HERBAGE MASS ACCUMULATION IN AN INTENSIVE ROTATIONAL GRAZING SYSTEM AT UNH’S ORGANIC DAIRY RESEARCH FACILITY

BY

ASHLEY GREEN
BS, University of New Hampshire, 2009

THESIS

Submitted to the University of New Hampshire in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Natural Resources

May, 2011
This thesis has been examined and approved.

__________________________
John D. Aber, Professor of Environmental Sciences

__________________________
Andrew B. Conroy, Professor of Applied Animal Science

__________________________
Thomas D. Lee, Associate Professor of Environmental Conservation Studies and Environmental Sciences and Forestry
ACKNOWLEDGEMENTS

The author wishes to thank the following organizations and individuals:

For financial support from New Hampshire’s Agricultural Experiment Station
(http://www.colsa.unh.edu/aes). For their guidance and comments to improve the quality
of the research and text, John Aber (advisor), Drew Conroy (committee member), and
Tom Lee (committee member). For their cooperation and assistance, University of New
Hampshire’s Organic Dairy Research Facility’s staff, management and cows, University
of New Hampshire’s Natural Resources lab, and University of New Hampshire’s Animal
Science lab.
# TABLE OF CONTENTS

**ACKNOWLEDGEMENTS** iii

**LIST OF TABLES** v

**LIST OF FIGURES** v

**ABSTRACT** vi

**INTRODUCTION** 1

**I. LITERATURE REVIEW** 7

  - Forage Biomass Estimation 7
  - Forage Productivity and Species Diversity 9
  - Integrating Forage Production with Livestock Requirements 20

**II. METHODS AND EXPERIMENTAL DESIGN** 26

  - Study Site 26
  - Methods Comparison 29
  - Pasture Biomass Observation 32

**III. RESULTS AND DISCUSSION** 33

  - Methods Comparison 33
  - Biomass Growth and Grazing Intensity 36

**IV. CONCLUSIONS** 47

**V. LITERATURE CITED** 48
LIST OF TABLES
Table 1: Total pasture productivity and consumption, 2009.............................37

LIST OF FIGURES
Figure 1: Voisin 1959, S-shaped growth curve...............................................11
Figure 2: Tracy and Sanderson 2000, Frequency of pasture forages..................13
Figure 3: Undersander et al. 2002, Seasonal distribution of forages..................17
Figure 4: Blaser 1986, Morphology response to grazing height.......................19
Figure 5: Blaser 1986, Kentucky bluegrass and white clover re-growth............20
Figure 6: Le Du et al. 1979, Herbage allowance and DMI..............................22
Figure 7: Hodgson 1990, Herbage utilization efficiency and DMI.......................24
Figure 8: Mean seasonal precipitation and temperature, 2009..........................28
Figure 9: Pasture ruler and dry biomass correlation......................................34
Figure 10: Initial calibrated plate meter and dry biomass correlation...............34
Figure 11: NDVI and dry biomass correlation..................................................35
Figure 12: Final calibrated plate meter and dry biomass correlation..................36
Figure 13: DMI versus pasture allowance (per ha)...........................................41
Figure 14: Individual paddocks - dry biomass vs. days since last grazing..........43
Figure 15: For both fields – dry biomass vs. days since last grazing...............44

LIST OF MAPS
Map 1: Map of UNH’s Burley Demeritt Organic Dairy.................................58
ABSTRACT

HERBAGE MASS ACCUMULATION IN AN INTENSIVE ROTATIONAL GRAZING SYSTEM AT UNH’S ORGANIC DAIRY RESEARCH FACILITY

by

Ashley Green

University of New Hampshire, May 2011

Pasture-based animal management in the Northeast U.S. relies on the ability to efficiently estimate pasture production and animal intake. Accuracy and precision of a rising plate meter, NDVI meter, and height measurements for estimating pasture biomass were compared relative to hand-clipped samples. Pasture measurements were used to describe biomass accumulation, lactating dairy herd intakes, and re-growth patterns for intensively rotated pastures. Pastures were measured from May-September, 2009 at the UNH Organic Dairy Research Facility in Lee, NH. The rising plate meter provided the most robust estimates of biomass ($R^2=0.58$, add SEE=). Forty-seven paddocks were measured for 82 grazing events; grazing periods were 12-hours on 0.15 ha paddocks (0.37 acres). Biomass accumulation was comparable to expected values for rotationally grazed Northeast pastures (5663 kg/ha and 7101 kg/ha). Herbage utilization efficiency (86%) was (40-50% higher than recommended values for maximizing animal productivity). Overgrazing pastures slowed the re-growth of adequate biomass for grazing.
INTRODUCTION

Forage-based livestock systems generate nearly two-thirds of the agricultural income for the Northeast U.S. (Northeast Pasture Consortium, 2005). Over the past decade the numbers of dairy livestock operations have decreased throughout New England; the total number of operations from 1995 to 2007 decreased in Maine from 750 to 480, in Massachusetts from 500 to 310, in Vermont from 2,100 to 1,200, and in New Hampshire from 400 to 220 (NASS, 2010). Over 85% of dairy operators in Vermont in 2007 were supporting herds of 200-head or less, contributing 46% of the state’s total dairy profits (NASS, 2010). Since 1995, the only growth in Vermont’s dairy operations has occurred in operations supporting 200-500 and 500+ head herds (NASS, 2010).

Lowering profit margins since the 1990s have forced dairy producers to adapt survival techniques such as major dairy expansion, methods to increase milk production per cow, or the adoption of alternative production methods such as intensive rotational grazing (Winsten et al., 2000, 2010). Major dairy expansion relies on confinement feeding strategies and requires large startup capital (Winsten et al., 2010). Increasing milk production per cow typically means high feed costs and use of growth hormones or antibiotics (Winsten et al., 2010). Pasture-based livestock systems can potentially improve farm financial sustainability despite lower milk production per cow (Taylor, 2009, Winsten et al., 2000, 2010). Intensive rotational grazing systems significantly reduce many of the costs of confinement-based systems including forage planting,
harvesting, and processing equipment, housing infrastructures, and feed storage space (USDA NRCS, 2007, Taylor, 2009). Additionally, in a pasture-based system cattle consume high-quality forage directly from the field for a portion of the year; labor and fuel for feed harvesting, mixing, and daily feeding is reduced (USDA NRCS, 2007). A survey of Michigan farmers found a 20.3% decrease in daily feed cost per hundredweight of milk during the grazing season (Taylor, 2009). In a confinement-based livestock system, feeding expenses typically account for 45-65% of milk production (Murphy, 1998). The overhead cost for pasture-based livestock systems is lower than confinement-based systems, decreasing the risk of debt for the farmer and often increasing the net income per cow (Winsten et al., 1996, 2000, 2010, USDA NRCS, 2007, White et al., 2002).

Cattle health is also suggested to improve in a grazing-based system. A study comparing a confinement feeding system with intensive rotational grazing found 1.8 times higher rates of clinical mastitis and 8 times higher cull rates (due to mastitis) in cows in the confinement feeding system (Muller et al., 2002, Washburn et al., 2002). The study also found that cows showed no difference in reproduction performance in intensive grazing versus confinement feeding; however body condition score and bodyweights were lower for cows on pasture (Washburn et al., 2002). Hoof and leg health and locomotion were better for cattle spending time on pasture versus in free stalls, straw beds or slatted floors; lameness was also found to be reduced for cows on pastures versus those housed in free stall barns (Onyiro and Brownstone, 2008, Hernandez-Mendo, et al. 2007). Increased
health performance reduces veterinary costs for pasture systems versus confinement operations.

Grazing-based dairy systems exhibit environmental benefits in comparison to confined animal feeding operations and the associated tilled row crops. Permanent sod-cover enhances soil microbial communities, soil structure, carbon sequestration, and reduces erosion (Murphy, 1998, Conant et al., 2001, USDA NRCS, 2007, Stout et al., 2006). A study observing the distribution of manure in an intensive grazing system found high correlation of manure and urine distribution relative to time spent in an area, such as a feeding stall, milking parlor or pasture (White et al., 2002). When cattle were managed with intensive grazing on pasture, the study concluded that manure was evenly distributed with the exception of high temperature events, which led to congregating around shade and watering points (White et al., 2002). Given proper stocking densities and herbage utilization (i.e. not overgrazing), permanent sod-cover decreases nutrient runoff to waterways (Murphy, 1998, Stout et al., 2006, USDA NRCS, 2007, Stout et al., 2000). Minimizing the use of N fertilizer on pastures and using legume crops for N fixation can further inhibit nitrate leaching from soils (Stout et al., 2000). In intensively rotated pastures, nearly 60-95% of ingested nutrients such as N, P, K, Mg, and Ca are directly cycled back to the soils through cattle excrement (Mott, 1974, Till and Kennedy, 1981, Whitehead, 1995, Murphy, 1998). This generally benefits pasture quality but site-specific awareness of soil quality is vital; nutrients derived from cattle supplements can exceed soil capacity, resulting in runoff to waterways (Schnabel et al., 2000).
Intensive rotational grazing (IRG), known also as management intensive grazing, strip grazing, cell grazing, or Voisin grazing, divides pastures into small paddocks (relative to herd size) that are rotated approximately every 12-24 hours (at least every 36 hours) (Voisin, 1959, Murphy, 1998). Lightweight (often polywire) electric fencing and portable water tubs are used to ease management (Murphy, 1998). Paddocks are allowed a rest period for vegetation re-growth after grazing. Duration of the rest period varies with plant growth rate, plant species, climatic factors, and soil type (Voisin, 1959, Noy-Meir, 2008, Slomp, 2009). Management with IRG encourages uniform grazing, resulting in even vegetation re-growth, improved soil quality and increased rainfall effectiveness (Voisin, 1959, McCosker, 2000). Studies have shown net returns for IRG-systems to be higher than confinement systems even given decreased milk productivity (Brown, 1990, Parker et al., 1992, Rust et al., 1995, Taylor, 2009, Winsten et al., 2000).

There are approximately 130 dairy farms with an average herd size of 115 milking animals in New Hampshire (Granite State Dairy Promotion, 2009). The majority of the farms feed stored forages, primarily corn (*Zea mays* L.) silage and alfalfa (*Medicago sativa* L.) haylage throughout the year; few farms use rotational grazing (UNH Cooperative Extension, 2004). Pastures in the Northeast are generally underutilized as a source of nutrition and feed for milking cows (Rust et al., 1995). Effective management of permanent pastures has the potential to increase the economic and environmental sustainability of dairy farms (Cherney and Allen, 1995, Taylor, 2009, Winsten et al., 2000). A strategic management plan is required to achieve optimal forage yield and
nutrient content while maximizing animal utilization and minimizing input costs (Rayburn, 2008).

Past research on rotational grazing has analyzed grazing management systems relative to animal productivity, plant genetics, profit measures and/or amounts of forage dry matter harvested (McMeekan and Walshe, 1963, Conway, 1963, O’Sullivan, 1984, Hodgson, 1990, Bransby, 1993, Wade and Carvalho, 2000). Kanneganti and Kaffka (1995) measured forage availability pre- and post-grazing event in a naturalized pasture rotationally grazed by Holstein heifers in Connecticut, USA. Kanneganti et al. (1998) measured forage availability, nutritive quality and species competition for two grazing seasons on rotationally grazed pastures with dairy cattle in Wisconsin, USA. Little information has been presented on daily herbage mass accumulation under IRG with lactating dairy-livestock. A survey of producers practicing intensive rotational grazing in Michigan cited education from extension and other graziers as the first step in the transition to intensive rotational grazing (Taylor, 2009). In the Northeast a survey was performed to analyze the barriers farmers face in adopting intensive grazing, following concerns about market prices, farmers in several states cited lack of on-farm technical assistance (Winsten et al., 2010). For extension to provide necessary assistance to producers, full-season results for mixed-species naturalized pastures under IRG in the Northeast region of the USA are needed.

This study had two objectives: 1) to determine the method of pasture biomass estimation with the broadest application for pastures varying in species composition and herbage
distribution and 2) to use the most efficient biomass measurement method to quantitatively describe herbage mass accumulation and grazing intensity patterns for mixed-species rotationally grazed pastures on an organic dairy in northern New England.
I.

LITERATURE REVIEW

Forage Biomass Estimation

The standard method of measuring dry matter from pasture biomass is clipping vegetation of a defined area, drying the sample in a forced air drying oven (55°C for 48 hrs), and weighing the dried sample for a measurement known as dry matter (DM) (Harmoney et al., 1997, Sanderson et al., 2001, Tarr et al., 2005). This method is precise but time-consuming and destructive.

An alternative approach is to use average forage height over a given area to estimate biomass. This method assumes a positive relationship between height and forage biomass. Pasture height measurements are ocular, creating observer bias and making precision between different observers difficult (Heady, 1957). Variances in method technique can cause inconsistencies in cross-literature comparison (Ganguli et al., 2000). Harmoney et al. measured plant height from the highest leaf tissue within a circular frame (frame area equal to area used for clipping samples) using a stick marked with 2-cm increments placed in the center of the frame (Harmoney et al., 1997). This method was fast and efficient but did not account for plant density and demonstrated variability in biomass estimation in the comparison of mixed-species paddocks (Harmoney et al., 1997).
Spectral reflectance has also been used to estimate herbage biomass (Hatfield et al., 2008, Weiser et al., 1986, Tucker, 1980, Tucker et al., 1985). The normalized difference vegetation index (NDVI) utilizes the ratio of near infrared (NIR) and red reflectance bands \[\text{NDVI} = \frac{(\text{NIR}-\text{red})}{(\text{NIR}+\text{red})}\] (Tucker, 1980, Deering, 1978), and has been correlated with biomass yield of species such as alfalfa (Medicago sativa) (Mitchell et al., 1990), barley (Hordeum vulgare) (Wendroth et al., 2003), and native grassland species (Todd et al., 1998, Weiser et al., 1986, Tucker et al., 1985, Tucker, 1980). NDVI source data varies from aerial infrared photography, advanced sensor setups, satellite broadband spectrometers, and handheld ground-based sensors (Wendroth et al., 2003, Hatfield et al., 2008, Tarr et al., 2005, Weiser et al., 1986, Tucker et al., 1985). The relationship between NDVI and biomass is affected by plant canopy maturity (green leaf area), species composition, reflectance from underlying soils, shadow proportion, plant moisture content, and cloud canopy conditions; methods for improving prediction are still under development (Butterfield and Malmström, 2009, Hatfield et al., 2008, Weiser et al., 1986, Tucker et al., 1985, Tucker, 1980).

The use of a rising plate meter gives a measurement known as bulk density that is a combination of forage height and plant density (Michalk and Herbert, 1977). It is a non-invasive and precise technique that is quick and easy to use (Flynn et al., 2008, Ganguli et al., 2000, Harmoney et al., 1997, Sanderson et al., 2001). The plate meter allows for calculation of density by calibrating the canopy resistance to the plate’s constant resistance. Forage density is a more representative biomass measurement than height in areas of high forage species diversity and intensive utilization (Harmoney et al., 1997).
Jenquip’s pasture meter manual (Feilding, NZ) includes calibrations for DM based on pastures in NZ and a recommendation of 30-50 readings per paddock. A study by Sanderson et al. found that standard equations were not adequate predictors and locally developed equations were necessary (2001). Senesced sward stems and soil surface variation can create variability in data (Flynn et al., 2008).

**Forage Productivity and Species Diversity**

Plant biomass is the total mass of all live plant components (leaf, shoot, and root). Aboveground biomass (the portion of the plant that occurs above the soil) is often measured as the dried weight absent of water content (dry matter – DM) (Fageria et al., 2006). Perennial plant growth is based on five growth periods: 1) germination, 2) vegetative, 3) elongation, 4) reproductive, and 5) seed ripening (in the case of grasses, vegetative and elongation stages are usually combined) (Moore et al., 1991, Kaiser, 1995). The accumulation of biomass during plant growth is represented in a S-shaped curve divisible into three periods: 1) an early period of slow growth, 2) a central period of rapid growth, and 3) a final period of slow growth (Bonner and Galston, 1952, Hunt, 1978, Moore et al., 1991). The periods of growth correspond with stages of plant maturation (Hunt, 1978, Moore et al., 1991). The initial period of slow growth occurs during germination as the seed’s resources are channeled to primary shoot and root growth (Hunt, 1978, Moore et al., 1991). The presence of leaves, stem and tillers marks the beginning of rapid growth in the vegetative and elongation periods (Hunt, 1978, Moore et al., 1991). The final period occurs when stem elongation ceases and inflorescence is present, marking the onset of the reproductive stage (Moore et al., 1991).
The rate of biomass accumulation slows in the final phase as nutrients and energy are assimilated into seed formation (Hunt, 1978, Moore et al. 1991).

Voisin applied the concept of the three-stage sigmoid growth curve to pastures and livestock; the slope of the sigmoid curve in Figure 1 represents the regeneration of forage biomass following a grazing event (1959). For optimal pasture utilization and animal digestion efficiency Voisin established two rules: 1) Pastures should never be grazed to biomass levels below the second phase (central period of rapid growth) in the curve (Voisin, 1959). Grazing to a level below the second phase, or the vegetative and elongation stages, creates a lag period before rapid re-growth, likely due to a depletion of the plant’s energy reserve. (2) Pastures should always be grazed before reaching the third phase (final period of slow growth) in the curve (Voisin, 1959). Allowing the pasture to be grazed after reaching the third phase, or reproductive and seed ripening phase, would force the animal to graze mature swards, resulting in decreased animal intake and utilization efficiency. The number of days in the rest period for maximum productivity is highly variable based on species present in sward, season, energy reserves of the sward, severity of defoliation and trampling due to grazing, and other climatic and environmental factors (Voisin, 1959, McNaughton, 1979, Savory, 1988, Hodgson, 1990, Murphy, 1998).
Species diversity in pastures can improve forage production, animal intake and resilience to weed invasion and climatic variation. A study in Europe positively correlated high pasture species diversity with increased biomass production and stability in response to disturbance (Minns et al., 2001). A similar study in Canada found that forage productivity was greatest in the treatment with the highest species diversity during 3 years of intensive grazing (Clark, 2001). In a survey of Northeast U.S. pastures on experimental and working farms, Tracy and Sanderson found that stands with even distribution of diverse pasture forages were less likely to support populations of undesirable forage species (2004a, 2004b). An economic model comparing a mixed grass-legume-forb stand with a fertilized grass stand both grazed by a 100-head dairy herd, predicted higher net returns, resilience to weather risk, and greater potential for hay
production from the mixed stand (Sanderson et al., 2006). Forage species richness has been found to have little to no effect on cattle DM intake or animal performance (Tracy and Faulkner, 2006, Soder et al., 2006). It has been found that cattle will maintain a mixed diet, often with a preference for legumes, when given the choice (Rutter et al., 1997, 2004, Parsons et al., 1994, Rook et al., 2002).

Surveying 37 Northeastern U.S. pastures, Tracy and Sanderson (2000) found the dominant pasture species to be white clover (*Trifolium repens*), Kentucky bluegrass (*Poa pratensis*), orchardgrass (*Dactylis glomerata*), and tall fescue (*Festuca arundinacea*) (Figure 2). They concluded that the dominant diversity relationships at the pasture-scale were representative of regional-scale relationships (Tracy and Sanderson, 2000). Average species richness of the pastures was 31.7 (+ 1.1)/0.1 ha; the functional groups with greatest diversity were perennial forbs, followed by perennial grasses, annual forbs, and legumes (Tracy and Sanderson, 2000).
Pasture diversity is affected by seasonal growth patterns of individual species; Figure 3 demonstrates the general biomass productivity patterns for common cool-season grasses, warm-season grasses, legumes, and alternative forages (Undersander et al., 2002). These patterns are affected by plant response to climatic and environmental factors such as day length, precipitation and temperature.

Perennial cool-season grasses are typically spring producers, decreasing in productivity in late summer through to fall (particularly in dry seasons) (Undersander et al., 2002, Balasko et al., 1995). Cool-season grasses such as Kentucky bluegrass (P. pratensis), orchardgrass (D. glomerata L.), timothy (Phleum pratense L.) and tall fescue (F. arundinacea), demonstrate variation in morphology, growth pattern, response to grazing, and heat and drought tolerance. Kentucky bluegrass is sod forming, winter-hardy and low growing (Balasko et al., 1995). Morphological presence of rhizomes and stolons and
a high concentration of leaf area close to the soil surface contribute to the persistence of bluegrass in heavy grazing and trampling scenarios (Balasko et al., 1995). Orchardgrass is shade-tolerant, and, due to its extensive fibrous root system, is more heat and drought tolerant than timothy or Kentucky bluegrass (Christie and McElroy, 1995). Orchardgrass is a bunch grass that grows in clumps (Christie and McElroy, 1995). It continuously produces tillers throughout the season, allowing for rapid recovery after grazing (Christie and McElroy, 1995). Timothy is an extremely winter-hardy bunch grass; it, unlike many cool-season grasses, does not persist well under frequent defoliation (McElroy and Kunelius, 1995). Timothy has a relatively shallow root system that makes it susceptible to moisture stress (McElroy and Kunelius, 1995). Tall fescue is a bunch grass that produces sod-forming rhizomes; this increases the plant’s tolerance of heat, drought and heavy grazing (Sleper and Buckner, 1995). Frequent defoliation stimulates tillering, which decreases the nutritive value of fescue (Sleper and Buckner, 1995). Some varieties of tall fescue harbor the endophytic fungus *Acremonium coenophialum*, which is linked to three animal disorders: 1) fescue foot, 2) bovine fat necrosis and 3) fescue toxicosis (or summer syndrome) (Sleper and Buckner, 1995, Schmidt and Osborn, 1993). Grazing management can decrease the severity of fungus toxicity by offering a diverse array of forages or eliminating fescue from the diet in extremely hot weather (Sleper and Buckner, 1995).

Legumes often start growth slightly later in the spring than cool season grasses (Undersander et al., 2002). Once established, legume production is consistent throughout the growing season; many legumes species are more heat and drought tolerant than cool
season grasses (Figure 3) (Undersander et al., 2002). Legumes provide two additional benefits in a grazing scenario: 1) N addition and 2) an increase of forage intake and forage quality (Rayburn et al., 1998, Nelson and Moser, 1995). N addition is possible via a symbiotic N-fixing bacterium that forms nodules on the roots of legumes and produces available N$_2$ from plant carbohydrates (Nelson and Moser, 1995). This process increases the amount of N available for plant uptake, greatly increasing forage productivity while decreasing dependence on fertilizer inputs (Rayburn et al., 1998). Legumes are generally characterized by more available N (protein) than grasses and are shown to improve animal performance when added to a grass diet (Rayburn et al., 1998). With most legumes, caution must be practiced when grazing to avoid overgrazing and causing cattle bloat (Taylor and Smith, 1995). Alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.) are the most abundant perennial legumes in Northeast pastures. Alfalfa has the highest feeding value in terms of available protein and is extremely drought tolerant (Barnes and Sheaffer, 1995). It is susceptible to winter kill without adequate snow cover (Barnes and Sheaffer, 1995). Alfalfa requires a long recovery period (30-40 d) after grazing to avoid stand loss (Barnes and Sheaffer, 1995). Alfalfa is sensitive to soil pH and will have low production on nutrient-poor soils (Barnes and Sheaffer, 1995). Red clover is easily established in closely grazed stands and is relatively shade-tolerant (Taylor and Smith, 1995). Red clover is more tolerant of moist and or flooded soils than alfalfa (Taylor and Smith, 1995). White clover growth differs from alfalfa and red clover due to its stoloniferous growth pattern (Pederson, 1995). Individual stolons grow prostrate to the ground and are rarely grazed, allowing for rapid re-growth of upright petioles and leaves (Pederson, 1995). This is unlike alfalfa
and red clover, which must elongate from the crown or axillary stem buds, depending on harvest height (Barnes and Sheaffer, 1995, Taylor and Smith, 1995). The relatively shallow growth habit of white clover makes it ideal for shallow soils but also susceptible to drought damage (Pederson, 1995). It is advised that cattle should not be allowed to graze pastures of 60-100% white clover to reduce the risk of bloat (Pederson, 1995).

Warm season forages are an option for providing high quality pasture during the hot summer months when cool season forages become semi-dormant (Moser and Vogel, 1995). Perennial warm season grasses, such as switchgrass (Panicum virgatum L.) and big bluestem (Andropogon gerardii Vitman), are slow to establish and typically not very winter-hardy (Moser and Vogel, 1995, Undersander et al., 2002). Due to their late-spring start, warm season forages are subject to competition by legumes, weeds, and cool-season grasses; the evolved method of management to maintain healthy warm season forage stands is periodic burning (Moser and Vogel, 1995). Forage quality is generally lower in warm season forages when compared with cool season forages (Moser and Vogel, 1995).
Figure 3 – Average seasonal distribution patterns of common pasture species. Shaded area indicates plant biomass production during relative period of season (month). From Undersander et al., 2002.

Plant defoliation by grazing removes plant tops, stimulating the movement of nutrients from reserves to new leaf production (Murphy, 1998). Several attributes of plant morphology dictate re-growth response following grazing: leaf area under grazing
horizon, location of growing point relative to grazing horizon, and storage of carbohydrate and protein reserves (Figure 4) (Blaser, 1986, Undersander et al., 2002, Butler, 2003, Rayburn, 2006). As demonstrated in Figure 4, the leaf area under a grazing horizon varies by species. When species, such as orchardgrass, are grazed to the stem-base in a routine grazing event they must allocate energy to a dormant growing point for regeneration (Blaser, 1986, Butler, 2003). This process takes time and energy, and the location of the plant’s growing point varies (Butler, 2003, Rayburn, 2006). Grasses demonstrate variation based on morphology, such as jointed or non-jointed grasses. Non-jointed grasses, including Kentucky bluegrass, orchardgrass, ryegrass and tall fescue, are relatively resistant to close grazing (Rayburn, 2006). Their growing point is near the soil surface, and leaves on tillers continue to grow following defoliation (Rayburn, 2006). Jointed grasses, such as timothy, depend on elongating internodes along the stem for growth; the internodes continuously push the growth point up above the grazing horizon as each internode elongates. When the growing point is grazed, a dormant bud must be initiated and stored food must be reallocated (Undersander et al., 2002). Overgrazing or continuous grazing reduces plant reserves of favored species and can decrease the chance of survival of stressed plants. By promoting uniform grazing, intensive grazing reduces selective, patchy grazing and competition from less desirable and un-grazed species (Murphy et al., 1995).
Grazing management can influence species composition given the differences in regrowth potential based on harvest height (Butler, 2003, Rayburn, 2006). For example, a producer interested in high quality pastures rich in white clover would allow for heavy grazing (less than 2” stubble remaining) to allow light to reach clover stolons and stimulate leaf growth (Figure 5) (Blaser, 1986, Butler, 2003, Rayburn, 2006). A producer interested in maintaining pastures rich in warm season forages for stockpiling would leave greater post-harvest stubble (2-3”); the stubble would out shade cool season grasses and legumes (Blaser, 1986, Butler, 2003, Rayburn, 2006). These management techniques would need to be altered based on periods of low precipitation, high heat, etc.
Plant maturity dictates the nutritive value of forages for ruminant digestion (Allison, 1984). As forages mature the proportion of stem biomass increases relative to leaf mass (Rayburn, 2008). This shift results in lower protein and non-structural carbohydrates, both sources of readily digestible energy for ruminants, and an increase in fiber, cellulose and complex carbohydrates due to a process known as lignification (Kennedy et al., 2006, Rayburn, 2008). At forage maturity there is a greater amount of aboveground harvestable biomass, however, digestibility, livestock intake rates, and, subsequently, milk production levels decrease (Holmes et al., 1992, McGilloway et al., 1999, Kennedy, 2006, Curran et al., 2010).

**Integrating Forage Production with Livestock Requirements**

Pasture intake is influenced by time spent grazing, herbage availability and quality, nutritional demands of the cattle, and the amount of supplementary feeds being offered.
(Hodgson, 1990, Sayers et al., 2003). Measures of cattle dry matter intake (DMI) demonstrate a saturating curvilinear relationship between DMI and pasture allowance (PA), or the amount of standing herbage offered to cattle relative to paddock area, where maximum DMI is not at the maximum PA (Greenhalgh et al., 1966, Combellas and Hodgson, 1979, Le Du et al., 1979, Mejis and Hoekstra, 1984, Peyraud et al., 1996, Dalley et al. 1999) (Figure 6). Peyraud et al. also suggested additional independent effects for animal DMI including original sward structure, animal behaviorisms, and individual animal potential milk yield (1996).

DMI predictions reflect the animal’s net-energy demands, including energy requirements for maintenance, milk yield and replenishment of lost weight (NRC, 2001). Equations developed to predict DMI for Jersey cattle based on animal-related variables (no considerations of dietary ingredients) were able to account for 69-81% of variation within measured DMI (Holter et al., 2001). DMI requirements and energy demand varies greatly for dairy cattle relative to their age and stage of pregnancy/lactation (NRC, 2001). The NRC recommended mean DMI value for Jersey cattle, measured for confined cows on a rationed diet, was 3.49% of individual live bodyweight (range between 2-4.2% of live bodyweight) (Holter et al., 2001).
Figure 6 - Relationships of daily herbage allowance relative to daily herbage intake for cattle on pasture as measured in 5 different studies. Intake and allowance represented in terms of g organic matter (OM) in DM of pasture per kg live weight (LW) for cattle. Organic matter digestibility of forages calculated for in vitro samples of herbage selected by fistulated cows in Le Du et al., 1979. From Le Du et al., 1979.

A literature survey by Vazquez and Smith compared 27 published grazing studies conducted worldwide (Australia, New Zealand, United States, Great Britain, and the Netherlands) from 1979 to 1992 for a variety of dairy cattle breeds (2000). There were variations in supplementation of pasture, species present in pasture, and rotational grazing strategy between the compared datasets (Vazquez and Smith, 2000). Mean pasture DMI and PA’s were, respectively, 11.6 and 25.5 kg DM/day; the data represented a large range (maximum reported pasture DMI was 21.3 kg DM/day) (Vazquez and Smith, 2000). Average pasture DMI was approximately 2.57% of reported bodyweight, not including supplementation. The survey’s mean pasture DMI (2.56% of live bodyweight) falls on the low-end of the range (2.17-3.76% of live bodyweight) measured by recent studies (Kolver et al., 1998, Dalley et al., 1999, McEvoy et al., 2009). Animal-related variables (bodyweight, change in bodyweight, and milk yield) were found to
explain 71% of total variation in DMI within the survey dataset (similar range to the findings of Holter et al., 2001) (Vazquez and Smith, 2000).

Herbage utilization efficiency is a measure of the amount of forage grazed (DMI) relative to the amount of forage available in pasture (PA). If the forage offered (PA) is in excess of that required by herd (i.e. low stocking rate) the resulting utilization efficiency is small. The manager’s aim is to optimize intake without forcing the herd to consume less desired and less nutritious forages; it is estimated that beyond 80% utilization efficiency animal intake suffers and animal production/acre declines (Figure 7) (Hodgson, 1990, Butler et al., 2003). Based on Figure 7, peak animal performance, or maximum animal health and milk production, occurs at 40% utilization efficiency; however, 40% utilization is not optimum for pasture performance (Hodgson, 1990, Butler et al., 2003). Given the survey by Vazquez and Smith, average herbage utilization efficiency was about 52% (Vazquez and Smith, 2000). Based on the curve offered by Hodgson, this suggests that average forage intake was not optimized in the survey herds (1990).
A study published by Curran et al. (2010) compared DMI, milk production, and herbage quality on paddocks rotationally grazed at high vs. low herbage mass. Paddocks grazed at the low herbage mass demonstrated a positive relationship with forage quality, milk production, and DMI; the study was also able to increase the length of the grazing season by ten days for the paddocks grazed at the low herbage mass (Curran et al., 2010). High herbage mass in pasture does not directly correlate with high animal productivity; plant maturity reduces forage quality, herbage utilization efficiency and DMI.

Some producers have adopted a system known as leader-follower grazing, which allows cows with higher nutrient demands (high milk yield potential) to graze first followed by cows with lower nutrient demands (low milk yield potential, heifers or dry cows). The first group grazes the high quality forage and the follower group grazes the
remaining/rejected herbage. The system has been shown to increase herbage utilization efficiency, milk productivity (for the leader group), and DMI (Mayne et al., 1988). Additionally, when properly managed, the method maintains a uniform healthy sward quality, which encourages optimal re-growth (Barrett et al., 2001).

Measurements of annual herbage biomass production (net primary productivity) allow for comparison between seasons and calculating the farm’s carrying capacity. A survey of the literature revealed an average biomass of 7766 kg DM/ha (SD ± 795) consumed seasonally (April-Sept) from pastures under IRG (Kanneganti and Kafka, 1995, Kanneganti et al., 1998, Carlassare and Karsten, 2002). These studies were based on naturalized pastures in Wisconsin, Connecticut and Pennsylvania with acreages of 19 ha, 4.4 ha, and 1.4 ha, respectively. The Penn State Agronomy Guide suggests the following yields for Northeast pastures under rotational grazing: 7616 kg/ha for red clover-cool season grass mixtures, 5376 kg/ha for white clover – Kentucky bluegrass mixtures, 8736 kg/ha for orchardgrass, and 7616 kg/ha for timothy (Martz, 2002).
II.

METHODS AND EXPERIMENTAL DESIGN

This study had two objectives: 1) to determine the method of pasture biomass estimation with the broadest application for pastures varying in species composition and herbage distribution and 2) to use the most efficient biomass measurement method to describe quantitatively herbage mass accumulation and grazing intensity patterns for mixed-species rotationally grazed pastures on an organic dairy in northern New England.

Study Site

The study was conducted from May-September, 2009 at the University of New Hampshire’s (UNH) Burley-Demeritt Organic Dairy Research Farm (ODRF) in Lee, NH (http://www.colsa.unh.edu/aes/odrf/). The ODRF was the first of its kind at a land-grant university. The 121-hectare (300-acre) working organic dairy is owned and operated by the New Hampshire Agricultural Experiment Station and administered by UNH’s College of Life Sciences and Agriculture (COLSA). The land was purchased by the University in 1969 and was established as an organic dairy in 2006. Historic production uses include a dairy (prior to University ownership), poultry, beef cattle, sheep, and haying. The ODRF supports research from multiple disciplines at UNH and in cooperation with USDA-ARS and partner universities. This study coincides with an investigation of nutrient and energy balances at the dairy for sustainable ecosystem management supported by USDA-SARE (http://www.colsa.unh.edu/aes/odrf/research/projects/SARE).
During the study, the dairy farm was milking a 40-head lactating herd of purebred Jersey cattle. Average live bodyweight was 397 kg/cow (876 lb/cow), based on data from feeding trials taking place in early spring. Average daily milk production through the study period was 15.5 kg/cow (34.07 lb/cow).

The pasture vegetation at the ODRF is largely composed of Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pratense*), orchardgrass (*Dactylis glomerata* L.), and red and white clover (*Trifolium pratense, T. repens*). The fields are located on nine different soil types classified as marine terraces with outwash and glacial till as parent material. Scantic silt loam covers 30% of the pasture area with a 2% slope. The Scantic soil is a member of the fine, illitic, nonacid, mesic Typic Haplaquepts. Nearly equal portions of Hollis-Charlton fine sandy loams, Swanton fine sandy loam, Hinckley loamy sand, and Charlton fine sandy loam dominate the remaining soils. The Hollis-Charlton soil has a 6% slope and is a member of the sandy-skeletal, mixed, mesic Typic Udorthents. The Swanton soil also has a 6% slope and belongs to the coarse-loamy over clayey, mixed, nonacid, mesic Aeric Haplaquepts. The Hinckley soil and the Charlton soil both have 12% slopes. The Hinckley soil belongs to the sandy-skeletal, mixed, mesic Typic Udorthents, and the Charlton soil is a member of the coarse-loamy over sandy or sandy-skeletal, mixed, mesic Typic Dystrochrepts (Websoil Survey 2010).

The mean temperature for May-September 2009 was 17.3°C (63.19° F) with a total measured rainfall of 54.05 cm (21.28 inches) (Figure 8) (http://www.weather.unh.edu/).
The total rainfall was above the 43.74 cm (17.22 inches) seasonal average for the region and the temperature was only slightly lower than the 18°C (64.4° F) seasonal average.

Figure 8 - Mean temperature and total precipitation for Durham, NH from May-September, 2009. Data from http://www.weather.unh.edu.

In 2009, two pastures, 7.77 ha (19.2 acres) and 5.30 ha (13.1 acres) in area, (respectively referred to as F1 and F2 for the remainder of the paper) were divided into paddocks with an average area of 0.15 ha (0.37 acres). Forty-seven paddocks, representing 7.1 ha (17.4 acres) of the total pastures, were used for observation data. From early May through late September, the pastures were managed with intensive rotational grazing (IRG). IRG is a grazing technique that aims to maximize pasture production by minimizing selective grazing and promoting uniform grazing (Murphy, 1998, Voisin, 1959). The annual stocking density of the pastures was approximately 2.56 AU/ha (1.03 AU/acre) (AU=animal unit=1000 lb live-weight animal). After every milking event (approximately every 12 hours) the herd was rotated to a new paddock.
F1, the 7.77 ha pasture, had rolling hill topography characteristic of New England pastures; there were several wet areas where vegetation was dominated by tall fescue \((Festuca arundinacea)\) and reed canarygrass \((Phalaris arundinacea)\). Through the season F1 was grazed three times with IRG and once at the end of the season (8/21-9/2) with continuous grazing.

F2, the 5.3 ha pasture, was flatter and without distinct wet areas. It was hayed in early June and grazed three times with IRG. Several paddocks were an exception to this pattern due to severe weather. Heifers and dry cows were used for cleanup on several paddocks following grazing by the lactating herd.

Cows were offered 3.6 kg/day (8 lb/day) of an organic lactating dairy cow supplement following milking during the 2009-grazing season. The supplement was primarily composed of cornmeal, wheat midds, barley, soy meal, and other ingredients with 14% crude protein, 4% fat and 7% fiber on a dry matter basis (Morrison’s Custom Feeds, http://www.morrisonfeeds.com/).

**Methods Comparison**

The first portion of this study was a comparison of methods for measuring pasture biomass. The objective was to determine the method that would maximize precision, minimize field and lab time requirements, and provide the most data samples for pasture growth and grazing intensity analysis. Four methods of pasture sampling were compared:
pasture ruler height, the normalized difference vegetation index, a plate meter, and clipping and drying.

A total of 203 samples were taken randomly across the two pastures from May 31st to June 16th, 2009. Sample sites were randomized to account for microhabitat variation including topography, vegetation composition, and soil type. At each sample site, measurements were made in order of least to most invasive: pasture ruler (PR), normalized difference vegetation index (NDVI), calibrated plate meter (CPM), and clipping (Ganguli et al., 2000).

PR height was measured with a meter stick placed at the soil level. The height (cm) was estimated from an average of the top three plants located closest to the meter stick. The plant height was measured from naturally occurring high spot if the plant had folded over (Heady, 1957).

The handheld Greenseeker NDVI meter (NTech Industries, Ukiah, CA) is endorsed for its ability to measure changing field conditions throughout a growing season, field condition variations due to inputs such as N fertilizer, and to measure biomass (Flynn et.al, 2008) (http://www.ntechindustries.com/greenseeker-home.html). The Greenseeker has high intensity light emitting diodes that pulse the canopy with red (660 nm) and near infrared (770 nm) radiation (25-nm band widths) at high frequencies while reflected light is measured with a photodiode detector. It is capable of filtering out ambient light with an active source of internal illumination, eliminating error due to weather or time of day.
The Greenseeker was set in log plots mode and held 0.8-1.2 m (2.3-4.0’) over the sample area for 10 seconds; the average NDVI reading was recorded.

The Jenquip folding plate pasture meter (Feilding, NZ) was used for calibrated plate meter (CPM) measurements (Sanderson et al., 2001, Soder et al., 2006) (http://www.jenquip.co.nz). This device allows for measurement of pasture forage density. The pole of the CPM was pressed vertically through the sward until it reached the ground. The weight of the mounted-plate compressed the pasture vegetation. A gear-based counter measured the compression in 5-mm increments; at each sample point the change in the counter was recorded. Manufacturer recommended calibration equations were not used because they were developed relative to NZ pastures.

Clipping occurred in a 0.1m$^2$ (1.08ft$^2$) area circle (same size as the plate of the CPM). Grass shears were used to clip all vegetation that was growing within the 0.1m$^2$ area to approximately 4 cm (1.6”) height (nearly ground level). The vegetation samples were dried in a forced-air drying oven at 55° C for 48 hours and weighed for dry weight (Sanderson et al., 2001).

The PR, CPM, and NDVI measurements were plotted and regressed against dried weights of clipping measurements using JMP software (JMP 8.0.2, 2010). Linear regression fits were tested and had lesser correlation than the inverse power regression with y-intercept set at zero. The inverse power regression was determined to be the best fit. The method (calibrated plate meter) with the best regression fit was the
calibrated plate meter; an additional 200 randomly located field samples (n=382) were taken with the CPM and clipped samples using the same protocol as previous samples. The additional samples were taken to add power to the biomass estimation equation. The equation for the regression fit between CPM samples and clipped dry weights was used for estimation of biomass in the remainder of the study.

**Pasture Biomass Observation**

As a result of the method comparison (see Results), the CPM was used for pasture biomass measurements from late June-September, 2009. Fifty CPM measurements were made per paddock before and after grazing events for a total of 82 grazing events and bi-weekly (533 total bi-weekly paddock measurements) during rest periods following grazing. The pre- and post-graze measurements provided an estimate of grazing intensity. The bi-weekly measurements represented an undisturbed estimate of biomass growth over time since grazing.

Dry matter intake was estimated from the pasture disappearance per grazing event (herbage intake=herbage offered-herbage refused) (Mejis et al., 1982, Macoon et al., 2003, Smit et al, 2005, Ferri et al., 2008). Re-growth of pastures during grazing was not calculated due to short grazing periods (less than 1 day) and rapid field measurements following a grazing event (Smit et al., 2005).

Stocking density and date and time (AM/PM) of grazing were also noted. Minimum and maximum temperatures and precipitation data were gathered using UNH’s weather station located less than 4 miles away in Durham, NH (www.weather.unh.edu).
III.

RESULTS AND DISCUSSION

Methods Comparison

A total of 203 sets of samples were measured with the PR, NDVI, CPM, and clipping. The PR, NDVI, and CPM measurements were plotted against the actual dry biomass from clipping and each fitted with an inverse power regression line for biomass estimation (Figure 9 - Figure 11). The exponential shape of the calibrated plate meter and pasture ruler biomass relationships were an accurate representation of the vegetation, in part due to the presence of ungrazed stubble of mature timothy (*Phleum pratense*) and orchardgrass (*Dactylis glomerata L*). The sturdy stems registered a greater biomass with the PR or CPM than actual biomass weighed when clipped and dried; this relationship resulted in poor linear regression correlation.

The CPM construction disallowed field measurements greater than 51 cm; this eliminated 23 measurements in the regression analysis (n=179). For future studies, the long-arm extension offered by the manufacturer is recommended (http://www.jenquip.co.nz/handbook_book_no3.pdf).

In the comparison with clipping measurements, a time-consuming but precise measurement, the CPM had the greatest coefficient of determination ($R^2=0.58$) and lowest standard error of the estimate (SEE = 2.85) (Figure 10). The pasture ruler had an $R^2=0.485$ (SEE=3.29) and the NDVI had an $R^2=0.139$ (SEE=5.82) (Figure 9, Figure 11).
The CPM was the most efficient and relatively precise method based on regression results and its unbiased repeatability and ease of use in the field.

![Graph showing the comparison of pasture ruler measurements (cm) and dried biomass sample for 0.1m² area.](image)

Figure 9 - Comparison of pasture ruler measurements (cm) and dried biomass sample for 0.1m² area. Samples taken May 31st-June 16th, 2009 at UNH’s Burley-Demeritt ODRF in Durham, NH. n=179. Solid line represents regression equation (with $R^2$), $SEE=3.29$.

![Graph showing the comparison of calibrated plate meter measurements and dry biomass sample for 0.1m² area.](image)

Figure 10 - Comparison of calibrated plate meter measurements and dry biomass sample for 0.1m² area. Samples taken May 31st-June 16th, 2009 at UNH’s Burley-Demeritt ODRF in Durham, NH. n=179. Solid line represents regression equation (with $R^2$). $SEE=2.85$. 
Figure 11 - Comparison of NDVI and dry biomass sample for 0.1m² area. Samples taken May 31st-June 16th, 2009 at UNH's Burley-Demeritt ODRF in Durham, NH. n=179. Solid line represents regression equation (with $R^2$). SEE=5.82.

From the additional two hundred samples (n=382), there was only a minimal decrease in the $R^2$ (=0.55) and a decrease in the SEE (=2.73) (figure 12). This regression equation allows for estimation of available biomass using the CPM.

High chlorophyll presence in healthy plants results in high NIR reflectance and low visible RED reflectance. This ratio results in high NDVI readings, typically synonymous with high green leaf density and chlorophyll absorption. The majority of NDVI readings occurred at NDVI levels greater than 0.75, reflecting saturated conditions and the inadequacies of the NDVI for measuring dense pasture forages.

Clipping is conclusively the most precise of the measured methods for pasture biomass analysis. When time and labor are of importance, as is often the case with field studies, the CPM proves to be a viable option. Based on field trials, an equivalent number of field samples made in two hours of clipping could be acquired in less than a quarter of the time with the CPM, not to mention time saved drying and weighing samples in the lab. The CPM introduces no user bias unlike the pasture ruler, which requires user training.
Figure 12 - Comparison of calibrated plate meter measurements and dried biomass (g/m$^2$) sample for 0.1m$^2$ area. Samples taken May 31st-June 30th, 2009 at UNH’s Burley-Demeritt ODRF in Durham, NH. n=382. Solid line represents exponential regression equation (with R$^2$). SEE = 2.72.

Biomass Growth and Grazing Intensity

Forty-seven paddocks were monitored with the CPM for vegetation growth and herd consumption between June 15$^{th}$ and September 25$^{th}$, 2009. The inverse power regression equation represented in Figure 12 ($y=6.5382x^{0.4783}$) was used for biomass estimation where $y=\text{CPM reading}$ and $x=\text{estimated biomass}$.

The maximum number of measured grazing events per paddock was three. The first grazing period was on F1 from May 10$^{th}$ - June 15$^{th}$. It is not included in this dataset; the results for the methods study were still being analyzed and routine grazing was delayed due to a simultaneous controlled feeding study. F2 was hayed in early June with a yield of 126 round bales each approximately 544 kg (1200 lbs) wet weight with 50-60% DM. The second grazing period was on F1 (6/15-7/7), followed by two grazing periods on F2 (7/7-7/23 and 7/23-8/5), a third grazing period on F1 (8/6-8/15), a light continuous
grazing on portions of F1 (8/21-9/2), and the final grazing period on F2 (9/5-9/22) (Table 1).

Table 1 - Total measured productivity and consumption patterns in kg DM/ha and kg DM/cow for individual grazing rotations on F1 and F2 at Burley Demeritt ODRF in Durham, NH from June-September 2009.

<table>
<thead>
<tr>
<th>Field 1</th>
<th></th>
<th>6/15-7/7</th>
<th>8/6-8/18</th>
<th>8/21-9/2</th>
<th>9/25</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (kg/hectare) Measured Productivity</td>
<td></td>
<td>2354.8</td>
<td>2327.1</td>
<td>336.4</td>
<td>645.4</td>
<td>5663.7</td>
</tr>
<tr>
<td>Average (kg/hectare) Consumption</td>
<td></td>
<td>1928.2</td>
<td>2038.8</td>
<td>256.5</td>
<td></td>
<td>4232.6</td>
</tr>
<tr>
<td>Average (kg/cow) Consumption</td>
<td></td>
<td>8.0</td>
<td>7.6</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field 2</td>
<td></td>
<td>6/7-7/23</td>
<td>7/23-8/5</td>
<td>9/5-9/22</td>
<td>9/25</td>
<td>SUM</td>
</tr>
<tr>
<td>Average (kg/hectare) Measured Productivity</td>
<td></td>
<td>2883.0</td>
<td>1242.1</td>
<td>2821.8</td>
<td>154.4</td>
<td>7101.3</td>
</tr>
<tr>
<td>Average (kg/hectare) Consumption</td>
<td></td>
<td>2141.5</td>
<td>2027.3</td>
<td>2652.9</td>
<td></td>
<td>6821.6</td>
</tr>
<tr>
<td>Average (kg/cow) Consumption</td>
<td></td>
<td>7.2</td>
<td>6.1</td>
<td>8.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average pasture allowance per grazing event was 8.34 (+2.49) kg/cow, or 2.1% of live BW/cow. Given two grazing events per 24 hours period, the herd was offered approximately 4.2% of live BW in pasture DM daily. Based on pasture disappearance, pasture intake per cow averaged 7.23 (+ 2.32) kg DM per grazing event, or 1.82% (+0.58) of live bodyweight in DMI. Per 24-hour period approximately 3.64% of live bodyweight was measured as pasture disappearance in DM. This value is greater than the 2.57% of live body as average pasture DMI as surveyed from the literature by Vazquez and Smith (2000). The value is also greater than the NRC recommended mean value of 3.4% live bodyweight as daily DMI as measured for Jersey cows on TMR by Holter et al. (2001). This estimate falls within the high-end of daily DMI ranges measured for Jersey cows (2.0-4.2% live bodyweight DMI) and Holsteins (2.85-3.76% live bodyweight DMI)
(Holter et al., 2001, McEvoy et al., 2009, Decruynaere et al., 2009), yet, it remains notably greater than published literature on DMI from pasture. Potential sources of error and variance will be addressed in subsequent text.

Estimated utilization efficiency (pasture DMI/pasture allowance), based on total herbage offered and a 2.57% live bodyweight as pasture DMI (from Vazquez and Smith, 2000), should have been approximately 60%. This utilization efficiency falls within the optimal range suggested by Hodgson (1990). The measured average herbage utilization efficiency (pasture disappearance/pasture allowance) was 86% (+9). As demonstrated by Hodgson, 1990 (Figure 7) high utilization efficiency does not correspond with peak intake (peak intake in this case also represents peak animal performance). Butler et al., 2003 states that a utilization efficiency above 80% results in declining animal production/acre, coinciding with a decrease in intake due to lack of high quality forage for consumption. At a low pasture allowance, cows graze lower than previous post-grazing heights, consequently consuming older and less nutritious pasture forages (Lee et al., 1998).

The high rates of pasture disappearance, contributing to high DMI estimations and utilization efficiency, suggest error in the method. Overestimation of forage intake could be attributed to variability of the post-graze sward, senescent leaves falling to ground level, or compression of sward by trampling (Ferri et al., 2008, Smit et al., 2005, Macoon et al., 2003). An additional and more likely source of variation, based on visual observation, is the avoidance of dung patches in post-graze measurements; Smit et al.
(2005) also observed this source of error. Cattle behavior dictates the avoidance of dung patches and vegetation surrounding the patches during grazing. The distribution of dung patches in the paddocks is significant. A study observing fecal and urine distribution for 36 cattle on 0.74 ha over 157 hours (6 study periods to stimulate 1 year of grazing) found over 10% of total pasture area was covered with excreta by the end of the study period (White et al., 2001). High stocking rates in intensive rotational grazing would suggest an even higher fecal concentration within the paddocks. The dung patches were avoided during sampling (both before and after grazing) in this study because of a possibility of yield overestimation due to their hardened structure. Because cattle avoided grazing in the area around dung patches, a portion of un-grazed herbage was unaccounted for and therefore could overestimate pasture disappearance/ herd intake (Smit et al., 2005). Based on the high likelihood of variability in the herbage disappearance method, previous research advised that the method was better applied to herd versus individual cattle calculations (Macoon et al., 2003, Smit et al., 2005, Ferri et al., 2008, Mejis et al., 1982). Given the apparent overestimation of the individual calculations, the remainder of the results are presented on a per herd basis.

There was a strong relationship in the data between available dry biomass (kg DM/ha) and the dry biomass disappearance (kg DM/ha) ($R^2$=0.96) (Figure 13). Previous literature (Figure 6) shows the relationship of daily herbage allowance and daily intake as a saturating curvilinear relationship (Le Du et al., 1979, Mejis and Hoekstra, 1984, Hodgson, 1990). The data from this study demonstrated a linear non-saturating relationship between total daily DMI/area (and per cow) versus available forage (PA).
For comparison of results with other literature, Le Du et al. (1979) assumed a mean herbage ash concentration of 100 g/kg DM to calculate the organic matter (OM) content of forages relative to herd live weight (LW). When this ash concentration is applied to the data from this study, the average values form a steep linear line that falls below the scale of allowances and intake rates (g OM/kg LW) measured in Figure 6. This comparison is limited without herbage ash concentration measurements from the forages offered in this study and clarification from Le Du et al. (1979) for calculating g OM/kg LW from DM. Based on studies measuring cow health and milk performance, optimum DMI does not occur at maximum pasture allowance; it occurs before the curvilinear relationship (Figure 6) become saturated (Greenhalgh et al., 1966, Combellas and Hodgson, 1979, Le Du et al., 1979, Peyraud et al., 1996, Dalley et al., 1999). Without having observed any plateau in the relationship of daily herbage allowance versus daily herbage intake, this study is unable to conclude if DMI was maximized. Given data gathered on herbage utilization efficiency it is possible to theorize that DMI was at or near its potential maximum (as measured in terms of daily pasture DMI relative to bodyweight) given animal limits of potential DMI. However, this study is unable to make conclusions on forage quality or animal performance without a control variable and data
on animal health, forage analysis, and/or milk components or quantity.

The amount of available biomass (DM kg/ha) and the amount of biomass consumed by grazing (DM kg/ha) displayed no correlation with calendar date.

Biomass re-growth (dry weight) followed an s-shaped curve for most paddocks (Figure 14). This pattern is less evident in the paddocks observed in F1, demonstrated in Figure 14 by the flat line representing the amount of biomass relative to days since graze for paddocks 1-1:26. F1 paddocks 1-4 and 1-8:11 show data for only one grazing (8/6-8/15), of note the period following this grazing was during the peak of summer heat with minimal rainfall. These climatic conditions generally deter growth of cool season grasses. With the exception of paddock 1-7 (grazing periods: 6/15-7/7 and 8/6-8/15), the remaining F1 paddocks, 9-28, include data for one IRG grazing (grazing periods: 8/6-8/15) and one subsequent “clean-up graze” that occurred in late August (8/21-9/2). F2 paddocks, 2-3 and 5-17, represent three grazings (7/7-7/23, 7/23-8/5, 9/5-9/22); F2
paddocks 22-29 represent two grazings (7/23-8/5 and 9/5-9/22).

The data from both fields were combined and fit with the classic S-shaped logistic equation for growth (Verhulst, 1838, Voisin, 1959, Noy-Meir, 1978, Hirata, 2000) (Figure 15). Using JMP software the fit was unable to reach acceptable convergence (as defined by JMP software) with the sample data as a result of the high variability of sample points around the line (SEE=428.7) (JMP 2010). When the logistic equation was fit to only F2 paddock data the SEE decreased (SEE=363.91).

Several factors can be theorized as contributors to the higher lack of correlation in F1, including: period of observation, topography variation, species composition and grazing management. F1 was observed for only one grazing event (8/6-8/15). The weather following this grazing period reflects the highest temperatures and relatively low daily rainfall in comparison to rest of the season (Figure 8). These climatic factors potentially caused slow growth due to moisture stress and temperature sensitivity, especially for cool season grasses. As previously mentioned, the topography of F1 was much more varied than F2, resulting in increased microhabitat variation in terms of soil types, soil fertility, moisture availability and forage species composition. These variations could reduce uniformity in re-growth in F1 versus the relatively flat and evenly vegetated F2. Grazing management decisions, such as a late spring grazing (May 1), may also have contributed to the stunted re-growth observed in F1 paddocks. A study by Kennedy et al. (2006), found that timing of spring grazing was essential for maximizing productivity and pasture quality throughout the pasture season. In late August (8/21-9/2), cows were allowed to
continuously graze a large tract of paddocks in F1 (paddocks 1-9:1-26). The stunted re-growth following this period is visible in flat line data for paddocks in Field 1 (paddocks 1-9:1-26) (Figure 14). The slow growth demonstrated in these paddocks could be the result of allowing cattle to graze paddocks before adequate biomass had accumulated, overgrazing and extensive selective grazing due to allowing continuous access, or low precipitation amounts and high temperatures into September.

![Figure 14 - Amount of dry biomass per area (kg DM/hectare) versus the number of days since the last grazing event per paddock. Each component panel represents a paddock; field and paddock number depicted in title above panel (Field #-Paddock #). Several paddocks contain data from 2+ grazing events. Data collected from UNH Burley Demeritt ODRF, Durham, NH from late June-September, 2009.](image-url)
Figure 15 - Available dry biomass/area (kg DM/ha) versus number of days since grazing for measured grazing events on F1 and F2. Fit with logistic equation \( y = \frac{\Theta_1}{1 + \Theta_2 e^{\Theta_3 X}} \), where \( \Theta_1=3237.1, \Theta_2=13.48, \Theta_3=-0.11 \). RMSE=428.7. N=539. Data from UNH Burley Demeritt ODRF in Durham, NH, June-September, 2009.

Overgrazing causes a lag before pasture re-growth achieves high growth rates in the S-shaped curve (Voisin, 1959). Literature surveying pastures with similar composition to Northeast pastures suggests grazing down to a biomass density of approximately 1290 kg DM/ha (±460) (Kanneganti et al., 1998, Kanneganti and Kafka, 1995, Murphy et al., 1995, Flack, 2007, and Murphy, 1990). Based on this value, Figure 15 demonstrates that much of the pastures were overgrazed in the 2009 season. Average standing biomass post-grazing event was 305.7 kg/ha (±153.3).

Pasture herbage density prior to grazing for Northeast pastures is suggested to be 2500 kg DM/ha (±518) (Kanneganti et al., 1998, Kanneganti and Kafka, 1995, Murphy et al., 1995, Flack, 2007, and Murphy, 1990). After this point vegetation matures and forage quality begins to decline (Murphy, 1998). Average standing biomass offered for grazing
was 2503.3 kg/ha (+ 743.5) (average value not including standing biomass before continuous grazing event on F1 from 8/21-9/2) or approximately 47.2 g DM/kg live weight daily.

Relative to the literature, paddocks were grazed at an appropriate time. Paddocks were, however, grazed very intensively; nearly half of the suggested levels for remaining standing biomass were consumed. Given visual observations during grazing events, overgrazing was more common than measurement variability due to trampling. Frequent overgrazing can be observed in the density of data points near the lower period of the s-shaped curve in Figure 15. To reduce the potential for overgrazing, which as mentioned previously has been found to reduce animal performance and to stunt forage re-growth rates, management should increase paddock size relative to herd demand. As shown by Hodgson (1990), increasing paddock size and offering a greater forage allowance has the potential to result in un-grazed biomass. Managers have the option to increase length of grazing period, or, to better match forage quality with animal energy demands and maximize animal productivity, other strategies such as leader-follower grazing can be used to maximize herbage utilization without encouraging overgrazing.

Total biomass production from 6/15-9/25 for F1 was 5663.7 kg/ha, the measurements exclude early spring grazing from 5/15-6/15. Total biomass consumption for the same period was 4223.6 kg/ha (Table 1). Total biomass production on F2 from 6/7-9/25 was 7101.3 kg/ha; this excludes spring biomass that was hayed in early June (approximately 3725 kg/ha). Total biomass consumption for the same period was 6821.6 kg/ha. In comparison with yields suggested by Martz (2002), F1 yields are above those expected
for Kentucky bluegrass – white clover in rotational grazing (5376 kg/ha) but low in comparison with other mixes (7616-8736 kg/ha). Cool season grasses demonstrate their highest growth rates in early spring; therefore, if the spring period of growth is accounted for, productivity of F1 is likely comparable to suggested yield rates (Martz, 2002, Undersander et al., 2002, Balasko et al., 1995). With spring haying on F2, total productivity (10826 kg/ha) is greater than suggested for rotational grazing by Martz (2002).

Literature measuring total seasonal consumption for lactating dairy cattle under intensive rotational grazing management averages 7766 kg DM/ha (±795) (Kanneganti et al., 1998, Kanneganti and Kafka, 1995, Carlassare and Karsten, 2002). These surveys represent pastures in Wisconsin (19 ha study area; measurements from one 0.4 ha paddock), Pennsylvania (1.4 ha study area), and Connecticut (4.4 ha study area). The averaged total seasonal (mid-June through September) consumption for this study was 5522.6 kg/ha. This value is below consumption levels measured in the literature, however the studies vary in study period (5-6 months in other studies), cattle age and type (beef cattle, Holstein heifers, and lactating Holsteins in other studies), study location and study area.
IV.

CONCLUSIONS

The results indicated that the calibrated plate meter is the most efficient and relatively precise method for measuring pasture biomass. Cattle showed a direct linear correlation of pasture DM consumption relative to the amount of pasture offered. The pasture disappearance method for measuring DMI was too variable for measuring individual intake. Herbage utilization efficiency was high, which previous studies suggest has negative implications for animal milk productivity and body maintenance (Hodgson, 1990, Butler et al., 2003). Annual forage consumption measurements from pastures were low relative to other studies, but there are inconsistencies in comparisons due to season length, study location and length, and cattle type. Total seasonal pasture production was in congruence with suggestions for Northeast pasture yields. Larger paddock size relative to herd demand is suggested for the management of pastures and animals used in this study as the herd consistently over-grazed paddocks. Intensive rotational grazing was shown to provide adequate DM for lactating dairy cattle in the Northeast with minimal supplementation given attentive and informed herd and grazing management.
LITERATURE CITED


Butterfield, H.S. and Malmström, C.M. 2009. The effects of phenology on indirect


JMP 8.0.2. 2010. SAS Institute, Inc, Cary, NC.


53


APPENDIX