.88	8.49
99RM21	3	1	2	1.12	1.75	4	36	24.80	0.15	0.26	5.15	2.80	11.40
99RM22	3	1	2	2.14	2.93	6	49	33.18	0.13	0.26	5.79	3.04	10.13
99RM23	3	1	2	2.66	3.52	6	59	36.20	0.18	0.32	6.32	2.90	10.11
99MG12	4	1	1	1.82	2.55	4	68	36.09	0.26	0.38	6.99	2.84	10.32
99MG14	4	1	1	3.41	4.39	6	126	42.03	0.14	0.29	7.13	2.59	9.77
99MG21	4	1	2	1.11	1.74	4	46	32.67	0.16	0.23	5.78	2.63	12.10
99MG22	4	1	2	1.93	2.68	5	60	36.24	0.15	0.22	6.78	2.49	11.53
99MG23	4	1	2	2.71	3.58	6	84	43.50	0.17	0.32	7.81	3.60	10.04
99MG24	4	1	2	3.39	4.37	6	89	42.52	0.17	0.29	8.42	2.10	9.78
99KK12	5	1	1	1.49	2.17	3	39	30.26	0.17	0.33	5.47	2.45	12.06
99KK13	5	1	1	2.59	3.44	5	61	38.19	0.20	0.22	6.83	2.29	10.17
99KK14	5	1	1	3.52	4.51	6	71	40.99	0.23	0.22	7.43	2.29	8.96
99KK21	5	1	2	1.18	1.81	4	37	30.50	0.14	0.26	4.85	2.54	11.04
99KK22	5	1	2	1.68	2.40	6	48	31.15	0.14	0.25	5.04	2.80	11.35
99KK23	5	1	2	2.17	2.96	6	54	36.79	0.19	0.35	6.51	2.70	10.47
99DG13	6	1	1	2.59	3.44	5	70	40.13	0.15	0.32	6.93	2.70	10.69
99DG14	6	1	1	3.79	4.83	6	83	43.79	0.17	0.31	8.47	3.41	8.71
99LH22	7	1	2	2.40	3.22	6	59	36.33	0.17	0.28	8.63	2.64	9.28
99LH24	7	1	2	4.05	5.13	6	75	41.65	0.18	0.40	8.09	2.89	8.89

randomly taken out to use for validation

99RM24	3	1	2	3.27	4.23	6	68	38.98	0.20	0.35	7.34	3.48	9.04

99KK24	5	1	2	3.58	4.58	7	67	42.25	0.20	0.30	7.93	2.00	9.51
99BS12	1	1	1	1.82	2.56	3	67	34.65	0.22	0.61	5.94	2.06	12.36
99BS13	1	1	1	2.57	3.42	4	87	42.60	0.17	0.23	7.40	2.20	10.14
99LH21	7	1	2	1.65	2.36	4	52	35.87	0.15	0.31	5.83	2.05	12.05
99RM12	3	1	1	1.00	1.60	3	34	28.47	0.15	0.33	5.12	2.97	11.02
99JC12	2	1	1	1.51	2.19	3	48	30.53	0.17	0.67	6.28	2.81	12.68
99DG12	6	1	1	1.68	2.40	4	54	34.20	0.15	0.46	6.72	2.85	10.99
99LH23	7	1	2	3.27	4.23	6	70	40.98	0.18	0.27	8.60	2.34	9.11
99MG13	4	1	1	2.32	3.14	4	80	41.15	0.18	0.37	7.52	2.73	11.16
99JC22	2	1	2	1.79	2.52	4	55	30.89	1.17	0.61	5.59	1.88	12.65

Appendix C. Site Information

Site Information

Samp #	Class	Soil Type	Texture	Location Qtr	Sec	Twp	Rng	Mer	pH	SE	Soil Test N	P	K	S	Cu	Mn	Zn	B	Fe
98BS	Hatton-Fox Valley	mixed fluvial, lacustrir	sandy loam	NE	30	21	18	W3	8.2	1.8	12	29	410	46	3	10	2	3	31
99BS	Hatton-Fox Valley	mixed fluvial, lacustrir	sandy loam	NE	30	21	18	W3	8.1	0.7	36	43	780	45	3	14	2	4	40
00BS	Hatton-Fox Valley	mixed fluvial, lacustria	sandy loam	NE	30	21	18	W3	8.2	0.5	19	**20**	452	47	**2**	6	**1**	3	24
99JC	Willows-Sceptre	orthic lacustrine	clay	SE	19	21	19	W3	8	1.3	16	27	1020	82	8	20	2	6	73
00JC	Willows-Sceptre	orthic lacustrine	clay	SE	19	21	19	W3	8.1	0.8	24	**10**	1020	69	6	14	2	5	61
99LH	Fox Valley-Birsay	orthic lacustrine	loamy sand	NW	20	21	18	W3	8.1	0.7	23	29	1080	60	5	17	2	4	58
00LH	Fox Valley-Birsay	orthic lacustrine	loamy sand	NW	20	21	18	W3	8.2	0.7	18	**11**	767	56	5	9	2	4	48
98RM	Kelstern	solonetzic lacustrine	silty clay loan	NW	22	17	10	W3											
99RM	Kelstern	solonetzic lacustrine	silty clay loan	NW	22	17	10	W3	7.5	0.7	17	**14**	1200	96	3	31	3	4	84
98MG	Swinton	orthic loess	silt loam	NW	9	16	13	W3	8	1.1	38	**53**	1048	86	4	19	5	9	56
99MG	Swinton	orthic loess	silt loam	NW	9	16	13	W3	8.3	1.5	26	**23**	694	82	4	17	3	12	44
00MG	Swinton	orthic loess	silt loam	NW	9	16	13	W3	8.5	1.3	20	**15**	561	82	4	8	**1**	9	35
98DG	Chaplin	orthic fluviar	sandy loam	NW	34	15	13	W3	8.6	1.2	11	**18**	968	96	4	14	**1**	5	50
99DG	Chaplin	orthic fluviar	sandy loam	NW	34	15	13	W3	8	2.1	25	**23**	1200	96	3	17	7	8	49
00DG	Chaplin	orthic fluviar	sandy loam	NW	34	15	13	W3	8.3	0.9	21	**14**	1051	86	3	12	2	6	35
98KK	Fox Valley	calcareous lacustrine	v.f.sandy loan	NE	26	15	11	W3	8.3	1.1	15	**19**	1080	86	4	19	2	5	63
99KK	Fox Valley	calcareous lacustrine	v.f.sandy loan	NE	26	15	11	W3	7.6	1.2	24	**17**	1172	96	5	22	5	5	126
00KK	Fox Valley	calcareous lacustrine	v.f.sandy loan	NE	26	15	11	W3	7.5	2	15	**17**	997	86	3	10	2	4	42
98DN	Willows-Sceptre	orthic lacustrine	clay	NW	19	21	18	W3	8.3	0.4	20	37	983	44	5	8	2	3	54

* Bold indicated a possible deficiency

Site	Alfalfa Variety	Established
BS	Centurian	1996
JC	Profit	1996
LH	Beaver	1997
RM	Algonquin	1994
MG	AC Blue J	1997
DG	Barrier	1997
KK	Unknown	1995
DN	Beaver	1996