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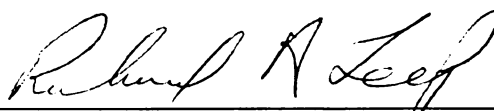
ADAPTATION OF DIPLOID AND TETRAPLOID CULTIVARS
OF PERENNIAL RYEGRASS THROUGHOUT MICHIGAN AS
GROWN IN ASSOCIATION WITH AND WITHOUT LADINO
CLOVER

presented by

Deborah L. Warnock

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Crop and Soil Sciences



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ADAPTATION OF DIPLOID AND TETRAPLOID CULTIVARS OF PERENNIAL
RYEGRASS THROUGHOUT MICHIGAN AS GROWN IN
ASSOCIATION WITH OR WITHOUT
LADINO CLOVER

By

Deborah L. Warnock

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

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2004

ABSTRACT

ADAPTATION OF DIPLOID AND TETRAPLOID CULTIVARS OF PERENNIAL RYEGRASS THROUGHOUT MICHIGAN AS GROWN IN ASSOCIATION WITH OR WITHOUT LADINO WHITE CLOVER

By

Deborah L. Warnock

Perennial ryegrass, *Lolium perenne* L., is a commonly seeded cool-season grass, but lacks winter hardiness. The objective of this study was to evaluate the adaptation of diploid ('Aries' and 'Mara') and tetraploid ('Barfort' and 'Quartet') perennial ryegrass cultivars in Michigan. 'Bronson' tall fescue, *Festuca arundinacea* Schreb., 'Tekapo' orchardgrass, *Dactylis glomerata* L., and 'Duo' festulolium, *Festulolium loliaceum* (Huds.), were used for comparison. Germination across a range of temperatures was evaluated in the laboratory, using a thermogradient plate, to determine if germination in cold temperatures was an indicator plant field performance. Cultivars were grown at three locations in Michigan as monocultures and co-cultures with ladino white clover, *Trifolium ambiguum* Bieb., and evaluated for winter injury, ground cover, tillering, yield, palatability, and clover content in the co-culture. Laboratory results were not indicative of field performance. Field results show Barfort, Mara, and Duo comparable to Bronson and Tekapo for winter injury. Fall ground cover and first harvest yield correlated with amount of winter injury. Quartet had lower ADF and NDF than other perennial ryegrass cultivars, and Duo was similar to perennial ryegrass. Based on these results, cultivar was more important than ploidy level for winter hardiness as Mara (diploid) and Barfort (tetraploid) perennial ryegrasses were winter hardy while Aries (diploid) and Quartet (tetraploid) were not.

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DEDICATION

To my parents, Stephen and Virginia Warnock, who have supported me in numerous ways throughout life and throughout my Master's program. Without their unconditional love and faith I could never have accomplished so many dreams. Also, to Charles Van Erp, for his patience and willingness to listen.

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LIST

INTR

P

V

E

EXPE

MATI

P

T

T

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STA

RES

A

N

TABLE OF CONTENTS

LIST OF TABLES	vii
INTRODUCTION	1
<i>Perennial Ryegrass</i>	1
<i>White Clover</i>	2
<i>Binary Mixtures</i>	3
EXPERIMENTAL DESIGN AND DATA ANALYSIS	4
MATERIALS AND METHODS	5
<i>Plant Material</i>	5
<i>Trial Establishment</i>	5
<i>Trial Maintenance</i>	8
<i>Data Collection</i>	8
Laboratory Experiment	8
Field Experiment	9
Stand Evaluations and Forage Yield	9
Grazing and Palatability	10
Forage Quality	11
STATISTICAL ANALYSIS	14
RESULTS AND DISCUSSION	14
<i>Laboratory Experiment</i>	14
<i>Winter Injury</i>	16
Hickory Corners – Establishment year	16
Lake City – Establishment year	17
Chatham – Establishment year	17
Hickory Corners – First production year	18
Lake City – First production year	18
Chatham – First production year	19

T

C

He

Pa

For

E

I

C

H

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C

CONCL

APPEND

LITERA

<i>Ground Cover</i>	24
Hickory Corners – Establishment year	24
Lake City – Establishment year	24
Chatham – Establishment year	25
Hickory Corners – First production year	25
Lake City – First production year	26
Chatham – First production year	26
<i>Tiller Production</i>	33
Hickory Corners – Establishment year	33
Lake City – Establishment year	33
Chatham – Establishment year	34
Hickory Corners – First production year	34
Lake City – First production year	35
Chatham – First production year	35
<i>Clover Ratings</i>	40
Hickory Corners – Establishment year	40
Lake City – Establishment year	40
Chatham – Establishment year	41
Hickory Corners – First production year	41
Lake City – First production year	42
<i>Yield</i>	46
Hickory Corners – Establishment year	46
Lake City – Establishment year	46
Chatham – Establishment year	47
Hickory Corners – First production year	47
Lake City – First production year	47
Chatham – First production year	48
<i>Palatability</i>	54
<i>Forage Quality</i>	57
Hickory Corners – Establishment year	57
Lake City – Establishment year	58
Chatham – Establishment year	59
Hickory Corners – First production year	60
Lake City – First production year	61
Chatham – First production year	61
 CONCLUSIONS	 75
 APPENDIX	 78
 LITERATURE CITED	 95

Table

Table

Table

Table

Table

Table

Table

Table 8

Table 9

Table 10

Table 11

Table 12

Table 13

Table 14

LIST OF TABLES

- Table 1. Treatments and seeding rates for all trial locations.
- Table 2. Trial locations, seeding dates and soil types.
- Table 3. Statistics for calibration (SEC, R^2) and cross validation (SECV, 1-VR) for Near Infrared Reflectance Spectroscopy analysis of nutritive value traits in co-culture samples.
- Table 4. Statistics for calibration (SEC, R^2) and cross validation (SECV, 1-VR) for Near Infrared Reflectance Spectroscopy of nutritive value traits in grass samples.
- Table 5. Germination results from the thermogradient plate experiment.
- Table 6. Co-culture winter injury means (n=3) taken during the establishment year.
- Table 7. Grass monoculture winter injury means (n=3) taken during the establishment year.
- Table 8. Co-culture winter injury means (n=3) taken during the first production year.
- Table 9. Grass monoculture winter injury means (n=3) taken during the first production year.
- Table 10. Co-culture ground cover means (n=3) taken during the establishment year.
- Table 11. Grass monoculture ground cover means (n=3) taken during the establishment year.
- Table 12. Co-culture ground cover means (n=3) taken during the first production year.
- Table 13. Grass monoculture means (n=3) taken during the first production year.
- Table 14. Co-culture tiller count means (n=3) taken during the establishment year.

Table

Table

Table

Table

Table

Table

Table

Table

Table

Table

Table

Table

- Table 15. Grass monoculture tiller count means (n=3) taken during the establishment year.
- Table 16. Co-culture tiller count means (n=3) taken during the first production year.
- Table 17. Grass monoculture tiller count means (n=3) taken during the first production year.
- Table 18. Co-culture clover means (n=3) taken during the establishment year using a 1-9 scale, where 1 = no clover in the plot and 9 = clover throughout the plot.
- Table 19. Co-culture clover means (n=3) taken during the first production year using a 1-9 scale, where 1 = no clover in the plot and 9 = clover throughout the plot.
- Table 20. Co-culture dry matter yield (t ha^{-1}) means (n=3) at each harvest during the establishment year.
- Table 21. Grass monoculture dry matter yield (t ha^{-1}) means (n=3) at each harvest during the establishment year.
- Table 22. Co-culture dry matter yield (t ha^{-1}) means (n=3) at each harvest during the first production year.
- Table 23. Grass monoculture dry matter yield (t ha^{-1}) means (n=3) at each harvest during the first production year.
- Table 24. Co-culture and grass monoculture palatability scores (n=3) at the fourth harvest for the establishment year and first production year. Scores are on a 1-5 scale with 1 being least palatable.
- Table 25. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Hickory Corners at each of the five harvests during the establishment year. Units for all analyses are g kg^{-1} .
- Table 26. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Hickory Corners at each of the five harvests during the establishment year. Units for all analyses are g kg^{-1} .

Tabl

Tabl

Table

Table

Table

Table 3

Table 33

Table 34

- Table 27. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Lake City at each of the three harvests during the establishment year. Units for all analyses are g kg^{-1} .
- Table 28. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Lake City at each of the three harvests during the establishment year. Units for all analyses are g kg^{-1} .
- Table 29. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Chatham at each of the three harvests during the establishment year. Units for all analyses are g kg^{-1} .
- Table 30. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Chatham at each of the four harvests during the establishment year. Units for all analyses are g kg^{-1} .
- Table 31. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Hickory Corners at each of the four harvests during the first production year. Units for all analyses are g kg^{-1} .
- Table 32. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Hickory Corners at each of the four harvests during the first production year. Units for all analyses are g kg^{-1} .
- Table 33. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Lake City at each of the four harvests during the first production year. Units for all analyses are g kg^{-1} .
- Table 34. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Lake City at each of the four harvests during the first production year. Units for all analyses are g kg^{-1} .

Tab

Tab

Tab

Tab

Tab

Table

Table

Table

Table 8

Table 9

Table 1

Table 1

Table 12

Table 13

Table 14

Table 35. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Lake City at each of the three harvests during the first production year. Units for all analyses are g kg⁻¹.

Table 1A. Fertilizer application dates at each location for both years of the trial.

Table 2A. Data collection dates for all locations and years of the trial.

Table 3A. Cattle description, number of cattle used, and number of grazing events at each location for both years.

Table 4A. Analysis of variance table for co-culture winter injury.

Table 5A. Analysis of variance table for grass winter injury.

Table 6A. Monthly minimum and maximum air temperatures (°C) at all locations for the establishment year, first production year, and 30 year average.

Table 7A. Monthly rainfall (mm) at all locations for the establishment year, first production year, and 30 year average.

Table 8A. Number of days with snow depth ≥ 2.5 cm by month at all locations for the establishment year, first production year, and 30 year average.

Table 9A. Analysis of variance table for co-culture ground cover.

Table 10A. Analysis of variance table for grass ground cover.

Table 11A. Analysis of variance table for co-culture tiller counts.

Table 12A. Analysis of variance table for grass tiller counts.

Table 13A. Analysis of variance table for co-culture clover ratings.

Table 14A. Botanical composition at Hickory Corners for the establishment year. Component means (n=3) are in grams.

Tab

Tab

Table

Table

Table

Table

Table 15A. Botanical composition at Lake City for the establishment year. Component means (n=3) are in grams.

Table 16A. Botanical composition at Chatham for the establishment year. Component means (n=3) are in grams.

Table 17A. Botanical composition at Hickory Corners for the first production year. Component means (n=3) are in grams.

Table 18A. Botanical composition at Lake City for the first production year. Component means (n=3) are in grams.

Table 19A. Co-culture palatability scores (n=9) at the first, second, third, and fifth harvests. Scores are averaged across years and location where 1 is least palatable and 5 is most palatable.

Table 20A. Grass palatability scores (n=9) at the first, second, third, and fifth harvests. Scores are averaged across years and location where 1 is least palatable and 5 is most palatable.

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INTRODUCTION

Perennial ryegrass

Perennial ryegrass (*Lolium perenne* L.) is the most commonly grown perennial forage grass in temperate regions throughout the world (Wilkins, 1991). It is a cool-season grass that is native to Europe, temperate Asia, and North Africa (Balasko et al., 1995). It has been widely distributed to other parts of the world, including North and South America, Europe, New Zealand, and Australia. In the United States, it is grown primarily in the coastal northwest and the northeast. It is also grown in the Midwest, including Michigan where it is grown on approximately 4,000 ha and is used primarily in pastures (Leep, 2001).

Perennial ryegrass is best adapted to cool, moist climates and has a bunch growth habit (gradual increase in clump size) (Moore, 2003). It grows well during early spring and fall, but production declines over the summer as the grass becomes dormant. It has a wide range of soil adaptability, growing in both well and poorly-drained soils having a pH range from 5.0 to 8.3, but grows best on fertile, well-drained soils with a pH range of 6 to 7.

The popularity of perennial ryegrass is due to its high forage quality, which makes it the first choice for pasture in regions where it is adapted. Advantages of perennial ryegrass are: it is highly digestible (Frame, 1989), easily established, and an adequate seed producer (Wilkins, 1991). The main limitation of perennial ryegrass is low winter hardiness. Humphreys and Eagles (1988) found that the cold tolerance of perennial ryegrass needed to be improved before the species could be used in northern continental climates. In much of the US, it is grown only as an annual (Allinson et al., 1986) because

it does not survive through winter. In the south, it is used as over seeding in the winter because it does not tolerate the heat

Perennial ryegrass cultivars are either diploid (contains two sets of chromosome; $2n = 2x = 14s$) or tetraploid (contains four sets of chromosomes; $2n = 4x = 28$). Tetraploid plants can occur naturally, but more often chromosome doubling is induced by chemical means, such as using colchicine (Morgan, 1976). Perennial ryegrass tetraploids were first developed in Holland in the 1960s (Connolly, 2001). Since then, many tetraploid cultivars have been developed, released, and widely used for herbage production in numerous countries (Dewey, 1980). Doubling chromosome number has both desirable and undesirable effects on several agronomic traits. Diploid cultivars have been shown to have higher cold tolerance than tetraploid cultivars (Dvorak and Fowler, 1978; Yamashita and Shimatmoto, 1996) and have better tolerance to animal treading (Edmond, 1966). Diploid cultivars have a higher growth rate following emergence and are more persistent than tetraploids (Balasko et al., 1995).

Tetraploids have fewer but larger tillers than diploid cultivars (Balasko et al., 1995). Pysher and Fales (1992) found that tetraploid perennial ryegrass had a slightly higher in vitro dry matter digestibility than diploid cultivars. Seeds of tetraploids are larger in size, but more seed must be sown to ensure good establishment because of their slower growth rate relative to diploids (Wilkins, 1991).

White Clover

White clover (*Trifolium repens* L.) is one of the most important and widely distributed forage legumes in the world. It is adapted to a wide range of climates, has a high nutritional quality, and the ability to fix atmospheric nitrogen (Pederson, 1995).

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Ladino white clover has larger petioles, leaflets, flowers, and stolons than the common varieties of white clover. Its greater biomass gives it the largest forage yields, especially under rotational grazing, but it does not persist as well as the smaller, common types (Pederson, 1995).

Binary Mixtures

As a pasture species, Ladino white clover is valuable when planted with cool season grasses such as perennial ryegrass. White clovers are able to fix nitrogen through a symbiotic relationship with *Rhizobium leguminosarum* biovar. *trifolii*. Nitrogen is transferred from the legume to the soil through grazing livestock (urine and feces) and decomposition of legume plant material (Tisdale and Nelson, 1975). The enrichment of soil nitrogen by white clover can improve the forage quality of pastures and supply pasture grasses with available forms of nitrogen. White clover when seeded with grass companions and grazed, can give greater yields than clover alone (Evans et al, 1996). This could be due to complementary growth habits, allowing more light penetration at the base of the sward than in monocultures (Jones and Roberts, 1994). Binary legume/grass mixtures have also been shown to improve forage yield and quality (Sleugh, et al., 2000). Herbage yields of grass/white clover swards tend to be relatively low in the establishment year, but generally increase during the second and third years of establishment (Spedding and Diekmahns, 1972).

Grass/legume mixtures generally do not need nitrogen applications; in fact, application of nitrogen contributes to a decline in the clover component of the mixture (Nassiri and Elgersma, 2002; Williams et al., 2003). The grass component of the mixture

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depends on nitrogen fixation by the clover and nitrogen mineralization and deposition in the soil (Elgersma and Hassink, 1997).

Currently, seed companies are offering improved cultivars of both perennial ryegrass and Ladino white clover. As a result of breeding efforts in both the United States and Europe, improved cultivars of perennial ryegrass are available with increased winter hardiness, forage quality, and disease resistance. Improved Ladino varieties were developed for greater yields, longer persistence, and better pest resistance (Lacefield, 1999; Ball, 2000). While much research has been done on Ladino white clover-ryegrass mixtures varying from evaluating competition (Hill and Michaelson-Yeates, 1987), seeding method (Mooso et al., 1990), plant and soil nitrogen levels (Elgersma and Hassink, 1997), seasonal variations (Hogh-Jensen and Schjoerring, 1997), and yield (Humphreys et al., 1998) there is a lack of data on binary mixtures of the newer, improved cultivars. This research has evaluated winter hardiness, persistence, yield, palatability, and forage quality of four improved cultivars of perennial ryegrass (both tetraploid and diploid) grown as both mono and binary mixtures of ladino clover over a wide range of climatic conditions in Michigan compared to a tall fescue cultivar, an orchardgrass cultivar, and a festulolium cultivar.

EXPERIMENTAL DESIGN AND DATA ANALYSIS

The trial was divided into three sections: grass or legume only, and co-culture (grass and legume mixture). Each section was a randomized complete block with three replications. In the grass section there were 16 cultivars, in the legume section there were

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eight cultivars, and in the co-culture there were 72 grass/legume combinations. For this research 7 cultivars were selected for further study.

MATERIALS AND METHODS

Plant Material

Cultivars in the grass section were Aries, Mara, Quartet, Barfort, Duo, Tekapo, and Bronson. Aries and Mara are diploid perennial ryegrasses, while Quartet and Barfort are tetraploid perennial ryegrasses. Duo is a festulolium (a cross between meadow fescue and tetraploid perennial ryegrass), Tekapo is an orchardgrass, and Bronson is a tall fescue. Co-culture combinations consisted of the above grasses with ladino clover. Treatments and seeding rates are listed in Table 1.

Trial Establishment

Three grass/legume co-culture trials were established at Michigan State University Experiment Stations in 2001. Co-culture and legume portions of the experiment at Chatham were destroyed and reseeded in 2002 due to a poor stand of clover. Experiment sites, soil types, and establishment dates are listed in Table 2. The seedbeds were prepared by moldboard plowing, disking once, and then passing over the fields multiple times with a drag. All of the plots were 1.8 m x 4.6 m and seeded with a Carter Forage Plot Seeder (Carter Manufacturing Co. Inc., Brookston, IN).

Table 1. Treatments and seeding rates for all trial locations.

Treatments

Seeding rate

Table 1. Treatments and seeding rates for all trial locations.

Treatments			Seeding Rates		
Grass Type	Grass Cultivar	Legume Type	Legume Cultivar	Grass Wt. (kg ha ⁻¹)	Legume Wt. (kg ha ⁻¹)
Diploid P. ryegrass	Aries			33.6	
Diploid P. ryegrass	Mara			33.6	
Tetraploid P. ryegrass	Barfort			33.6	
Tetraploid P. Ryegrass	Quartet			33.6	
Tall Fescue	Bronson			16.8	
Festulolium	Duo			24.65	
Orchardgrass	Tekapo			16.8	
Diploid P. ryegrass	Aries	White clover	Ladino	28.0	3.36
Diploid P. ryegrass	Mara	White clover	Ladino	28.0	3.36
Tetraploid P. ryegrass	Barfort	White clover	Ladino	28.0	3.36
Tetraploid P. Ryegrass	Quartet	White clover	Ladino	28.0	3.36
Tall Fescue	Bronson	White clover	Ladino	16.8	3.36
Festulolium	Duo	White clover	Ladino	16.8	3.36
Orchardgrass	Tekapo	White clover	Ladino	8.97	3.36

Table 2. Trial locations, seeding dates, and soil types.

Table 2. Trial locations, seeding dates, and soil types.

Trial Location	Seeding Date	Soil Type
Upper Peninsula Experiment Station Chatham, MI Latitude – 46.7 North	7 August 2001 and 6 August 2002 [†]	Chatham stony loam (Coarse-loamy, mixed, frigid Typic Haplorthods)
Lake City Experiment Station Lake City, MI Latitude – 44.2 North	14 August 2001	Nester sandy loam (Fine, mixed, semiactive, frigid Oxyaquic Glossudalfs)
W. K. Kellogg Biological Station Hickory Corners, MI Latitude – 42.2 North	21 August 2001	Kalamazoo loam (Fine-loamy, mixed, semiactive, mesic Typic Hapludalfs)

[†]The original stands of the co-culture and legume sections of the trial were destroyed and a new stand was established because there was a poor stand of clover.

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Trial Maintenance

The grass only section was maintained with split applications of ammonium sulfate fertilizer (21-0-0). Each of the four applications consisted of 45.4 kg of nitrogen per hectare, for a total of 181.6 kg of nitrogen per hectare per year. Applications were in early spring, following the first and second grazing periods, and in mid-autumn. For application dates see Appendix Table 1A.

Soil samples were taken from each section in the fall and tested at the Michigan State University soil testing laboratory for phosphorus (P), potassium (K), and pH. P and K were adequate, so no additional fertilization was applied. In the late fall all plots were clipped and the clippings were removed.

Data Collection

Laboratory Experiment

Germination response to a range of temperatures was evaluated for the four perennial ryegrass cultivars (Aries, Mara, Barfort, and Quartet) using a one-way thermogradient plate. The procedure used was a modified version of that described by Wade et al. (1993).

The experiment was a completely randomized block design, with three replications of each cultivar. The thermogradient plate was marked such that Petri dishes could be placed equidistantly across the apparatus, allowing seeds to be tested at temperatures of approximately 4, 10, 16, 21, 27, 32, 38, and 43 °C. At each of the eight temperature regimes, three Petri dishes were randomly placed in three blocks for a total of nine Petri dishes per temperature regime. The Petri dishes were lined with Whatman Number 4 filter paper, which was divided into four equal quadrants. Five seeds were

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placed in each quadrant and covered with another layer of the filter paper. One week constituted one run of the experiment. At the end of the week, seeds were scored as germinated or not germinated. Germination was defined as the emergence of a radicle from the seed coat.

Field Experiment

For a complete list of all data collections and dates see Appendix Table 2A.

Stand Evaluations and Forage Yield

In early spring (March-April) all plots were visually assessed for winter injury (WI) and amount of ground cover (GC). Plots were rated on a 1-9 scale (WI: 1 = no winter injury, 9 = plot winter killed; GC: 1 = least amount of ground cover, 9 = greatest amount of ground cover). Plots in the co-culture treatment were rated on a 1-9 scale for amount of clover (1 = no clover in stand, 9 = clover present throughout stand). For all visual assessments, two people rated the plots and the average was taken. Observers were trained, and one individual was appointed be present at all ratings; the second individual was not always the same at each rating. Grass stand counts were also taken in the spring for the grass only and co-culture treatments by randomly selecting a 30.5 cm section of one row and counting all the grass tillers within that section. In the fall, all treatments were again rated for ground cover and grass stand counts were taken for the grass only and co-culture treatments.

Forage yield was determined at each grazing event by randomly placing a 45.7 cm x 45.7 cm quadrat per plot. The forage inside the quadrat was clipped at a 7.6 cm height and removed. All removed samples were dried at 60°C for 48 hours and dry weight was

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recorded, however, prior to drying the co-culture samples were hand separated into grass, legume, or weed groups for botanical composition.

Grazing and Palatability

To determine how the cultivars performed under grazing pressure, trials were grazed when the average grass height was between 20 and 30 cm tall. The number of grazing events at each location was dependent on the growth rate of the grass. The grazing events for each location, type of cattle used, average cattle weights, and stocking density are listed in Appendix Table 3A. The number and type of cattle used was determined by availability at each Experiment Station. For data collection purposes, the trial area at each location was divided in half using a temporary fence. The first half was composed of the grass only and legume only sections of the trial, while the second half consisted of the co-culture section.

Palatability of the cultivars was assessed visually using a single digit scale. Visually assessing palatability has been sensitive enough to detect differences in cultivars when grazing cattle (van Santen, 1992; Shewmaker et al., 1997) and sheep (Johnston, 1988). Cattle were allowed into the first half of the trial and approximately half-way through the grazing period, plots were rated on a 1-5 scale for palatability (1 = least preferred and 5 = most preferred) as described by McCaughey (1998). The length of time required for the cattle to graze the plot area down to approximately a 7.6 cm height varied at each location. The area at Hickory Corners took 36 hours during the establishment year and 102 hours during the first production year (due to differing numbers of cattle available). At Lake City, 24 hours was required both years and at Chatham it took 48 hours both years. When the cattle had grazed most of the forage down to a 7.6 cm height,

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they were moved into the second half. The second half of the grazing trial was rated for palatability in the same manner.

Forage Quality

Samples collected for forage yield were ground to pass through a 1 mm screen in a Christy 8" lab mill (Christy-Norris Co., Ipswich, UK). Each sample was scanned with a 6500 near-infrared spectrophotometer (FOSS NIRSystems, Inc., Silver Spring, MD) with wavelengths between 800 and 2500 nm.

All three replicates of the seven cultivars were scanned for each grazing period and location. A subset of samples (84 for the co-culture and 74 for the grass monoculture during the establishment year; 46 for the co-culture during the first production year) was selected using the Select program from WinISI software (Infrasoft International, LLC., Port Matilda, PA.) for wet chemistry analysis. The co-culture establishment subset was used to create an equation for prediction of crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF). The co-culture subset from the first production year was used to verify the equation. The grass only subset was used to verify an equation from the NIRS consortium. Statistics for calibration and cross-validation are included for the co-culture (Table 3) and grass (Table 4).

Total nitrogen was determined for the subset by the Hach modified Kjeldahl procedure using 0.25 ± 0.001 g of sample (Watkins et al., 1987), and CP was estimated by multiplying total N by 6.25, since most feed proteins contain about 16% nitrogen. The Goering and Van Soest (1970) method was used for sequential NDF and ADF determination using 0.50 ± 0.001 g of sample. For NDF analysis, a ground sample, 100 mL of neutral-detergent solution, and 2 mL of amylase were refluxed for 60 minutes.



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Samples were then filtered and rinsed with acetone before drying at 100°C for 8 hours, after which they were hot weighed. ADF analysis included covering the crucible and remaining sample from NDF analysis with 200 ml of acid detergent solution and refluxing for 60 minutes. Samples were then filtered and rinsed with acetone before drying at 100°C for 8 hours, after which they were hot weighed. Dry matter (DM) content was determined by drying 0.50 ± 0.001 g of sample in ceramic crucibles at 100°C for 12 hours. The samples were then ignited in a muffle furnace at 500°C for 6 hours to determine ash content.

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Table 3. Statistics for calibration (SEC, R^2) and cross validation (SECV, 1-VR) for Near Infrared Reflectance Spectroscopy analysis of nutritive value traits (g kg⁻¹) in co-culture samples.

Parameters	N [†]	Mean	SD [‡]	SEC [§]	R ^{2¶}	SECV ^a	1-VR ^b
ADF	84	234	43.0	8.3	0.96	9.6	9.5
NDF	84	448	78.8	2.0	0.94	26.1	8.9
CP	75	202	45.8	9.6	0.96	1.2	9.3

[†]N= number of samples in the calibration equation.

[‡]Standard deviation of know quality values.

[§]Standard error of calibration.

[¶]Coefficient of determination.

^aStandard error of cross validation.

^bCross validation performance expressed as the coefficient of determination.

Table 4. Statistics for calibration (SEC, R^2) and cross validation (SECV, 1-VR) for Near Infrared Reflectance Spectroscopy analysis of nutritive value traits (g kg⁻¹) in grass samples.

Parameters	N [†]	Mean	SD [‡]	SEC [§]	R ^{2¶}	SECV ^a	1-VR ^b
ADF	1443	362	65.4	16.4	.94	8.2	9.3
NDF	1013	490	115.0	23.3	.96	16.9	9.6
CP	1630	170	55.2	79.9	.98	8.2	9.8

[†]N= number of samples in the calibration equation.

[‡]Standard deviation of know quality values.

[§]Standard error of calibration.

[¶]Coefficient of determination.

^aStandard error of cross validation.

^bCross validation performance expressed as the coefficient of determination.

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STATISTICAL ANALYSIS

Data were collected in 2002 and 2003 and analyzed with the PROC MIXED function in SAS version 8e (SAS Institute Inc., 2001). Rep nested within location and year and treatment * rep nested within location and year were considered random effects. Unequal variances were accounted for using the repeated/group command.

RESULTS AND DISCUSSION

Laboratory Experiment

The germination results over a range of temperatures are presented in Table 5. At three of the eight temperature regimes (4, 38, and 43°C) there was no germination, and these are not included in Table 5. There was a significant difference in germination among the cultivars at only two of the five temperatures where germination occurred. At a temperature of 16°C, Aries, Barfort, and Quartet showed the highest germination percentages. The germination of Mara was significantly lower. At 10°C the only significant difference was between Barfort and Mara. Diploid cultivars have greater cold tolerance than tetraploids (Yamahita and Shimatmoto, 1996), but this experiment showed Barfort, a tetraploid cultivar, to tolerate the cold stress and have better germination than Mara, a diploid cultivar.

Soil temperature affects both the rate of germination and growth of seedlings. Cool season grasses grow actively when soil temperatures are between 16 and 21°C. Too

high or low of a temperature, however, can prevent germination or greatly reduce the rate of seed germination. Germination did not occur at 4, 38, and 43°C because the temperatures were too extreme and the seeds were either dormant or dead.

The ability to germinate in cold temperatures was not indicative, however, of how the cultivars would perform in the field in this experiment. This is similar to findings by Humphreys and Eagles (1988) where laboratory assessments of perennial ryegrass freezing tolerance did not always accurately predict survival under natural freezing conditions.

Table 5. Germination results from the thermogradient plate experiment.

Grass Type	Grass Cultivar	Percent Germination (%)				
		10 °C	16 °C	21 °C	27 °C	32 °C
Diploid	Aries	57 AB	93 A	87 A	93 A	50 A [†]
Diploid	Mara	37 B	70 B	93 A	97 A	53 A
Tetraploid	Barfort	70 A	97 A	97 A	87 A	63 A
Tetraploid	Quartet	53 AB	93 A	93 A	87 A	63 A
	Mean	54	88	92	91	57
	S.E.	12.1	8.2	5.0	5.0	6.5

[†]Means in a column followed by the same letter are not significantly different ($p \leq 0.05$).

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Winter Injury

There was no year*location*treatment or year*treatment interaction (Appendix Table 4A) for the co-culture, therefore, at each location establishment year and first production year data could have been combined. Data were separated by year, however, in order to evaluate cultivar performance under different winter conditions.

In the grass monoculture, there was a significant ($P < .0001$) year* location* treatment interaction (Appendix Table 5A), so data needed to be compared at each location and year.

Weather data was obtained and is included in the Appendix. Data recorded include the monthly minimum and maximum air temperatures (Appendix Table 6A), amount of rainfall per month (Appendix Table 7A), and number of days with 2.5 cm of snow depth or greater per month (Appendix Table 8A).

Hickory Corners – Establishment year

There were no significant differences in winter injury among cultivars in either the co-culture (Table 6) or the grass monoculture (Table 7). In both the co-culture and monoculture, Aries was the only cultivar with an injury rating greater than 1.0. None of the cultivars had much injury because winter conditions during the establishment year were relatively mild. Warmer than normal air temperatures (Appendix Table 6A), along with adequate snow cover from December 2001 to March 2002 (Appendix Table 8A) , were not harsh enough to result in significant differences among cultivars.

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Lake City – Establishment year

In the co-culture, there was no significant difference in winter injury among cultivars (Table 6). There were, however, significant differences in the grass monoculture. Aries had the most winter injury, followed by Quartet, having means of 2.3 and 1.5, respectively (Table 7). Air temperatures were warmer than the 30 year average (Appendix Table 6A), but there were 20 days less than the 30 year average which had snow cover greater than or equal to 2.5 cm (Appendix Table 8A). This might not have been adequate snow cover to prevent all cultivars from having some injury.

Chatham – Establishment year

Establishment year data for the Chatham co-culture was from 2003 because it was destroyed and reseeded due to a poor stand of clover, whereas establishment year data at Lake City and Hickory Corners was from 2002. In the co-culture, Barfort had significantly more winter injury than all the cultivars except for Aries (Table 6). There were no differences in winter injury among cultivars in the grass monoculture (Table 7). Although Chatham had the coldest minimum and maximum air temperatures of all locations in both the establishment year and first production year (Appendix Table 6A), it also had the greatest amount of snow cover (Appendix Table 8A), which insulated the forage, keeping winter injury relatively low.

At all three locations, establishment year minimum and maximum air temperatures were warmer than the 30 year averages. The mild weather conditions during the establishment year resulted in few significant differences between species and cultivars. In fact, over all locations there were only two significant differences. One

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significant difference occurred in the Lake City monoculture where Aries, then Quartet, had the most injury. Another significant difference occurred in the Chatham co-culture. Differences at Chatham occurred during the 2003 winter which was quite harsh. Barfort had the greatest winter injury at Chatham, but it was observed that Barfort also had the fastest growth after seeding.

Hickory Corners – First production year

There was no difference in winter injury among cultivars in the co-culture (Table 8). In the grass monoculture, Aries and Quartet had significantly more winter injury than all other cultivars except Barfort (Table 9). There was more winter injury in the monoculture than the co-culture. This could be due to better insulation as a result of more biomass, better N nutrition, or a combination of these factors. There was a greater amount of winter injury during the first production year because air temperatures were cooler than the establishment year and the 30 year averages from October to November (Appendix Table 6A). Also, the forage was not insulated during these cooler months as there was less than the average number of days of snow cover from October to November (Appendix Table 8A).

Lake City – First production year

In the co-culture, Quartet had significantly more winter injury than all the cultivars except Aries (Table 8). Quartet and Aries also had the greatest amount of injury in the grass monoculture (Table 9). Like Hickory Corners, there was a greater amount of winter injury than the monoculture than the co-culture. At Lake City, there was also a

greater amount of winter injury when compared to the establishment year. Minimum and maximum air temperatures were cooler than the 30 year averages from October to January (Appendix Table 6A). There were also less than the average days of snow cover from October to December (Appendix Table 8A).

Chatham – First production year

There is no first production year data for the co-culture because it was reseeded. In the grass monoculture, Aries and Quartet had significantly more winter injury than all other cultivars with means of 8.5 and 8.2, respectively (Table 9). Chatham did have reliable snow cover during the first production year, but air temperatures were extremely cold. Temperatures were cooler than the 30 year averages from October to July, with February having the coolest temperatures of -18.4°C minimum and -5.3°C maximum (Appendix Table 6A).

There was a greater amount of winter injury at all locations during the first production year. Winter conditions were harsh, so significant differences can be seen between species and cultivars. Minimum and maximum air temperatures were below average from at least the months of October to December. At Hickory Corners and Lake City, there were also less than average days of snow cover.

Aries and Quartet had significantly more injury at all locations, except in the co-culture at Hickory Corners. This was expected as perennial ryegrass is used primarily in lower Michigan where it is adapted. Barfort and Mara, however, often performed as well as the tall fescue cultivar, Bronson, and the orchardgrass cultivar, Tekapo. This is because these cultivars are from Europe which has a similar climate as Michigan and are

therefore better adapted to this region than Aries and Quartet which are from New Zealand. Orchardgrass is classified as being adapted to the entire lower peninsula of Michigan, while tall fescue is classified as being adapted to both the lower and upper peninsulas. The festulolium cultivar, Duo, had a similar amount of winter injury as Bronson at all locations and years. Duo had less winter injury than Aries and Quartet, but a similar amount of injury as Barfort and Mara.

Previous research has determined that diploid perennial ryegrass has greater cold tolerance than tetraploid perennial ryegrass (Yamashita and Shimamoto, 1996; Sugiyama 1998). Aries and Quartet are diploid and tetraploid cultivars, respectively, from New Zealand and had a greater amount of winter injury than all the other cultivars when damage occurred. Mara and Barfort are a diploid cultivar from Romania and a tetraploid cultivar from Holland, respectively. This research suggests that location of origin is a more important factor for winter injury than ploidy level.

Earlier research has also found location of origin to be an important factor for winter injury and survival. Cooper (1964) found a similar relationship between cold survival and temperature at site of origin in ryegrass populations. A study in Canada evaluated the hardiness of thirty perennial ryegrass cultivars and found a large variability for tolerance to subfreezing temperatures, however, cultivars from Canada and northern Europe were the most winter hardy (Kunelius and Castonguay, 2003). Research done in the United Kingdom, at Wales, found that varieties from northern Europe were more cold tolerant than ecotypes from the Mediterranean region (Lorenzetti et al., 1971).

Typically, there was less winter injury in the co-culture than the grass monoculture. This might be due to the extra biomass of the clover helping to “catch” the

snow, providing insulation, or less regrowth after the last fall clipping than the grass monoculture. White (1973) found that high levels of N, especially late in the season, encourage vegetative growth, which predisposes perennials to winter injury.

Table 6. Co-culture winter injury means (n=3) taken during the establishment year. A 1 – 9 scale was used where 1 = no winter injury and 9 = winterkilled.

Cultivar (species)[†]	Hickory Corners	Lake City	Chatham[§]
Aries (dPR)	1.7 A [‡]	1.7 A	3.5 AB
Mara (dPR)	1.0 A	1.0 A	1.0 A
Barfort (tPR)	1.0 A	1.0 A	3.8 B
Quartet (tPR)	1.0 A	2.2 A	1.0 A
Bronson (TF)	1.0 A	1.0 A	1.0 A
Duo (Fest)	1.0 A	1.0 A	1.2 A
Tekapo (OR)	1.0 A	1.3 A	1.2 A
Mean	1.1	1.3	1.8
S.E.	0.2	0.7	1.3

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same letter are not significantly different ($p \leq 0.05$).

[§]Chatham data is from 2003 because the original co-culture stand was destroyed and reseeded.

Table 7. Grass monoculture winter injury means (n=3) taken during the establishment year. A 1 – 9 scale was used where 1 = no winter injury and 9 = winterkilled.

Cultivar (species)[†]	Hickory Corners	Lake City	Chatham
Aries (dPR)	1.2 A [‡]	2.3 A	1.0 A
Mara (dPR)	1.0 A	1.0 C	1.0 A
Barfort (tPR)	1.0 A	1.0 C	1.0 A
Quartet (tPR)	1.0 A	1.5 B	1.0 A
Bronson (TF)	1.0 A	1.0 C	1.0 A
Duo (Fest)	1.0 A	1.0 C	1.0 A
Tekapo (OR)	1.0 A	1.0 C	1.0 A
Mean	1.0	1.3	1.0
S.E.	0.1	0.1	0.1

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same letter are not significantly different ($p \leq 0.05$).

Table 8. Co-culture winter injury means (n=3) taken during the first production year. A 1 – 9 scale was used where 1 = no winter injury and 9 = winterkilled.

Cultivar (species)[†]	Hickory Corners	Lake City
Aries (dPR)	2.2 A [‡]	3.7 AB
Mara (dPR)	1.3 A	1.0 B
Barfort (tPR)	2.3 A	1.2 B
Quartet (tPR)	1.3 A	5.8 A
Bronson (TF)	1.7 A	1.0 B
Duo (Fest)	1.8 A	1.0 B
Tekapo (OR)	1.7 A	1.3 B
Mean	1.8	2.1
S.E.	0.2	0.7

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same letter are not significantly different (p=0.05).

Table 9. Grass monoculture winter injury means taken during the first production year. A 1 – 9 scale was used where 1 = no winter injury and 9 = winterkilled.

Cultivar (species)[†]	Hickory Corners	Lake City	Chatham
Aries (dPR)	3.8 A [‡]	5.7 A	8.5 A
Mara (dPR)	1.8 B	2.0 BC	2.5 BC
Barfort (tPR)	2.2 AB	3.0 B	2.7 BC
Quartet (tPR)	3.8 A	7.2 A	8.2 A
Bronson (TF)	1.3 B	1.0 C	1.0 C
Duo (Fest)	2.0 B	1.3 BC	1.5 BC
Tekapo (OR)	1.8 B	1.0 C	2.8 B
Mean	2.4	3.0	3.9
S.E.	0.6	0.6	0.6

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same letter are not significantly different (p=0.05).

Ground Cover

There was a year*location*treatment interaction (Appendix Table 9A) for the co-culture, therefore, ground cover was compared within a location and year. In the grass monoculture, there was also a significant year*location*treatment interaction (Appendix Table 10A), so data compared at each location and year.

Hickory Corners – Establishment year

Barfort had a similar amount of spring ground cover as Bronson, Duo, and Tekapo in the co-culture. Mara and Quartet had significantly less ground cover than the above listed cultivars. Aries had the least amount of ground cover (Table 10). In the fall, there was no difference in the amount of ground cover for the perennial ryegrass cultivars or the orchardgrass cultivar in the co-culture (Table 10). Bronson had a greater amount of ground cover than Barfort, and Duo.

The only significant difference in spring ground cover in the monoculture was between Barfort and Quartet. Means for these cultivars were 8.7 and 7.8, respectively (Table 11). In the fall, Mara had more ground cover than all cultivars except Quartet (Table 11).

Lake City – Establishment year

Barfort and Mara had significantly more spring ground cover in the co-culture than Aries, Quartet, and Bronson. Quartet had less spring ground cover than all cultivars except for Aries (Table 10). The perennial ryegrass cultivars, Bronson, and Duo had similar amounts of fall ground cover, but Mara had significantly more ground cover than Tekapo (Table 10).

In the monoculture, Barfort, Mara also had a greater amount of spring ground cover than Aries and Quartet. Aries had less ground cover than all other cultivars; Quartet had more ground cover than Aries, but less spring ground cover than the other five cultivars (Table 11). Barfort and Mara also had significantly more ground cover than Aries and Quartet in the fall (Table 11).

Chatham – Establishment year

The co-culture was reseeded at Chatham, hence, establishment year data is from spring 2003 instead of spring 2002. There were no significant differences among cultivars for either spring or fall ground cover (Table 10).

There were no differences in spring ground cover among perennial ryegrass cultivars in the monoculture. Barfort and Quartet had more spring ground cover than Duo and Tekapo (Table 11). In the fall, all cultivars had equal amounts of ground cover (Table 11).

Hickory Corners – First production year

In the co-culture, there were no differences in spring ground cover among perennial ryegrass cultivars. Barfort had significantly less ground cover than both Tekapo and Bronson (Table 12). All cultivars had similar fall ground cover ratings (Table 12).

There were no significant differences in amount of spring or fall ground cover among cultivars in the grass monoculture (Table 13).



Lake City – First production year

Barfort and Mara had significantly more spring ground cover in the co-culture than Aries and Quartet. Quartet had less ground cover than all other cultivars; Aries had more ground cover than Quartet, but less spring ground cover than the other five cultivars (Table 12). In the fall, Quartet had less ground cover than Aries, Mara, Bronson, and Duo in the co-culture (Table 12)

Aries and Quartet had significantly less spring ground cover than all other cultivars in the monoculture (Table 13). In the fall, all cultivars had a similar amount of ground cover (Table 13).

Chatham – First production year

There is no first production year data for the co-culture because it was reseeded. Aries and Quartet had significantly less spring ground cover than all other cultivars in the monoculture (Table 13). All cultivars had similar amounts of fall ground cover (Table 13).

The amount of spring ground cover was inversely related to the amount of winter injury in both the co-culture and monoculture. Aries and Quartet, which tended to have the most winter injury, also had the least amount of spring ground cover. Bronson, Duo, and Tekapo had little to no winter injury and good spring ground cover, but during the establishment year at Lake City, Bronson had less ground cover than Mara and Barfort in both the co-culture and monoculture. Overall, there was a lower amount of spring ground cover in the first production year because of the harsher winter conditions.

Humphreys and Eagles (1988) came to a similar conclusion when they subjected perennial ryegrass accessions to freezing temperatures from 2°C to -10°C, then let surviving plants recover for six weeks. They found that growth was severely limited by freezing and determined that spring growth may be limited by previous winter conditions even in the absence of plant death. Hofgaard et al. (2003) also found greater spring growth in perennial ryegrass cultivars with greater tolerance to freezing and ice encasement.

Casler et al. (2002) found that selected strains of 'Spring Green' festulolium had a greater survival rate and averaged 30% more ground cover than its unselected parents in USDA hardiness zones 2 through 4. The researchers also found mean ground cover was highly correlated with USDA hardiness zone classification. The only exception was at Rosemount, MN (USDA hardiness zone 4) which they attributed to longer and more reliable snow cover.

Amount of fall ground cover was not as predictable as the amount of spring ground cover. As both the co-culture and monoculture treatments recovered from the winter injury, the difference in ground cover means became smaller so more winter injury did not necessarily mean less fall ground cover. A study by Frame (1989) evaluated herbage productivity of fourteen grasses and during the winter of the third year, both Yorkshire fog (*Holcus lanatus*), a perennial grass originally from Europe, and perennial ryegrass plots were damaged with some plant death, however, both species largely recovered by the second harvest.

Overall, the amount of ground cover decreased from spring to fall in the establishment year. In the first production year, the amount of ground cover typically

increased from spring to fall. This is partly due to a larger amount of winter injury and partly because fall ground cover ratings were taken in before grass was becoming dormant.

Table 10. Co-culture ground cover means (n=3) taken during the establishment year. A 1 – 9 scale was used where 1 = no ground cover and 9 = complete ground cover.

Location	Cultivar (species) [†]	Spring Ground Cover Rating	Fall Ground Cover Rating
Hickory Corners	Aries (dPR)	6.5 C [†] b [§]	7.5 ABCa
	Mara (dPR)	7.3 Ba	7.7 ABa
	Barfort (tPR)	8.5 Aa	7.2 BCb
	Quartet (tPR)	7.3 Ba	7.3 ABCa
	Bronson (TF)	8.7 Aa	8.0 Aa
	Duo (Fest)	8.5 Aa	6.8 Cb
	Tekapo (OR)	8.7 Aa	7.0 BCb
	Mean	7.9	7.4
	S.E.	0.3	0.3
Lake City	Aries (dPR)	6.3 CDb	7.3 ABa
	Mara (dPR)	8.0 Aa	8.0 Aa
	Barfort (tPR)	8.2 Aa	6.7 ABb
	Quartet (tPR)	5.3 Da	7.0 ABa
	Bronson (TF)	7.0 BCa	7.3 ABa
	Duo (Fest)	7.7 ABa	7.3 ABa
	Tekapo (OR)	7.3 ABCa	6.5 Ba
	Mean	7.1	7.2
	S.E.	0.3	0.3
Chatham [¶]	Aries (dPR)	6.7 Ab	8.8 Aa
	Mara (dPR)	6.8 Ab	9.0 Aa
	Barfort (tPR)	7.2 Ab	9.0 Aa
	Quartet (tPR)	7.7 Aa	9.0 Aa
	Bronson (TF)	7.3 Ab	9.0 Aa
	Duo (Fest)	6.8 Ab	9.0 Aa
	Tekapo (OR)	7.0 Ab	9.0 Aa
	Mean	7.1	9.0
	S.E.	0.3	0.3

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

[¶]Chatham data is from 2003 because the original co-culture stand was destroyed and reseeded.

Table 11. Grass monoculture ground cover means (n=3) taken during the establishment year. A 1 – 9 scale was used where 1 = no ground cover and 9 = complete ground cover.

Location	Cultivar (species) [†]	Spring Ground Cover Rating	Fall Ground Cover Rating
Hickory Corners	Aries (dPR)	8.3 AB [‡] a [§]	7.0 BCb
	Mara (dPR)	8.3 ABa	8.2 Aa
	Barfort (tPR)	8.7 Aa	7.3 BCb
	Quartet (tPR)	7.8 Ba	7.5 ABa
	Bronson (TF)	8.0 ABa	7.2 BCb
	Duo (Fest)	8.2 ABa	7.3 BCb
	Tekapo (OR)	8.3 ABa	6.7 Cb
	Mean	8.2	7.3
	S.E.	0.2	0.2
Lake City	Aries (dPR)	4.8 Db	6.9 Da
	Mara (dPR)	8.3 Aa	8.7 Aa
	Barfort (tPR)	8.2 Aa	8.3 ABa
	Quartet (tPR)	6.0 Cb	7.5 CDa
	Bronson (TF)	7.5 Ba	7.8 BCa
	Duo (Fest)	8.5 Aa	8.8 Aa
	Tekapo (OR)	8.0 ABa	8.5 Aa
	Mean	7.3	8.1
	S.E.	0.2	0.2
Chatham	Aries (dPR)	8.3 ABb	9.0 Aa
	Mara (dPR)	8.7 ABa	9.0 Aa
	Barfort (tPR)	9.0 Aa	9.0 Aa
	Quartet (tPR)	9.0 Aa	9.0 Aa
	Bronson (TF)	8.3 ABb	9.0 Aa
	Duo (Fest)	8.0 Bb	9.0 Aa
	Tekapo (OR)	8.0 Bb	9.0 Aa
	Mean	8.5	9.0
	S.E.	0.2	0.2

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

Table 12. Co-culture ground cover means (n=3) taken during the first production year. A 1 – 9 scale was used where 1 = no ground cover and 9 = complete ground cover.

Location	Cultivar (species) [†]	Spring Ground Cover Rating	Fall Ground Cover Rating
Hickory Corners	Aries (dPR)	6.5 AB ^{†b§}	8.5 Aa
	Mara (dPR)	6.8 ABb	9.0 Aa
	Barfort (tPR)	6.3 Bb	9.0 Aa
	Quartet (tPR)	7.0 ABb	8.8 Aa
	Bronson (TF)	7.2 Ab	9.0 Aa
	Duo (Fest)	6.5 ABb	9.0 Aa
	Tekapo (OR)	7.3 Ab	9.0 Aa
	Mean	6.8	8.9
	S.E.	0.3	0.3
Lake City	Aries (dPR)	6.7 Cb	9.0 Aa
	Mara (dPR)	8.0 ABb	9.0 Aa
	Barfort (tPR)	8.0 ABa	8.5 ABa
	Quartet (tPR)	3.3 Db	7.5 Ba
	Bronson (TF)	8.5 Aa	9.0 Aa
	Duo (Fest)	7.7 Bb	9.0 Aa
	Tekapo (OR)	8.0 ABa	8.8 ABa
	Mean	7.2	8.7
	S.E.	0.3	0.3

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

Table 13. Grass monoculture ground cover means (n=3) taken during the first production year. A 1 – 9 scale was used where 1 = no ground cover and 9 = complete ground cover.

Location	Cultivar (species) [†]	Spring Ground Cover Rating	Fall Ground Cover Rating
Hickory Corners	Aries (dPR)	5.3 A [†] b [§]	9.0 Aa
	Mara (dPR)	7.0 Aa	9.0 Aa
	Barfort (tPR)	6.3 Ab	8.7 Aa
	Quartet (tPR)	5.0 Ab	8.8 Aa
	Bronson (TF)	6.0 Ab	9.0 Aa
	Duo (Fest)	7.0 Aa	8.5 Aa
	Tekapo (OR)	5.5 Ab	9.0 Aa
	Mean	6.0	8.9
	S.E.	0.8	0.8
Lake City	Aries (dPR)	4.7 Bb	8.8 Aa
	Mara (dPR)	7.7 Aa	9.0 Aa
	Barfort (tPR)	7.7 Aa	8.7 Aa
	Quartet (tPR)	3.7 Bb	8.2 Aa
	Bronson (TF)	8.3 Aa	9.0 Aa
	Duo (Fest)	7.8 Aa	8.5 Aa
	Tekapo (OR)	9.0 Aa	9.0 Aa
	Mean	7.0	8.7
	S.E.	0.8	0.8
Chatham	Aries (dPR)	3.7 Bb	7.5 Aa
	Mara (dPR)	7.2 Aa	9.0 Aa
	Barfort (tPR)	8.2 Aa	8.8 Aa
	Quartet (tPR)	1.5 Bb	7.0 Aa
	Bronson (TF)	6.8 Aa	7.5 Aa
	Duo (Fest)	8.5 Aa	8.7 Aa
	Tekapo (OR)	7.2 Aa	9.0 Aa
	Mean	6.2	8.2
	S.E.	0.8	0.8

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

Tiller Production

There was no year*treatment*location or year*treatment (Appendix Table 12A) interaction for the co-culture, therefore, at each location establishment year and first production year data could have been combined. In the grass monoculture, there were no interactions (Appendix Table 13A), so data from all locations and years could have been combined. Both co-culture and monoculture data were separated by location and year, however, to easily compare seasonal results with winter injury and ground cover.

Hickory Corners – Establishment year

The perennial ryegrass cultivars had similar numbers of spring tillers in the co-culture. Quartet had a significantly greater number of tillers than Duo and Tekapo; Tekapo had the lowest number of tillers overall (Table 14). In the fall, Mara had a significantly greater number of tillers than the other cultivars in the co-culture (Table 14).

Mara had a greater number of spring tillers than all cultivars except Bronson in the monoculture (Table 15). All cultivars had a similar number of fall tillers (Table 15).

Lake City – Establishment year

Mara and Barfort, which had less winter injury, had significantly more spring tillers than Quartet, Duo, and Tekapo in the co-culture (Table 14). Perennial ryegrass cultivars had a similar number of fall tillers, but Aries had more tillers than Bronson, Duo, and Tekapo (Table 14).

In the monoculture, Mara had a significantly greater number of tillers than Aries, Quartet, Bronson, and Tekapo which would indicate it has better winter hardiness. Barfort only had more tiller than Aries (Table 15). Fall tiller numbers were similar

among cultivars, which indicates that cultivars that exhibit winter injury often recover during the growing season. (Table 15).

Chatham – Establishment year

Co-culture data is from 2003 because it was reseeded. Perennial ryegrass cultivars had a similar number of spring tillers in the co-culture. Aries and Mara had significantly more tillers than Bronson and Duo (Table 14). In the fall, Mara had a greater number of tillers than Barfort, Quartet, Bronson, Duo, and Tekapo (Table 14).

Spring tiller numbers were similar among perennial ryegrass cultivars in the grass monoculture. Bronson and Tekapo had significantly less tillers than all cultivars except Barfort (Table 15). Fall tiller numbers were similar, but Mara had significantly more tillers than Quartet (Table 15).

Hickory Corners – First production year

There were no differences in spring tiller number for the perennial ryegrass cultivars in the co-culture, but Mara had more tillers than Tekapo (Table 16). Mara and Quartet had a significantly greater number of fall tillers than Aries, Bronson, and Duo (Table 16).

In the monoculture, Aries and Mara had more spring tillers than Quartet; Mara had more tillers than Bronson as well (Table 17). Mara had a greater number of fall tillers than all other cultivars (Table 17).

Lake City – First production year

Mara had a greater number of spring tillers in the co-culture than all other cultivars. Barfort and Tekapo had a greater number of spring tillers than Quartet (Table 16). Aries and Mara had more tillers than Quartet and Bronson in the fall (Table 16)

Mara had more spring tillers than the other perennial ryegrass cultivars and Duo in the monoculture (Table 17). Fall tiller numbers were similar among all cultivars, but Aries had a significantly greater number of tillers than Bronson (Table 17).

Chatham – First production year

There is no first production year data for the co-culture because it was reseeded. In the monoculture, Mara had a greater number of spring tillers than Aries, Quartet, Bronson, and Tekapo. Barfort also had a greater number of tillers than Quartet and Bronson (Table 17). Mara and Barfort both had more tillers than Aries, Quartet, and Bronson in the fall (Table 17).

There were a total of 22 tiller counts (10 from the co-culture section and 12 from the grass only section) from the three locations. For eight of the tiller counts, there was no difference among perennial ryegrass cultivars. Mara tillered significantly more than the other three perennial ryegrass cultivars on five occasions and was among cultivars with the greatest number of tillers on the remaining 11 occasions. Tetraploids have been known to have fewer, but larger, tillers than diploid cultivars which explains why Mara tillered more than Barfort and Quartet. Tiller numbers may have been greater for Aries if it had less winter injury.

Table 14. Co-culture tiller count means (n=3) taken during the establishment year.

Location	Cultivar (species) [†]	Spring Tiller Counts	Fall Tiller Counts
Hickory Corners	Aries (dPR)	186 AB [†] a [§]	54 Bb
	Mara (dPR)	191 ABa	121 Ab
	Barfort (tPR)	174 ABa	39 Bb
	Quartet (tPR)	210 Aa	52 Bb
	Bronson (TF)	168 ABa	54 Bb
	Duo (Fest)	154 Ba	37 Bb
	Tekapo (OR)	76 Ca	65 Ba
	Mean	166	60
	S.E.	19.6	19.6
Lake City	Aries (dPR)	136 ABa	125 Aa
	Mara (dPR)	180 Aa	89 ABb
	Barfort (tPR)	190 Aa	89 ABb
	Quartet (tPR)	101 Ba	55 ABa
	Bronson (TF)	142 ABa	48 Bb
	Duo (Fest)	107 Ba	31 Bb
	Tekapo (OR)	94 Ba	42 Ba
	Mean	136	68
	S.E.	26.6	26.6
Chatham [¶]	Aries (dPR)	64 Aa	66 ABa
	Mara (dPR)	64 Ab	76 Aa
	Barfort (tPR)	43 ABa	42 BCa
	Quartet (tPR)	50 ABa	52 BCa
	Bronson (TF)	31 Ba	40 Ca
	Duo (Fest)	33 Ba	44 BCa
	Tekapo (OR)	47 ABa	43 BCa
	Mean	47	52
	S.E.	9.2	9.2

[†] Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡] Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§] Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

[¶] Chatham data is from 2003 because the original co-culture stand was destroyed and reseeded.

Table 15. Grass monoculture tiller count means (n=3) taken during the establishment year.

Location	Cultivar (species) [†]	Spring Tiller Counts	Fall Tiller Counts
Hickory Corners	Aries (dPR)	223 B ^{†a} [§]	69 Ab
	Mara (dPR)	289 Aa	71 Ab
	Barfort (tPR)	231 Ba	40 Ab
	Quartet (tPR)	205 Ba	48 Ab
	Bronson (TF)	247 ABa	44 Ab
	Duo (Fest)	238 Ba	58 Ab
	Tekapo (OR)	215 Ba	37 Ab
	Mean	235	52
	S.E.	15.9	15.9
Lake City	Aries (dPR)	106 Ca	138 Aa
	Mara (dPR)	263 Aa	154 Ab
	Barfort (tPR)	214 ABa	110 Ab
	Quartet (tPR)	120 BCa	93 Aa
	Bronson (TF)	118 BCa	64 Aa
	Duo (Fest)	171 ABCa	82 Ab
	Tekapo (OR)	151 BCa	78 Aa
	Mean	163	102
	S.E.	38.0	38.0
Chatham	Aries (dPR)	103 Aa	94 ABa
	Mara (dPR)	109 Aa	99 Aa
	Barfort (tPR)	78 ABa	88 ABa
	Quartet (tPR)	108 Aa	62 Bb
	Bronson (TF)	54 Ba	64 ABa
	Duo (Fest)	99 Aa	93 ABa
	Tekapo (OR)	60 Ba	72 ABa
	Mean	87	81
	S.E.	12.8	12.8

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

Table 16. Co-culture tiller count means (n=3) taken during the first production year.

Location	Cultivar (species) [†]	Spring Tiller Counts	Fall Tiller Counts
Hickory Corners	Aries (dPR)	40 AB [†] a [§]	35 Ba
	Mara (dPR)	93 Aa	116 Aa
	Barfort (tPR)	43 ABa	79 ABa
	Quartet (tPR)	42 ABb	121 Aa
	Bronson (TF)	41 ABa	49 Ba
	Duo (Fest)	42 ABa	52 Ba
	Tekapo (OR)	33 Ba	66 ABa
	Mean	47	74
	S.E.	19.6	19.6
Lake City	Aries (dPR)	113 BCa	136 Aa
	Mara (dPR)	213 Aa	149 Aa
	Barfort (tPR)	119 Ba	114 ABCa
	Quartet (tPR)	39 Ca	64 BCa
	Bronson (TF)	110 BCa	60 Ca
	Duo (Fest)	79 BCa	126 ABa
	Tekapo (OR)	131 Ba	75 ABCa
	Mean	114	103
	S.E.	26.6	26.6

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

Table 17. Grass monoculture tiller count means taken during the first production year.

Location	Cultivar (species) [†]	Spring Tiller Counts	Fall Tiller Counts
Hickory Corners	Aries (dPR)	92 AB [‡] b [§]	127 Ba
	Mara (dPR)	106 Ab	242 Aa
	Barfort (tPR)	79 ABCa	103 BCa
	Quartet (tPR)	46 Cb	84 BCa
	Bronson (TF)	50 BCa	77 Ca
	Duo (Fest)	76 ABCa	91 BCa
	Tekapo (OR)	71 ABCa	97 BCa
	Mean	74	117
	S.E.	15.9	15.9
Lake City	Aries (dPR)	48 CDb	178 Aa
	Mara (dPR)	197 Aa	133 ABa
	Barfort (tPR)	84 BCDA	163 ABa
	Quartet (tPR)	23 Da	123 ABa
	Bronson (TF)	165 ABa	69 Ba
	Duo (Fest)	79 BCDA	135 ABa
	Tekapo (OR)	144 ABCa	92 ABa
	Mean	105	127
	S.E.	38.0	38.0
Chatham	Aries (dPR)	37 CDEa	52 Ba
	Mara (dPR)	99 Aa	87 Aa
	Barfort (tPR)	72 ABCa	90 Aa
	Quartet (tPR)	13 Ea	23 Ba
	Bronson (TF)	32 DEa	51 Ba
	Duo (Fest)	74 ABa	91 Aa
	Tekapo (OR)	51 BCDA	57 ABa
	Mean	54	64
	S.E.	12.8	12.8

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

Clover Ratings

There was no year*treatment*location or location*treatment (Appendix Table 14A) interaction for the co-culture, therefore, each year of data could have been combined all across locations. Data were separated by location and year, however, to compare seasonal results at each location. Botanical composition data are included in Appendix Tables 14A-18A. Visual ratings did not relate well to the botanical composition data because only presence of clover was taken into account and not size of the clover. When clover was present throughout the plot, but small in size, a high clover rating was given. Since botanical composition data is based on biomass, a plot with small clover throughout would have a low clover content.

Hickory Corners – Establishment year

Aries had the least amount of clover of all the cultivars in the spring. Mara, Barfort, and Quartet had similar amounts of clover (Table 18). In the fall, Barfort had a greater amount of clover than the other perennial ryegrass cultivars (Table 18). The amount of clover present in a stand is an indication of its compatibility with grass. Grass with little or no clover present is not as compatible with the clover as a grass with a large amount of clover present. Aries, which had the least amount of clover, is very non-dormant and may have been too competitive during establishment resulting in less clover.

Lake City – Establishment year

Tekapo had the greatest amount of spring clover of all the cultivars. Barfort had more clover present than Aries (Table 18). Perennial ryegrass cultivars had similar amounts of clover in the fall. Tekapo had a greater amount of clover than Mara, Quartet,

and Bronson (Table 18). Aries again had a small presence of clover, most likely due to competition during establishment. Tekapo, which had the greatest amount of clover, is slower to establish than the other cultivars, resulting in less competition. Lake City had less overall clover than both Hickory Corners and Chatham. Soil pH was similar at all locations, so pH was not a contributing factor to the low clover content.

Chatham – Establishment year

In the spring, Barfort and Quartet both had more clover present than Aries; Duo and Tekapo also had greater amounts of clover than Aries (Table 18). Cultivars had similar amounts of clover in the fall (Table 18). Since Aries had a small amount of clover at Chatham as well as the other locations, it may be too competitive for clover establishment. Duo and Tekapo again had more clover, indicating they are less competitive with ladino clover during establishment.

Hickory Corners – First production year

There were no significant differences in the amount of clover among perennial ryegrass cultivars in the spring because all cultivars experienced some winter injury. This decreased competition between the grass and clover, allowing a greater clover presence throughout the plots. Barfort had more clover than Bronson and Tekapo (Table 19). In the fall, Mara had less clover present than the other perennial ryegrass cultivars. Barfort most likely had more clover than Mara because it has less tillers and they are more upright than Mara. Bronson had significantly less clover than all perennial ryegrass cultivars except for Mara and Tekapo (Table 19), which could be due to canopy shade or grass density.

Lake City – First production year

In the spring, the four perennial ryegrass cultivars had similar amounts of clover. Duo had significantly more clover than Mara and Bronson (Table 19). Quartet had a greater amount of fall clover than Aries, Mara, Bronson, and Tekapo (Table 19). Once again, Lake City had less overall clover than Hickory Corners in the fall. Soil pH was similar at all locations, so pH was not a contributing factor to the low clover content.

There were not many significant differences in the amount of clover present among perennial ryegrass cultivars. When there were significant differences, Barfort had more clover present than Aries and/or Mara. Differences between these cultivars may be a result of differences in grass density. Mara tillered more than the other perennial ryegrass cultivars and therefore may have been more competitive with the clover in the spring. Also, Aries had significantly less clover in the establishment year at two locations probably due to its rapid establishment resulting in more competition

Duo had similar amounts of clover as Barfort on all occasions, and also had similar number of tillers as Barfort. Bronson had a similar amount of clover as Mara, but had significantly less tillers half of the times tillers were counted.

The relationship between presence of another plant species and tiller number has been noted in several studies. Short and Carlson (1989) researched compatibility of orchardgrass with birdsfoot trefoil (*Lotus corniculatus* L.) and found increased compatibility was associated with fewer tillers per plant. Gilliland (1996) studied 33 varieties of perennial ryegrass and 4 varieties of white clover as binary mixtures. The perennial ryegrass differed in maturity, ploidy, yield potential, and morphological

characteristics. Gilliland found tetraploid varieties were more compatible with white clover than diploids, and that sward density was the most important factor in grass/clover compatibility. Tetraploid perennial ryegrass varieties were also found to be more compatible with white clover than diploid varieties by Gooding et al. (1996). The researchers observed that a more open grass growth habit increased the presence of white clover in the stand.

Table 18. Co-culture clover means (n=3) taken during the establishment year using a 1 – 9 scale, where 1 = no clover in the plot and 9 = clover throughout the plot.

Location	Cultivar (species) [†]	Spring Clover Ratings	Fall Clover Ratings
Hickory Corners	Aries (dPR)	1.0 C [†] b [§]	3.3 BCa
	Mara (dPR)	2.7 Ba	2.2 CDa
	Barfort (tPR)	3.7 ABb	5.0 Aa
	Quartet (tPR)	2.7 Ba	3.2 BCDA
	Bronson (TF)	4.0 ABa	1.8 Db
	Duo (Fest)	4.3 Aa	4.3 ABa
	Tekapo (OR)	4.0 ABa	2.5 CDb
	Mean	3.2	3.1
	S.E.	0.5	0.5
Lake City	Aries (dPR)	1.2 Da	1.8 BCa
	Mara (dPR)	1.5 CDa	1.3 Ca
	Barfort (tPR)	2.8 BCa	2.2 ABCa
	Quartet (tPR)	1.7 CDa	1.7 Ca
	Bronson (TF)	3.2 Ba	1.7 Cb
	Duo (Fest)	3.2 Ba	3.2 ABa
	Tekapo (OR)	6.2Aa	3.3 Ab
	Mean	2.8	2.1
	S.E.	0.5	0.5
Chatham	Aries (dPR)	6.0 Cb	8.8 Aa
	Mara (dPR)	7.2 BCb	9.0 Aa
	Barfort (tPR)	9.0 Aa	9.0 Aa
	Quartet (tPR)	8.5 ABa	9.0 Aa
	Bronson (TF)	7.3 BCb	9.0 Aa
	Duo (Fest)	9.0 Aa	9.0 Aa
	Tekapo (OR)	9.0 Aa	9.0 Aa
	Mean	8.0	9.0
	S.E.	0.5	0.5

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

Table 19. Co-culture clover means (n=3) taken during the first production year using a 1 – 9 scale, where 1 = no clover in the plot and 9 = clover throughout the plot.

Location	Cultivar (species) [†]	Spring Clover Ratings	Fall Clover Ratings
Hickory Corners	Aries (dPR)	4.0 A [†] Bb [§]	8.8 Aa
	Mara (dPR)	3.7 ABa	5.3 Ba
	Barfort (tPR)	6.3 Aa	9.0 Aa
	Quartet (tPR)	4.3 ABb	9.0 Aa
	Bronson (TF)	2.0 Bb	5.7 Ba
	Duo (Fest)	5.0 ABb	9.0 Aa
	Tekapo (OR)	3.0 Bb	7.0 ABa
	Mean	4.0	7.7
	S.E.	1.1	1.1
Lake City	Aries (dPR)	3.3 ABa	2.2 BCa
	Mara (dPR)	2.3 Ba	1.7 BCa
	Barfort (tPR)	4.3 ABa	3.8 ABa
	Quartet (tPR)	4.7 ABa	5.3 Aa
	Bronson (TF)	1.7 Ba	1.0 Ca
	Duo (Fest)	6.0 Aa	4.5 ABa
	Tekapo (OR)	3.3 ABa	1.3 Ca
	Mean	3.7	2.8
	S.E.	1.1	1.1

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Means in a row followed by the same lower case letter are not significantly different within a location ($p \leq 0.05$).

Yield

Yield was determined at each harvest, however, only the first and total yields are discussed here. For the establishment year there were five harvests at Hickory Corners, three at Lake City, and four at Chatham. During the first production year there were four harvests at Hickory Corners and Lake City, and three harvests at Chatham. Data were separated by location and year, however, to account for different weather conditions. For botanical composition data see Appendix Tables 14A to 18A.

Hickory Corners – Establishment year

There was no significant difference in first or total harvest yields among perennial ryegrass cultivars in the co-culture. Bronson had greater yields than all the perennial ryegrass cultivars at the first harvest, but only yielded more than Barfort for total yield (Table 20). In the monoculture, Mara had greater first yields than Barfort. Aries and Mara had significantly greater total yields than Quartet, Duo, and Tekapo (Table 21).

Lake City – Establishment year

Quartet had lower first and total yields than all other cultivars in the co-culture. Bronson had greater first yields than Aries, Barfort, Quartet, and Tekapo. Duo had a greater total yield than Aries, Barfort, and Quartet (Table 20). In the monoculture, Mara, Barfort, and Duo out yielded Aries and Quartet at the first harvest. This is probably due to winter injury at this location resulting in fewer tillers at the first harvest. Mara had a greater total yield than all perennial ryegrass cultivars and Tekapo most likely because it did not exhibit any winter injury (Table 21).

Chatham – Establishment year

In the co-culture, perennial ryegrass cultivars had similar yields at the first harvest, but Mara had a greater total yield than Aries. Duo and Tekapo also had greater total yields than Aries (Table 20). Aries had greater first yields than all cultivars, except Duo, at the first harvest in the monoculture. Tekapo yielded the least amount at the first harvest. Mara had a greater total yield than Aries, Barfort, Bronson, and Tekapo (Table 21). Again, this may be related to winter injury symptoms in Aries and Quartet.

Hickory Corners – First production year

All cultivars had similar total yields in the co-culture which indicates that white clover makes up for grass cultivar yield differences (Table 22). Aries had the lowest total yield of all cultivars in the monoculture due to winter injury. Quartet had a greater total yield than Aries, but lower yields than the other cultivars due to winter injury (Table 23).

Lake City – First production year

Bronson and Tekapo had significantly greater first yields than the other cultivars in the co-culture. Perennial ryegrass cultivars had similar first yields. Bronson was the greatest total yielding cultivar. Of the perennial ryegrass cultivars, Aries had a greater total yield than Barfort and Quartet, which indicates it recovered from winter injury; Mara had a greater total yield than Quartet (Table 22). In the monoculture, perennial ryegrass cultivars again had similar yields, and Bronson and Tekapo out yielded the perennial ryegrasses at the first harvest. Bronson and Tekapo also had the greatest total yields. Of the perennial ryegrass cultivars Mara had a greater total yield than Barfort and

Quartet (Table 23). These data indicate tall fescue and orchardgrass may be better adapted to conditions at Lake City.

Chatham – First production year

There is no first production year data for the co-culture because it was reseeded due to poor clover establishment. Bronson, then Duo, were the highest yielding cultivars in the monoculture at the first harvest. Mara, Barfort, and Tekapo had greater first yields than Aries or Quartet indicating better adaptation at this location. For total yield, Bronson out yielded all cultivars, except for Mara. Mara, Barfort, Duo, and Tekapo had a greater total yield than Quartet (Table 22).

Yields at the first harvest were closely related to winter injury. In both the co-culture and monoculture, treatments with the least amount of winter injury typically had the highest yields. Winter damage affecting spring yields has also been reported by Frame (1989).

Total yields, however, did not seem to follow a definite pattern. This is probably because there are other factors that affect production over the season besides winter injury and ground cover including amount of precipitation, amount of sunlight, and animal preference. In addition, perennial ryegrass cultivars recovered from winter injury resulting in yields similar to those cultivars exhibiting less winter injury. Mara was among the highest yielding groupings of perennial ryegrass and had significantly higher yields than all the other ryegrass cultivars during the establishment year at Lake City and Chatham. This would be due to a combination of winter hardiness and tillering ability.

Duo had comparable yields to Mara, while Tekapo yielded slightly less than the perennial ryegrass cultivars in the establishment year. Tekapo had similar yields to Mara and Barfort and higher yields than Aries and Quartet in the first production year due to winter injury in the perennial ryegrass cultivars. Bronson yielded as much or more than perennial ryegrass, especially during the warmer, drier summer months.

Previous research has found higher yields in mixtures as opposed to monocultures, (Roberts and Olsen, 1942; Aberg, 1943; Evans et al., 1989; Sleugh et al., 2000), however, that was not true in this research. Other previous research has shown no yield advantage over a monoculture for mixtures of grasses (Keane, 1982; Culleton, Murphey, and O’Keeffe, 1986) or an alfalfa/grass mixture (Wilsie 1949; Mooso and Wedin, 1990). However, Culleton, Murphey, and O’Keeffe (1986) reported mixtures tended to be less variable, giving relatively high yields each year. That was true of this study as well, especially during the warm, dry summer months.

Table 20. Co-culture dry matter yield (t ha⁻¹) means (n=3) at each harvest during the establishment year.

Location	Cultivar (species) [†]	Yield 1	Yield 2	Yield 3	Yield 4	Yield 5	Yield Total
Hickory Corners	Aries (dPR)	1.17 C [‡]	2.58	2.26	1.45	1.23	8.69 AB
	Mara (dPR)	1.26 BC	1.70	1.97	1.54	1.05	7.52 AB
	Barfort (tPR)	1.29 BC	1.64	1.70	1.32	0.93	6.88 B
	Quartet (tPR)	1.33 BC	2.18	1.58	1.19	1.20	7.48 AB
	Bronson (TF)	1.76 A	1.84	1.89	1.71	1.69	8.89 A
	Duo (Fest)	1.51 AB	2.16	1.54	1.43	1.31	7.95 AB
	Tekapo (OR)	1.42 BC	1.42	1.55	1.75	1.17	7.31 AB
	Mean	1.39	1.93	1.78	1.48	1.22	7.82
	S.E.	0.13	0.23	0.29	0.22	0.24	0.69
Lake City	Aries (dPR)	1.99 B	2.33	1.53	.	.	5.85 B
	Mara (dPR)	2.29 AB	2.95	1.05	.	.	6.29 AB
	Barfort (tPR)	2.20 B	2.50	1.21	.	.	5.91 B
	Quartet (tPR)	1.38 C	2.13	1.24	.	.	4.75 C
	Bronson (TF)	2.81 A	2.23	1.06	.	.	6.10 AB
	Duo (Fest)	2.42 AB	2.82	1.86	.	.	7.10 A
	Tekapo (OR)	1.91 B	2.53	1.72	.	.	6.16 AB
	Mean	2.14	2.50	1.38	.	.	6.02
	S.E.	0.19	0.23	0.18	.	.	0.45
Chatham [§]	Aries (dPR)	0.59 AB	0.14	0.88	.	.	1.61 C
	Mara (dPR)	0.54 AB	0.58	1.39	.	.	2.51 AB
	Barfort (tPR)	0.59 AB	0.72	0.95	.	.	2.26 ABC
	Quartet (tPR)	0.69 AB	0.57	1.04	.	.	2.30 ABC
	Bronson (TF)	0.73 A	0.36	1.35	.	.	2.44 ABC
	Duo (Fest)	0.52 AB	1.01	1.33	.	.	2.86 A
	Tekapo (OR)	0.43 B	0.66	0.84	.	.	1.93 B
	Mean	0.58	0.58	1.11	.	.	2.27
	S.E.	0.11	0.23	0.21	.	.	0.40

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

[§]Chatham data is from 2003 because the original co-culture stand was destroyed and reseeded.

Table 21. Grass monoculture dry matter yield (t ha⁻¹) means (n=3) at each harvest during the establishment year.

Location	Cultivar (species) [†]	Yield 1	Yield 2	Yield 3	Yield 4	Yield 5	Yield Total
Hickory Corners	Aries (dPR)	1.35 AB [‡]	2.57	1.70	1.46	1.71	8.79 AB
	Mara (dPR)	1.41 A	2.94	2.41	1.23	1.77	9.76 AB
	Barfort (tPR)	1.09 B	1.77	2.79	1.32	1.37	8.34 BC
	Quartet (tPR)	1.39 AB	1.60	1.24	1.10	1.22	6.56 CD
	Bronson (TF)	1.37 AB	2.61	2.18	1.90	2.43	10.49 A
	Duo (Fest)	1.40 AB	2.37	2.32	1.16	1.18	8.43 B
	Tekapo (OR)	1.20 AB	1.26	1.33	1.14	1.47	6.40 D
	Mean	2.74	2.16	1.99	1.33	1.59	8.39
Lake City	S.E.	0.15	0.28	0.36	0.25	0.27	0.66
	Aries (dPR)	1.20 C	2.76	1.54	.	.	5.50 C
	Mara (dPR)	2.25 AB	3.63	2.22	.	.	8.10 A
	Barfort (tPR)	2.08 AB	2.38	2.00	.	.	6.46 BC
	Quartet (tPR)	1.31 C	3.24	1.52	.	.	6.07 BC
	Bronson (TF)	1.79 ABC	2.85	2.73	.	.	7.37 AB
	Duo (Fest)	2.32 A	3.62	1.65	.	.	7.59 AB
	Tekapo (OR)	1.56 BC	2.25	2.17	.	.	5.98 BC
Chatham	Mean	1.79	2.96	1.98	.	.	6.72
	S.E.	0.26	0.28	0.29	.	.	0.66
	Aries (dPR)	2.32 A	1.67	1.30	1.64	.	6.93 BC
	Mara (dPR)	1.74 BC	2.92	2.08	2.07	.	8.81 A
	Barfort (tPR)	1.43 C	2.76	0.92	1.59	.	6.70 BC
	Quartet (tPR)	1.49 C	2.14	1.76	1.94	.	7.33 ABC
	Bronson (TF)	1.46 C	2.10	1.59	1.47	.	6.62 BC
	Duo (Fest)	2.05 AB	2.69	1.43	1.62	.	7.79 AB
Chatham	Tekapo (OR)	1.10 D	1.40	1.84	1.54	.	5.88 C
	Mean	1.65	2.24	1.56	1.69	.	7.15
	S.E.	0.11	0.28	0.25	0.30	.	0.66

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location (p≤0.05).

Table 22. Co-culture dry matter yield (t ha⁻¹) means (n=3) at each harvest during the first production year.

Location	Cultivar (species) [†]	Yield 1	Yield 2	Yield 3	Yield 4	Yield Total
Hickory Corners	Aries (dPR)	.	2.02	0.84	0.87	3.73 A
	Mara (dPR)	.	2.16	0.95	0.54	3.65 A
	Barfort (tPR)	.	2.36	1.10	0.72	4.18 A
	Quartet (tPR)	.	1.95	1.07	0.37	3.39 A
	Bronson (TF)	.	1.66	1.64	1.45	4.75 A
	Duo (Fest)	.	1.98	0.84	0.62	3.44 A
	Tekapo (OR)	.	2.00	1.25	1.26	4.51 A
	Mean	.	2.02	1.10	0.83	3.95
	S.E.	.	0.21	0.29	0.22	0.69
Lake City	Aries (dPR)	0.90 B [‡]	1.04	0.64	1.70	4.28 B
	Mara (dPR)	0.76 B	0.61	0.80	1.09	3.26 BC
	Barfort (tPR)	0.62 B	0.79	0.59	1.08	3.08 C
	Quartet (tPR)	0.52 B	0.37	0.40	0.81	2.10 D
	Bronson (TF)	1.22 A	1.15	1.05	1.58	5.01 A
	Duo (Fest)	0.75 B	0.78	0.31	1.34	3.18 C
	Tekapo (OR)	1.19 A	0.69	0.67	1.10	3.65 BC
	Mean	0.85	0.78	0.64	1.24	3.51
	S.E.	0.19	0.21	0.17	0.33	0.37

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location (p≤0.05).

Table 23. Grass monoculture dry matter yield (t ha⁻¹) means (n=3) at each harvest during the first production year.

Location	Cultivar (species) [†]	Yield 1	Yield 2	Yield 3	Yield 4	Yield Total
Hickory Corners	Aries (dPR)	.	1.52	0.43	0.36	2.31 C
	Mara (dPR)	.	1.81	0.52	0.95	3.28 A
	Barfort (tPR)	.	1.63	0.84	0.99	3.46 A
	Quartet (tPR)	.	1.18	0.84	0.81	2.83 B
	Bronson (TF)	.	1.82	1.57	1.23	4.62 A
	Duo (Fest)	.	1.97	0.52	0.84	3.33 A
	Tekapo (OR)	.	1.82	1.25	0.93	4.00 A
	Mean	.	1.68	0.85	0.87	3.40
	S.E.	.	0.28	0.36	0.25	0.48
Lake City	Aries (dPR)	0.58 C	1.62	1.01	0.92	4.13 BCD
	Mara (dPR)	1.19 BC	1.32	1.08	1.55	5.14 B
	Barfort (tPR)	1.14 BC	0.93	0.47	1.23	3.77 CD
	Quartet (tPR)	0.49 C	0.65	0.75	1.05	2.94 D
	Bronson (TF)	2.02 A	0.60	1.46	2.76	6.84 A
	Duo (Fest)	1.35 AB	0.85	1.08	1.59	4.87 BC
	Tekapo (OR)	2.17 A	1.08	1.20	2.29	6.74 A
	Mean	1.28	1.00	1.01	1.63	4.92
	S.E.	0.26	0.28	0.29	0.39	0.48
Chatham	Aries (dPR)	0.17 D	1.31	0.84	.	2.32 BC
	Mara (dPR)	0.78 C	1.45	1.15	.	3.38 AB
	Barfort (tPR)	0.87 C	0.93	1.07	.	2.87 B
	Quartet (tPR)	0.13 D	0.62	0.64	.	1.39 C
	Bronson (TF)	1.75 A	1.76	1.11	.	4.62 A
	Duo (Fest)	1.19 B	0.69	0.93	.	2.81 B
	Tekapo (OR)	0.68 C	1.15	1.64	.	3.47 AB
	Mean	0.79	1.13	1.05	.	2.98
	S.E.	0.11	0.28	0.25	.	0.48

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a location ($p \leq 0.05$).

Palatability

Palatability data was separated by each harvest because the fourth harvest had a significant ($P < .001$) year*treatment interaction, and data is separated by year. There were no interactions for all other harvests, so these data are combined by location and year.

There were no significant differences among cultivars in the co-culture at the first, second, third, and fifth harvests (Appendix Table 19A). Cultivars had similar palatability scores at the fourth harvest of the establishment year. Bronson had a significantly lower palatability than all other cultivars at fourth harvest of the first production year. Tekapo and Mara were more palatable than Bronson, but significantly less palatable than the other cultivars (Table 24).

Bronson was less palatable than the other cultivars at the first harvest of the monoculture. All cultivars had similar palatability scores at the second, third, and fifth harvests (Appendix Table 20A). Cultivars also had similar palatability scores at the fourth harvest of the establishment year. Bronson was the least palatable, then Tekapo, then Mara at the fourth harvest of the first production year (Table 24).

The year*treatment interaction at the fourth harvest was most likely because of a difference in disease presence between years. In the first year, no disease was observed, whereas during late fall of the first production year both leaf spot (*Helminthosporium* spp.) and brown patch (*Rhizoctonia* spp.) were observed. Disease presence was the greatest in Bronson, Tekapo, and Mara. In addition, there may have been differences due to species maturity with tall fescue being earlier than orchardgrass and perennial

ryegrasses. Given enough time, however, the animals consumed all species of grasses presented to them.

Although research has shown tetraploid cultivars of perennial ryegrass are preferred to diploids (Wilkins, 1991), this research did not have similar results. Also, tall fescue and orchardgrass are considered to be less palatable than perennial ryegrass but these data indicate the four species were similar in palatability. This is most likely because the grasses were grazed while still immature. McCaughey (1998) found that animal preference was similar when grass species had similar proportions of reproductive to vegetative tillers. A low proportion of reproductive to vegetative tillers was associated with greater animal preference.

Table 24. Co-culture and grass monoculture palatability scores (n=3) at the fourth harvest for the establishment year and first production year. Scores are on a 1-5 scale with 1 being least palatable.

Year	Cultivar (species) [†]	Co-culture Cut 4	Monoculture Cut 4
Establishment	Aries (dPR)	5.000 A [‡]	5.000 A
	Mara (dPR)	5.000 A	5.000 A
	Barfort (tPR)	5.000 A	5.000 A
	Quartet (tPR)	5.000 A	5.000 A
	Bronson (TF)	5.000 A	5.000 A
	Duo (Fest)	5.000 A	5.000 A
	Tekapo (OR)	5.000 A	5.000 A
First Production	Aries (dPR)	5.000 A	4.000 AB
	Mara (dPR)	3.667 B	3.000 C
	Barfort (tPR)	5.000 A	4.333 A
	Quartet (tPR)	5.000 A	3.667 B
	Bronson (TF)	2.333 C	1.000 E
	Duo (Fest)	5.000 A	4.000 AB
	Tekapo (OR)	3.667 B	2.000 D

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a column followed by the same capital letter are not significantly different within a year ($p \leq 0.05$).

Forage Quality

Forage quality is defined as the potential of a forage to produce the desired animal response (Collins and Fritz, 2003). It is the physical and chemical characteristics of a forage that make it valuable to animals as a source of nutrients. Forage quality is often evaluated by measuring characteristics such as crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and hemicellulose (Pavetti et al., 1994). For this research, quality is defined as forage which with high concentrations of CP and low concentrations of both NDF and ADF.

When analyzing the data there was no pattern to the interactions for ADF, NDF, and CP, hence data was separated by year, location, and harvest to present results in a logical format. Forage quality for the co-culture ranged from 138 to 357, 305 to 589, and 110 to 312 g kg⁻¹ for ADF, NDF, and CP respectively. Forage quality for the grass monoculture ranged from 163 to 411, 242 to 630, and 40 to 322, for ADF, NDF, and CP respectively.

Hickory Corners – Establishment year

In the co-culture, Barfort and Tekapo had lower ADF and NDF values and higher CP values than the other cultivars at the first harvest. For the second harvest, Tekapo Barfort, and Mara had lower ADF values than Aries and lower NDF values than Aries and Bronson. Tekapo had a higher CP value than all cultivars. Tekapo and Barfort had lower ADF and NDF values than Aries and Mara at the third harvest. Bronson, Tekapo and Barfort had a greater amount of CP than Mara. At the fourth harvest, Barfort and Quartet had a smaller amount of ADF than Duo. Mara had a lower NDF value than all

cultivars, except Tekapo and Aries. Barfort and Duo had lower fiber values and higher crude protein values at the final harvest (Table 25).

In the grass monoculture, Barfort, Tekapo, and Duo had lower ADF concentrations than Aries at the first harvest; Mara had a lower NDF concentration than Duo. Tekapo had greater CP values than Mara and Quartet. At the second harvest, Barfort, Quartet, and Tekapo had lower ADF values than Aries and Bronson. Bronson had a higher NDF concentration than all cultivars except for Aries. Tekapo had a higher CP concentration than Barfort, Mara, and Bronson. Quartet had lower ADF values than all cultivars except Bronson and Tekapo at the third harvest and lower NDF values than all cultivars except Duo and Tekapo. The only significant difference in CP values was between Barfort and Mara, with Barfort having a greater CP value. Duo and Quartet had lower ADF concentrations than Barfort and lower NDF concentrations than Tekapo at the fourth harvest. Crude protein was similar among all the cultivars. At the final harvest Tekapo had greater ADF and NDF concentrations than Barfort, Quartet, and Duo. Barfort and Quartet had greater CP values than Mara, Bronson, and Tekapo (Table 26).

Lake City – Establishment year

In the co-culture, Quartet had the lowest ADF value compared to all cultivars at the first harvest. Quartet and Tekapo had lower NDF values than Bronson. Tekapo had a greater amount of CP than Duo and Mara. For the second harvest, Quartet and Tekapo had lower ADF and NDF concentrations than all cultivars except Bronson. Tekapo and Bronson had greater CP concentrations than Duo and Quartet. Quartet had the lowest concentration of ADF of all cultivars and a lower NDF concentration than Tekapo and

Mara at the third harvest. Crude protein values were similar among all cultivars (Table 27).

Quartet had the lowest ADF values of all cultivars in the monoculture at the first harvest. Quartet also had lower NDF values than the other cultivars except for Aries and Duo. Barfort had the least amount of CP except for Bronson and Duo. At the second harvest, Barfort, Mara, and Tekapo had a greater concentration of ADF than Quartet; Quartet had a lower NDF concentration than all cultivars. Crude protein concentrations were higher in Quartet and Tekapo than Aries and Duo. Bronson had a greater ADF concentration than all cultivars, except Tekapo, at the final harvest. Tekapo had a higher NDF value than all cultivars. Crude protein values for Quartet and Duo were greater than those for Bronson (Table 28).

Chatham –Establishment year

Acid detergent fiber concentrations were greater in Aries, Bronson, and Tekapo than the other cultivars at the first harvest in the co-culture. Aries and Bronson also had the greatest NDF concentrations. Tekapo had the largest CP value. At the second harvest, both ADF and NDF values were similar among cultivars. Tekapo had a greater ADF value than Duo and Quartet at the final harvest, while Mara had a greater NDF value than Barfort and Quartet. Barfort, Quartet, and Duo had a greater CP concentration than Mara (Table 29).

In the monoculture, Quartet had the lowest ADF concentration at the first harvest. Duo, then Quartet, had the lowest NDF concentrations. Tekapo had the greatest CP concentration. Bronson had smaller ADF and NDF values than all the other cultivars at the second harvest. Bronson and Tekapo had the greatest CP values. At both the third

and fourth harvests, Tekapo had a greater ADF and NDF concentration than all the other cultivars. There was no difference in CP values among cultivars (Table 30).

Hickory Corners – First production year

Tekapo and Bronson had the greatest ADF and NDF concentrations at the first harvest of the co-culture. Crude protein levels were similar among cultivars. At the second harvest, Mara had a greater ADF value than Aries and Quartet. Mara had a greater NDF than Duo and Quartet. Quarter had a higher concentration of CP than Mara, Barfort, and Tekapo. Bronson had a greater ADF concentration than Aries and Duo at the third harvest. Bronson and Mara had a greater NDF concentration than Aries. Bronson also had a lower CP value than the other cultivars. At the fourth harvest, Bronson and Tekapo had the greater ADF values. Bronson and Tekapo also had greater NDF values than Barfort and Duo. Bronson, then Tekapo, had the lowest CP concentrations (Table 31).

Bronson had the highest ADF values at the first harvest of the monoculture, while Bronson and Tekapo had the greatest NDF values. Quartet and Aries had greater CP concentrations than Bronson and Duo. Quartet had the lowest ADF and NDF values at the second harvest. Bronson had a greater CP value than Mara and Quartet. At the third harvest, Barfort, Duo, and Tekapo had a greater ADF value than Aries. Barfort, Tekapo, and Duo had greater NDF values than Mara. Mara and Aries had a greater CP concentration than both Barfort and Duo. Tekapo had the greatest ADF and NDF concentrations at the final harvest, while Duo had the greatest CP concentration (Table 32).

Lake City – First production year

Bronson had the greatest ADF and NDF concentrations at the first harvest of the co-culture. Tekapo had a greater CP concentration than Mara. Quartet had a lower ADF concentration than the other cultivars, except for Barfort and Tekapo, at the second harvest. Quartet had a lower NDF concentration than all the other cultivars. Tekapo had a greater CP concentration than Mara. Tekapo also had the lowest ADF and NDF values at the third harvest. Quartet and Tekapo had greater CP values than Mara and Bronson. At the final harvest, Quartet had a lower ADF and NDF values than the other cultivars, except Aries and Duo. Crude protein values were similar among cultivars (Table 33).

Quartet had the lowest ADF concentration at the first harvest of the monoculture. Bronson and Tekapo had the greatest NDF concentrations. Quartet had a greater CP value than Mara, Bronson, and Duo. Bronson had a lower ADF value than the other cultivars, except Mara, at the second harvest. Quartet had a lower NDF value than all the other cultivars. Quartet, Bronson, and Duo had the greatest CP values. At the third harvest, Tekapo had a greater ADF concentration than Quartet, Aries, and Bronson. Quartet, Duo, and Tekapo had greater NDF concentrations than Bronson. Bronson had higher CP values than Quartet and Duo. Quartet had the lowest ADF values at the fourth harvest, while Tekapo had the largest NDF value. Quartet had greater CP values than both Mara and Tekapo (Table 34).

Chatham – First production year

There is no data for the first production year of the co-culture because it was reseeded. In the monoculture, Barfort had a greater ADF concentration than all the other cultivars, except Tekapo, at the first harvest. Quartet had the lowest NDF concentrations. Aries

and Quartet had greater CP concentrations than Bronson and Duo. At the second harvest, Barfort and Duo had greater ADF values than Aries and Quartet. Quartet also had a lower NDF value than the other cultivars. Crude protein concentrations were similar among cultivars. Duo and Tekapo had a greater ADF value than Mara at the third harvest. Tekapo had the greatest ADF concentration. Aries had a greater CP concentration than Aries (Table 35).

ADF and NDF levels were lower and CP levels were higher in the co-culture than the monoculture. This was expected as clovers are known to be higher in protein and lower in fiber than cool-season grasses. Other research also found that a grass/legume mixture has improved forage quality over a grass monoculture (Sleugh et al., 2000; Zemenchick et al., 2002).

Perennial ryegrass cultivars were compared in the grass monoculture to determine if there were differences in forage quality. Overall, Quartet had lower ADF and NDF values. This supports research by Pysher and Fales (1992) that tetraploid perennial ryegrass is more digestible than diploid perennial ryegrass. Crude protein values were similar among the perennial ryegrass cultivars at half of the harvest events. When there were significant differences, Quartet often had a greater CP concentration than Mara.

Duo had similar ADF, NDF, and CP concentrations as perennial ryegrass. This would be expected as it is a cross between perennial ryegrass and meadow fescue, bred for high forage quality and improved persistence. Tekapo and Bronson had similar ADF and NDF concentrations which were greater than the perennial ryegrass cultivars. Baker et al. (1988) also found tall fescue and orchardgrass had similar ADF concentrations

when grazed. Unlike Baker et al. (1988), CP was not lower for tall fescue than for orchardgrass during spring grazing, but was similar for both grass species throughout the grazing season. Research by Jensen et al. (2003) found perennial ryegrass had higher CP and lower NDF concentrations than orchardgrass, which was also true in this study.

Perennial ryegrass had greater forage quality than the tall fescue and orchardgrass cultivars. This is important because animal performance is highly influenced by intake, nutrient concentration, and digestibility. Voluntary intake is correlated with laboratory measures of NDF, such that increased NDF concentrations mean decreased dry matter intake (Casler and Vogel, 1999). As ADF increases, digestibility of forage usually decreases (Pond et al, 1995).

Table 25. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Hickory Corners at each of the five harvests during the establishment year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	ADF	225 A [‡]	207 BC	188 D	197 CD	212 B	212 B	189 D	204	6.2
	NDF	422 A	381 B	320 C	364 B	379 B	390 AB	326 C	369	15.5
	CP	237 D	254 CD	294 AB	278 BC	260 CD	262 BCD	312 A	271	16.0
2	ADF	255 A	230 BC	223 BC	234 BC	239 AB	232 BC	217 C	233	10.0
	NDF	469 A	426 B	419 B	446 AB	466 A	435 AB	410 B	439	20.0
	CP	162 C	192 BC	203 BC	192 BC	212 B	206 BC	262 A	204	21.9
3	ADF	280 A	281 A	233 C	249 ABC	245 BC	265 AB	238 BC	256	15.5
	NDF	519 A	503 A	413 C	440 BC	435 BC	457 ABC	409 C	454	31.1
	CP	198 AB	158 B	227 A	195 AB	237 A	205 AB	236 A	208	21.6
4	ADF	249 AB	279 AB	232 B	229 B	240 AB	293 A	245 AB	252	26.5
	NDF	466 AB	534 A	410 B	437 B	437 B	436 B	454 AB	453	40.0
	CP	222 B	226 AB	255 AB	248 AB	257 A	239 AB	259 A	244	16.7
5	ADF	237 AB	250 A	207 C	244 A	244 A	213 BC	246 A	234	12.3
	NDF	452 AB	508 A	392 BC	480 A	494 A	380 C	485 A	456	28.1
	CP	207 BC	179 D	228 AB	207 BC	192 CD	243 A	214 BC	210	11.4

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 26. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Hickory Corners at each of the five harvests during the establishment year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	ADF	229 A [‡]	218 AB	210 B	220 AB	213 AB	208 B	209 B	215	6.0
	NDF	341 AB	357 A	337 AB	344 AB	346 AB	318 B	341 AB	340	11.3
	CP	280 AB	265 B	267 AB	266 B	268 AB	286 AB	288 A	274	10.5
2	ADF	257 A	242 AB	231 B	228 B	260 A	243 AB	226 B	241	9.2
	NDF	438 AB	423 BC	415 BC	403 C	464 A	424 BC	408 BC	425	15.0
	CP	189 AB	182 B	179 B	185 AB	175 B	183 AB	229 A	189	23.1
3	ADF	295 A	289 A	295 A	249 B	282 AB	288 A	266 AB	280	16.5
	NDF	470 A	482 A	464 A	405 B	470 A	452 AB	457 AB	457	26.4
	CP	163 AB	149 B	198 A	174 AB	173 AB	183 AB	183 AB	175	17.5
4	ADF	315 AB	295 AB	333 A	263 B	302 AB	276 B	308 AB	299	18.9
	NDF	494 ABC	477 ABC	508 AB	420 C	494 ABC	431 BC	537 A	480	30.0
	CP	188 A	190 A	188 A	215 A	184 A	216 A	182 A	195	17.3
5	ADF	236 ABC	234 ABC	215 BC	205 C	241 AB	217 BC	256 A	229	18.3
	NDF	386 CD	403 BC	354 DE	342 E	438 AB	368 CDE	470 A	394	17.5
	CP	206 AB	192 BC	233 A	230 A	176 C	218 AB	197 BC	207	13.6

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 27. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Lake City at each of the three harvests during the establishment year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)	Mean S.E.
1	ADF	167 B [‡]	183 AB	167 AB	138 C	188 A	166 B	178 AB	169 10.4
	NDF	355 AB	358 AB	340 ABC	306 C	379 A	346 ABC	329 BC	345 19.5
	CP	184 AB	170 B	196 AB	177 AB	178 AB	197 B	212 A	188 17.6
2	ADF	316 AB	315 AB	309 AB	357 A	283 BC	327 A	268 C	311 23.9
	NDF	571 A	567 A	556 A	483 BC	526 BC	589 A	477 C	471 21.4
	CP	149 AB	155 AB	146 AB	140 B	182 A	135 B	182 A	156 18.1
3	ADF	218 A	228 A	222 A	183 B	224 A	219 A	233 A	218 8.8
	NDF	474 AB	495 A	483 AB	428 B	484 AB	464 AB	491 A	474 28.0
	CP	174 A	161 A	184 A	172 A	158 A	193 A	178 A	174 17.5

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 28. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Lake City at each of the three harvests during the establishment year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	ADF	320 A [‡]	324 A	304 A	270 B	316 A	320 A	300 A	308	12.3
	NDF	272 BC	297 B	293 B	242 C	317 B	290 BC	407 A	302	23.9
	CP	242 A	222 ABC	202 C	236 AB	223 ABC	214 BC	236 AB	225	10.5
2	ADF	174 CD	209 ABC	226 AB	166 D	190 BCD	198 ABCD	235 A	200	18.6
	NDF	525 A	519 A	490 A	433 B	504 A	523 A	525 A	503	17.8
	CP	149 C	160 BC	168 ABC	185 AB	169 ABC	156 C	189 A	122	12.7
3	ADF	203 BC	200 BC	163 C	182 C	252 A	196 C	238 AB	174	19.9
	NDF	309 D	350 BC	384 B	298 D	352 BC	322 CD	442 A	306	15.1
	CP	164 AB	154 AB	165 AB	170 A	150 B	173 A	169 AB	164	9.5

67

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

*Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 29. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Chatham at each of the three harvests during the establishment year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	ADF	211 A [‡]	181 B	179 B	169 B	218 A	172 B	209 A	191	6.7
	NDF	398 A	351 B	340 BC	309 C	403 A	320 BC	341 BC	352	16.1
	CP	129 B	138 B	132 B	136 B	135 B	143 B	191 A	143	7.2
2	ADF	290 A	292 A	285 A	278 A	292 A	293 A	281 A	287	7.9
	NDF	467 A	495 A	455 A	481 A	493 A	498 A	451 A	477	23.5
	CP	138 ABC	114 BC	123 BC	110 C	113 C	164 A	145 AB	130	15.6
3	ADF	257 AB	265 AB	260 AB	254 B	259 AB	249 B	272 A	259	8.3
	NDF	443 AB	490 A	416 B	424 B	436 AB	449 AB	460 AB	445	27.0
	CP	187 AB	166 B	202 A	197 A	178 AB	206 A	188 AB	189	14.3

[†] Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡] Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 30. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Chatham at each of the four harvests during the establishment year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	ADF	210 A [‡]	204 AB	195 B	174 C	198 AB	206 AB	201 AB	171	5.9
	NDF	330 AB	338 A	315 B	288 C	328 AB	247 D	317 B	309	7.6
	CP	240 B	218 CD	230 BC	232 BC	242 B	210 D	286 A	237	7.4
2	ADF	391 A	405 A	400 A	390 A	339 B	411 A	400 A	391	10.5
	NDF	589 C	624 AB	596 BC	591 C	517 D	609 ABC	630 A	594	14.2
	CP	49 B	40 B	46 B	48 B	71 A	40 B	72 A	53	4.7
3	ADF	274 B	270 B	270 B	268 B	260 B	266 B	323 A	276	7.8
	NDF	445 B	430 B	441 B	436 B	441 B	426 B	572 A	456	9.7
	CP	119 A	136 A	116 A	126 A	130 A	114 A	118 A	123	11.1
4	ADF	210 BC	216 BC	218 BC	221 BC	239 B	200 C	276 A	226	14.6
	NDF	364 C	371 C	362 C	365 C	440 B	352 C	492 A	392	9.9
	CP	166 A	156 A	139 A	159 A	132 A	168 A	166 A	155	18.0

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 31. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Hickory Corners at each of the four harvests during the first production year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	ADF	191 B [‡]	206 B	189 B	194 B	228 A	197 B	230 A	205	8.5
	NDF	314 D	369 BC	305 D	324 D	426 A	340 CD	405 AB	355	18.8
	CP	224 A	210 A	252 A	245 A	204 A	242 A	234 A	230	24.0
2	ADF	214 CD	260 A	231 BCD	208 D	232 BC	227 BCD	249 AB	232	11.6
	NDF	330 CD	470 A	376 BCD	317 D	394 BC	365 BCD	419 AB	381	32.1
	CP	240 AB	166 C	217 B	257 A	228 AB	230 AB	214 B	221	14.7
3	ADF	241 C	270 AB	251 BC	257 ABC	278 A	252 BC	266 AB	259	10.6
	NDF	365 D	473 AB	396 CD	421 BCD	512 A	411 BCD	453 ABC	433	31.1
	CP	231 A	201 BC	230 A	211 AB	177 C	220 AB	216 AB	212	12.2
4	ADF	210 B	220 B	201 B	210 B	252 A	201 B	247 A	220	9.5
	NDF	315 BC	396 AB	306 C	351 BC	472 A	311 C	444 A	371	40.5
	CP	207 B	209 B	230 A	211 AB	163 D	217 AB	183 C	203	9.7

[†] Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡] Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 32. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Hickory Corners at each of the four harvests during the first production year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)	S.E.
1	ADF	208 BC [‡]	212 BC	191 C	189 C	240 A	197 BC	216 B	7.8
	NDF	345 BC	365 B	327 C	333 BC	410 A	362 BC	415 A	17.7
	CP	261 AB	226 CD	237 BCD	263 A	236 CD	214 D	251 ABC	12.4
2	ADF	293 AB	269 B	275 AB	223 C	277 AB	281 AB	299 A	12.0
	NDF	485 AB	451 B	451 B	390 C	458 B	469 AB	509 A	20.2
	CP	148 AB	148 B	156 AB	146 B	186 A	161 AB	150 AB	18.9
3	ADF	245 C	261 BC	322 A	273 BC	272 BC	321 A	293 AB	16.1
	NDF	407 B	435 B	518 A	460 AB	466 AB	520 A	507 A	30.0
	CP	221 A	221 A	177 C	203 ABC	198 ABC	187 BC	208 AB	11.6
4	ADF	224 C	222 C	249 B	251 B	248 B	224 C	288 A	1.7
	NDF	390 C	402 C	444 B	436 B	462 B	372 C	542 A	3.3
	CP	208 ABC	184 CDE	199 BCD	215 AB	158 E	226 A	177 DE	13.2

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 33. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for co-culture samples at Lake City at each of the four harvests during the first production year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	ADF	202 B [‡]	208 B	201 B	182 B	241 A	211 B	210 B	208	14.1
	NDF	396 BC	436 B	407 B	328 C	501 A	403 B	385 BC	408	34.0
	CP	151 AB	146 B	156 AB	168 AB	172 AB	179 AB	189 A	166	19.3
2	ADF	273 A	255 A	240 AB	208 B	270 A	262 A	251 AB	251	21.5
	NDF	484 A	495 A	449 A	352 C	516 A	465 A	444 AB	458	36.0
	CP	166 AB	128 B	164 AB	142 AB	173 AB	158 AB	196 A	161	22.6
3	ADF	225 BC	268 A	253 AB	210 C	272 A	256 AB	213 C	242	15.4
	NDF	388 BC	521 A	456 AB	343 C	514 A	467 AB	337 C	432	38.5
	CP	244 ABC	202 CD	232 ABCD	263 AB	185 D	222 BCD	271 A	231	23.5
4	ADF	246 AB	284 A	275 A	231 B	279 A	254 AB	284 A	265	19.2
	NDF	474 BC	568 A	534 AB	422 C	532 AB	485 ABC	534 AB	507	31.5
	CP	175 A	157 A	166 A	198 A	157 A	187 A	152 A	146	23.1

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 34. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Lake City at each of the four harvests during the first production year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	ADF	267 A [‡]	235 BC	222 C	186 D	250 AB	243 BC	236 BC	234	10.6
	NDF	354 B	361 B	295 B	320 B	433 A	331 B	457 A	364	33.2
	CP	235 AB	224 B	240 AB	250 A	232 B	226 B	235 AB	234	12.4
2	ADF	280 AB	266 BC	286 AB	290 AB	236 C	308 A	277 AB	277	15.5
	NDF	457 A	409 BC	386 C	324 D	423 B	417 B	414 BC	404	14.2
	CP	186 B	191 B	196 B	233 A	234 A	190 B	234 A	209	5.9
3	ADF	272 BC	314 AB	297 ABC	262 C	263 C	308 AB	337 A	293	21.0
	NDF	458 AB	452 AB	479 AB	486 A	423 B	501 A	510 A	473	28.9
	CP	193 AB	198 AB	191 AB	174 B	224 A	178 B	211 AB	196	18.5
4	ADF	210 A	204 AB	195 B	174 C	198 AB	206 AB	201 AB	198	6.3
	NDF	429 CD	513 B	475 BC	408 D	440 CD	489 BC	604 A	480	30.0
	CP	172 AB	132 C	165 ABC	196 A	183 AB	162 ABC	145 BC	165	18.9

[†] Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡] Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Table 35. Acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) values for grass samples at Chatham at each of the three harvests during the first production year. Units for all analyses are g kg⁻¹.

Harvest Number	Type of Analysis	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	ADF	167 BC [‡]	163 C	176 BC	158 C	235 A	174 BC	202 AB	182	17.5
	NDF	355 BC	329 C	360 BC	283 D	457 A	328 C	419 AB	362	32.2
	CP	154 A	119 ABC	116 ABC	143 A	94 BC	87 C	136 AB	121	21.0
2	ADF	300 C	308 BC	335 A	290 C	326 AB	332 A	321 AB	316	9.1
	NDF	494 C	512 BC	547 AB	437 D	540 ABC	522 BC	580 A	519	22.9
	CP	122 A	102 A	92 A	120 A	102 A	93 A	123 A	108	15.8
3	ADF	325 AB	294 B	301 AB	326 AB	326 AB	340 A	338 A	321	19.6
	NDF	486 C	504 BC	494 BC	519 BC	546 BC	549 B	627 A	532	30.0
	CP	153 A	137 AB	133 AB	115 AB	117 AB	106 B	120 AB	126	19.0

[†] Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡] Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

CONCLUSIONS

This study indicates that perennial ryegrass can be grown throughout Michigan successfully if cultivars are chosen carefully. Although past research has shown that diploid cultivars have greater cold tolerance than tetraploid cultivars, this research indicates that winter survival may depend more on location origin than ploidy level. Mara and Barfort, both European cultivars, typically had less winter injury than the New Zealand cultivars, Aries and Quartet. This is important because less winter injury is an important factor in stand persistence. Aries and Quartet would persist in Michigan as long as the winters remained mild. Although Mara and Barfort are able to withstand harsh winter conditions, more research is needed to determine the length of time these cultivars can persist in Michigan. The ability to germinate in cold temperatures was not indicative of how grasses would perform in the field, and should not be used to determine how plants will respond to cold stress.

Winter injury was inversely related to spring ground cover and first harvest yields. However, as the season progressed and the grass recovered from the injury, differences in ground cover and yield were not as apparent. By choosing an adapted cultivar, a producer could grow perennial ryegrass and still have high yields even in a more northern region of Michigan. First harvest yields were decreased by winter injury, however, so a producer should rely on a more winter hardy species such as tall fescue or orchardgrass for the first grazing event to be safe. Although this research did not show co-cultures to have a yield advantage over monocultures, there was less variability in yield throughout the season for the co-cultures. This would be important especially

during the warm, dry summer months when the cool-season grasses become less productive.

The four perennial ryegrass cultivars typically had similar amounts of clover, although Mara had less clover than Barfort. The results of this study indicate that grass density is an important factor in legume compatibility. Barfort and Duo were less dense than Mara and had a greater amount of clover present. Since ADF and NDF levels were lower and CP levels were higher in the co-culture than the monoculture it appears that presence of clover has a positive affect on forage quality. To take full advantage of a mixture, a producer would need to plant grasses compatible with clover.

There were no palatability differences among perennial ryegrass cultivars. Bronson was less palatable on only a few occasions, probably because grasses were grazed before they matured. Producers could increase palatability by grazing earlier, or by including a legume. In this study, the same cultivars had higher palatability scores when grown in association with ladino white clover than without.

Forage quality was the greatest among the perennial ryegrass cultivars and Duo, with Quartet having the lowest ADF and NDF concentrations and often having higher CP concentrations. Although previous studies have found differences in quality between diploid and tetraploid cultivars, a greater number of cultivars need would need to be researched in this case to determine if differences do exist. Even though Quartet was a high quality cultivar, it is not well adapted to Michigan unless winter conditions are mild. A producer should determine whether quality or persistence is more important for their operation, and plant a species and cultivar which excel in the desired characteristics. Bronson and Tekapo were considered to have the lowest quality, but since it is adapted

throughout Michigan producers could include a legume to increase quality and palatability. If planting a monoculture, Barfort and Mara would be able to withstand a harsh Michigan winter.

Although producers should plant a variety of species, this research indicates that Michigan producers would benefit by including an adapted perennial ryegrass cultivar such as Mara or Barfort in their operation. These cultivars have high yields and better forage quality than Bronson and Tekapo, but will persist better than Aries or Quartet when exposed to harsh winter temperatures. Duo, festulolium, would also benefit producers as it has good forage quality like perennial ryegrass and is winter hardy like fescue. Even though co-cultures had no yield advantage over monocultures, the yields were less variable throughout the season. Co-cultures also had better forage quality and less winter injury than monocultures.

APPENDIX

Appendix Table 1A. Fertilizer application dates at each location for both years of the trial.

Location	Application Dates	
	Establishment Year	First Production Year
W. K. Kellogg Biological Station Hickory Corners, MI	22 April 2002 21 May 2002 22 August 2002 5 November 2002	4 March 2003 21 May 2003 24 June 2003 15 September 2003
Lake City Experiment Station Lake City, MI	28 March 2002 23 May 2002 28 June 2003 31 October 2002	2 March 2003 27 May 2003 23 June 2003 3 September 2003
Upper Peninsula Experiment Station Chatham, MI	3 May 2002 7 June 2002 31 July 2002 16 October 2002	25 April 2003 9 June 2003 14 July 2003 20 August 2003

Appendix Table 2A. Data collection dates for all locations and years of the trial.

Year	Location	Winter Injury	Ground Cover	Clover Rating	Tiller Counts	Harvest	Palatability Rating	Disease Rating
Establishment (2002)	Hickory Corners	10 April	18 April 5 November	22 April 5 November	22 April 5 November	22 April	24 April	No disease observed
						14 May	18 May	
						7 June	10 June	
						15 August	19 August	
	Lake City	15 April	30 April 31 October	30 April 31 October	30 April 17 October	10 October	15 October	No disease observed
						17 May	20 May	
						17 June	19 June	
						17 October	n/a [†]	
	Chatham	3 June	3 June 28 August	7 July [†] 4 October	3 June 28 August	3 June	7 June	No disease observed
						15 July	18 July	
						29 August	31 August	
						9 October	11 October	
First Production (2003)	Hickory Corners	23 April	29 April 31 August	12 June 31 August	7 May 31 August	7 May	9 May	19 August
						10 June	12 June	
						17 July	24 July	
						10 September	16 September	
	Lake City	2 May	12 May 1 October	12 May 1 October	12 May 27 August	19 May	23 May	1 October
						17 June	23 June	
						24 July	27 July	
						27 August	n/a [†]	
	Chatham	6 May	4 June 4 October	n/a [†] n/a	4 June 4 October	4 June	6 June	4 October
						7 July	10 July	
						14 August	18 August	

[†]The co-culture portion of was reseeded at Chatham, so establishment ratings are from 2003 instead of 2002. There are no first production year ratings for the co-culture at Chatham.

[‡]Cattle not available for grazing.

Appendix Table 3A. Cattle description, number of cattle used, and number of grazing events at each location for both years.

Location	Establishment Year					First Production Year				
	No. of Grazing Events	Type of Cattle	No. of Cattle	Average Weight (kg)	Stocking Density (AU ha ⁻¹)	No. of Grazing Events	Type of Cattle	No. of Cattle	Average Weight (kg)	Stocking Density (AU ha ⁻¹)
Hickory Corners	5	Dairy	12 cows	723	58.1	4	Dairy	5 steers	314	13.8
Lake City	3	Beef	17 cows 9 heifers 19 calves	748 544 206	99.7	4	Beef	20 cows 5 heifers 18 calves	759 521 202	99.1
Chatham	4	Dairy	8 cows	635	34.0	3 [†]	Dairy	8 cows	650	34.8

[†]The establishment year for the co-culture portion at Chatham was 2002-2003 because it was reseeded, so cattle information is the same as the first production year for the monoculture portion.

Table 4A. Analysis of variance table for co-culture winter injury.

Effect	Num DF	Den DF	F value	Pr > F
Year	1	10	6.81	0.0261
Location	2	10	2.02	0.1830
Year*Location	1	10	0.08	0.7778
Treatment	6	60	4.69	0.0006
Year*Treatment	6	60	1.51	0.1894
Location*Treatment	12	60	2.22	0.0215
Year*Location*Treatment	6	60	1.70	0.1368

Table 5A. Analysis of variance table for grass winter injury.

Effect	Num DF	Den DF	F value	Pr > F
Year	1	82	229.82	<.0001
Location	2	82	10.13	0.0001
Year*Location	2	82	11.55	<.0001
Treatment	6	82	43.82	<.0001
Year*Treatment	6	82	32.99	<.0001
Location*Treatment	12	82	3.82	0.0001
Year*Location*Treatment	12	82	3.96	<.0001

Appendix Table 6A. Monthly minimum and maximum air temperatures (°C) at all locations for the establishment year, first production year, and 30 year average.

Year	Month	Hickory Corners		Lake City		Chatham	
		Min	Max	Min	Max	Min	Max
Establishment (2001-2002)	Aug	14.3	25.8	12.5	20.2	10.5	23.1
	Sep	10.4	22.7	7.3	19.3	6.6	18.4
	Oct	6.5	16.9	2.1	13.3	0.0	13.4
	Nov	4.0	14.4	0.7	10.7	-0.4	8.7
	Dec	-0.9	6.1	-4.0	3.1	-6.2	2.3
	Jan	-3.7	4.8	-7.3	0.9	-9.7	-0.7
	Feb	-3.8	5.9	-10.0	1.4	-11.2	-0.3
	Mar	-4.2	7.2	-8.8	1.7	-12.2	-0.2
	Apr	4.2	16.8	-0.3	11.2	-1.9	7.8
	May	6.6	19.7	3.1	15.1	0.8	12.9
	Jun	15.2	29.2	12.2	24.1	8.9	22.8
	Jul	17.9	32.1	15.1	29.5	13.0	28.5
First Production (2002-2003)	Aug	16.2	29.2	11.7	26.4	10.6	24.4
	Sep	12.8	27.9	8.5	24.7	8.5	22.4
	Oct	5.0	15.8	0.7	11.4	-1.2	10.1
	Nov	0.1	7.9	-3.9	4.5	-7.8	2.8
	Dec	-5.4	2.5	-8.9	0.5	-11.3	-0.3
	Jan	-9.8	-2.0	-12.6	-4.8	-15.6	-4.7
	Feb	-10.1	0.3	-15.4	-3.9	-18.4	-5.3
	Mar	-3.2	10.3	-9.3	4.3	-12.8	1.2
	Apr	3.3	18.0	-2.3	11.0	-5.8	7.4
	May	7.9	20.8	5.6	17.5	1.1	17.6
	Jun	12.1	27.3	8.6	23.4	6.4	22.3
	Jul	15.2	29.8	12.0	25.2	9.7	26.3
30 Year Average (1971-2000)	Aug	15.6	27.9	11.4	25.1	11.7	24.9
	Sep	11.4	23.8	6.9	20.3	7.7	20.6
	Oct	5.6	17.1	1.6	13.5	1.9	13.3
	Nov	0.3	8.9	-3.3	5.5	-3.6	4.8
	Dec	-5.6	2.1	-9.3	-0.8	-9.6	-1.0
	Jan	-8.8	-0.4	-13.0	-3.4	-12.7	-3.3
	Feb	-8.1	1.9	-12.8	-1.5	-12.4	-1.2
	Mar	-3.2	8.1	-7.9	3.9	-8.3	3.6
	Apr	2.4	15.3	-0.9	11.4	-2.3	10.4
	May	8.6	22.2	4.8	19.3	3.7	18.9
	Jun	13.8	27.2	9.8	24.2	9.2	24.3
	Jul	16.3	29.2	12.3	26.6	11.6	25.6

Appendix Table 7A. Monthly rainfall (mm) at all locations for the establishment year, first production year, and 30 year average.

Year	Month	Hickory Corners	Lake City	Chatham
Establishment (2001-2002)	Aug	147.8	91.4	99.3
	Sep	125.2	101.4	103.6
	Oct	195.8	150.4	115.3
	Nov	52.1	51.1	60.5
	Dec	71.1	33.3	42.9
	Jan	58.4	15.2	18.0
	Feb	51.1	42.4	39.9
	Mar	55.4	73.2	73.2
	Apr	82.6	87.6	112.5
	May	114.1	55.1	90.7
	Jun	51.8	70.8	98.3
	Jul	109.0	40.1	126.0
	Annual	1114.4	812.0	980.2
First Production (2002-2003)	Aug	146.1	76.2	150.1
	Sep	43.4	14.7	82.8
	Oct	58.7	58.7	158.2
	Nov	52.1	27.2	50.0
	Dec	60.5	15.8	21.8
	Jan	23.4	16.8	39.4
	Feb	28.5	16.5	31.8
	Mar	47.5	29.7	65.5
	Apr	77.2	78.5	68.6
	May	158.5	79.5	120.4
	Jun	62.7	49.8	49.5
	Jul	74.2	12.2	76.5
	Annual	832.8	475.6	914.6
30 Year Average (1971-2000)	Aug	99.8	92.9	53.9
	Sep	107.7	94.6	33.3
	Oct	78.6	74.7	51.0
	Nov	84.4	63.0	47.9
	Dec	75.5	45.7	69.1
	Jan	54.0	40.0	82.9
	Feb	44.3	30.4	92.7
	Mar	67.0	51.1	91.0
	Apr	96.9	70.4	99.2
	May	88.8	70.8	84.8
	Jun	96.0	75.0	78.8
	Jul	93.6	72.8	55.9
	Annual	986.6	781.4	840.5

Appendix Table 8A. Number of days with snow depth ≥ 2.5 cm by month at all locations for the establishment year, first production year and 30 year average.

Year	Location	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Annual
Establishment (2001-2002)	Hickory Corners	0	0	0	0	10	24	17	9	0	0	0	0	60
	Lake City	0	0	2	3	13	24	26	23	5	0	0	0	96
	Chatham	0	0	2	6	12	31	23	31	13	0	0	0	118
First Production (2002-2003)	Hickory Corners	0	0	0	5	22	25	26	14	3	0	0	0	122
	Lake City	0	0	0	4	24	25	28	20	7	0	0	0	108
	Chatham	0	0	3	11	27	24	28	31	15	0	0	0	139
30 Year Average (1971-2000)	Hickory Corners	0	0	0	3	16	22	18	7	1	0	0	0	67
	Lake City	0	0	1	9	24	30	27	21	4	0	0	0	116
	Chatham	0	0	1	11	27	31	28	29	11	0	0	0	138

Appendix Table 9A. Analysis of variance table for co-culture ground cover.

Effect	Num DF	Den DF	F Value	Pr > F
Year	1	10	8.68	0.0146
Location	2	10	5.47	0.0248
Year*Loc	1	10	2.81	0.1244
Trt	6	60	5.41	0.0002
Year*Trt	6	60	0.84	0.5425
Loc*Trt	12	60	2.89	0.0033
Year*Loc*Trt	6	60	2.48	0.0331
Season	1	70	191.53	<.0001
Year*Season	1	70	112.49	<.0001
Loc*Season	2	70	41.22	<.0001
Year*Loc*Season	1	70	9.48	0.0030
Trt*Season	6	70	4.69	0.0005
Year*Trt*Season	6	70	6.03	<.0001
Loc*Trt*Season	12	70	3.61	0.0003
Year*Loc*Trt*Season	6	70	2.15	0.0578

Appendix Table 10A. Analysis of variance table for grass ground cover.

Effect	Num DF	Den DF	F Value	Pr > F
Year	1	12	16.25	0.0017
Location	2	12	1.99	0.1799
Year*Loc	2	12	12.68	0.0011
Trt	6	72	11.65	<.0001
Year*Trt	6	72	3.70	0.0029
Loc*Trt	12	72	2.09	0.0278
Year*Loc*Trt	12	72	2.23	0.0190
Season	1	82	69.26	<.0001
Year*Season	1	82	57.51	<.0001
Loc*Season	2	82	0.58	0.5612
Year*Loc*Season	2	82	9.08	0.0003
Trt*Season	6	82	4.89	0.0003
Year*Trt*Season	6	82	2.76	0.0170
Loc*Trt*Season	12	82	0.69	0.7605
Year*Loc*Trt*Season	12	82	0.79	0.6577

Appendix Table 11A. Analysis of variance table for co-culture tiller counts.

Effect	Num DF	Den DF	F Value	Pr > F
Year	1	10	10.79	0.0082
Location	2	10	45.16	<.0001
Year*Loc	1	10	18.58	0.0015
Trt	6	60	9.00	<.0001
Year*Trt	6	60	1.41	0.2250
Loc*Trt	12	60	2.26	0.0196
Year*Loc*Trt	6	60	0.69	0.6565
Season	1	70	20.31	<.0001
Year*Season	1	70	64.19	<.0001
Loc*Season	2	70	58.80	<.0001
Year*Loc*Season	1	70	10.33	0.0020
Trt*Season	6	70	0.87	0.5191
Year*Trt*Season	6	70	2.27	0.0465
Loc*Trt*Season	12	70	2.60	0.0064
Year*Loc*Trt*Season	6	70	0.63	0.7075

Appendix Table 12A. Analysis of variance table for grass tiller counts.

Effect	Num DF	Den DF	F Value	Pr > F
Year	1	12	22.95	0.0004
Location	2	12	47.15	<.0001
Year*Loc	2	12	2.91	0.0935
Trt	6	72	10.34	<.0001
Year*Trt	6	72	0.64	0.6999
Loc*Trt	12	72	1.31	0.2302
Year*Loc*Trt	12	72	1.26	0.2624
Season	1	84	33.65	<.0001
Year*Season	1	84	116.50	<.0001
Loc*Season	2	84	81.41	<.0001
Year*Loc*Season	2	84	171.63	<.0001
Trt*Season	6	84	2.42	0.0332
Year*Trt*Season	6	84	1.17	0.3324
Loc*Trt*Season	12	84	3.17	0.0009
Year*Loc*Trt*Season	12	84	3.36	0.0005

Appendix Table 13A. Analysis of variance table for co-culture clover ratings.

Effect	Num DF	Den DF	F Value	Pr > F
Year	1	10	16.99	0.0021
Location	2	10	83.76	<.0001
Year*Loc	1	10	5.27	0.0445
Trt	6	60	8.80	<.0001
Year*Trt	6	60	5.22	0.0002
Loc*Trt	12	60	1.01	0.4494
Year*Loc*Trt	6	60	1.05	0.4001
Season	1	70	18.73	<.0001
Year*Season	1	70	18.20	<.0001
Loc*Season	2	70	39.98	<.0001
Year*Loc*Season	1	70	22.44	<.0001
Trt*Season	6	70	2.02	0.0738
Year*Trt*Season	6	70	1.32	0.2615
Loc*Trt*Season	12	70	3.77	0.0002
Year*Loc*Trt*Season	6	70	0.50	0.8087

Appendix Table 14A. Botanical composition at Hickory Corners for the establishment year. Component means (n=3) are in grams.

Harvest Number	Botanical Component	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	Grass	1196 B [‡]	749 C	669 C	1100 B	940 BC	1387 A	845 BC	984	176.1
	Legume	95 B	255 B	366 A	271 AB	350 A	255 B	510 A	300	119.8
	Weed	95 B	127 AB	255 AB	127 AB	287 A	95 B	143 AB	161	80.4
2	Grass	2443 A	1410 BC	1234 BC	1884 AB	1424 BC	1872 AB	982 C	1607	325.0
	Legume	26 B	209 A	280 A	174 A	156 AB	220 A	295 A	194	69.7
	Weed	107 AB	84 B	122 AB	123 AB	257 A	67 B	142 AB	129	74.9
3	Grass	1791 A	1642 AB	1045 B	1105 AB	1232 AB	1067 B	879 B	1252	343.3
	Legume	430 A	306 A	608 A	449 A	589 A	449 A	612 A	492	15.6
	Weed	35 BC	17 C	41 ABC	30 BC	69 A	23 BC	55 AB	39	16.1
4	Grass	1000 ABC	1392 A	757 C	921 BC	1287 AB	861 BC	1324 AB	1077	231.5
	Legume	390 B	1369 A	541 B	257 B	373 B	531 B	356 A	545	142.6
	Weed	59 A	8 A	24 A	10 A	51 A	42 A	68 A	37	30.2
5	Grass	946 AB	956 AB	597 B	968 AB	1515 A	777 B	986 AB	964	284.7
	Legume	253 AB	91 B	279 AB	208 B	153 B	495 A	161 B	234	121.0
	Weed	30 AB	6 B	58 A	19 AB	20 AB	35 AB	18 AB	27	20.9

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Appendix Table 15A. Botanical composition at Lake City for the establishment year. Component means (n=3) are in grams.

Harvest Number	Botanical Component	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	Grass	1913 AB [‡]	2142 AB	1037 BC	1237 BC	2508 A	2089 AB	816 C	1677	452.5
	Legume	37 B	54 AB	42 AB	54 AB	105 A	68 AB	227 A	84	92.6
	Weed	37 C	97 BC	95 BC	91 BC	196 B	35 C	869 A	203	52.5
2	Grass	2206 BC	2951 A	2425 BC	1834 CD	1693 CD	2531 B	1305 D	1899	366.3
	Legume	63 B	38 B	42 B	183 B	264 B	254 B	637 A	212	113.7
	Weed	62 BC	30 C	28 C	112 BC	264 B	32 C	583 A	159	101.1
3	Grass	1451 AB	1011 B	1131 B	1168 B	980 B	1744 A	1446 AB	1276	235.8
	Legume	45 B	19 B	55 B	30 B	41 B	97 AB	180 A	67	41.5
	Weed	35 B	16 B	24 B	44 B	41 B	19 B	92 A	39	14.3

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Appendix Table 16A. Botanical composition at Chatham for the establishment year. Component means (n=3) are in grams.

Harvest Number	Botanical Component	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	Grass	546 AB [‡]	502 BC	557 AB	726 A	634 AB	456 BC	354 C	539	90.3
	Legume	32 B	25 B	29 B	31 B	67 A	39 AB	38 B	37	14.4
	Weed	12 C	11 C	4 C	3 C	31 AB	20 BC	41 A	17	8.6
2	Grass	19 B	347 B	279 B	295 B	137 B	775 A	245 B	300	164.9
	Legume	121 C	224 ABC	411 A	271 ABC	185 BC	229 ABC	352 AB	256	93.5
	Weed	1 A	4 A	9 A	1 A	36 A	4 B	60 A	16	12.1
3	Grass	726 A	665 A	416 C	583 B	591 AB	314 C	398 C	528	67.7
	Legume	130 D	803 AB	505 BC	411 CD	653 BC	974 A	435 CD	559	152.5
	Weed	25 B	1 B	27 B	44 B	108 A	42 B	11 B	37	22.0

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Appendix Table 17A. Botanical composition at Hickory Corners for the first production year. Component means (n=3) are in grams.

Harvest Number	Botanical Component	Cultivar (Species) [†]								Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)			
1	Grass	.	.	.	.	.	.	.	.	.	.
	Legume	.	.	.	.	.	.	.	.	.	.
	Weed	.	.	.	.	.	.	.	.	.	.
2	Grass	1595 AB [‡]	1279 B	1870 A	1340 AB	921 B	1481 AB	1592 AB	1440	337.1	
	Legume	405 A	808 A	400 A	511 A	702 A	470 A	409 A	529	204.8	
	Weed	24 AB	72 A	91 A	99 A	33 AB	29 AB	1 B	50	37.5	
3	Grass	160 B	681 AB	581 B	452 B	979 A	287 B	759 AB	557	299.4	
	Legume	679 A	253 B	441 AB	586 AB	659 AB	494 AB	466 AB	511	203.3	
	Weed	5 A	14 A	76 A	30 A	5 A	63 A	22 A	31	35.5	
4	Grass	298 BC	380 BC	405 BC	178 C	868 A	253 BC	586 B	424	166.7	
	Legume	482 AB	152 B	272 AB	176 B	465 AB	288 AB	632 A	352	180.2	
	Weed	94 AB	6 C	47 ABC	19 BC	116 A	79 ABC	44 ABC	58	37.5	

[†]Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡]Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Appendix Table 18A. Botanical composition at Lake City for the first production year. Component means (n=3) are in grams.

Harvest Number	Botanical Component	Cultivar (Species) [†]							Mean	S.E.
		Aries (dPR)	Mara (dPR)	Barfort (tPR)	Quartet (tPR)	Bronson (TF)	Duo (Fest)	Tekapo (OR)		
1	Grass	599 BC [‡]	700 AB	506 BC	200 C	1071 A	516 BC	762 AB	622	199.8
	Legume	76 AB	22 B	46 AB	83 AB	26 B	158 A	69 AB	69	44.5
	Weed	221 AB	40 B	68 B	232 AB	120 AB	73 B	357 A	129	118.6
2	Grass	787 AB	599 ABC	779 AB	121 C	1049 A	692 AB	544 BC	653	239.0
	Legume	3 B	2 B	4 B	3 B	49 A	67 A	41 A	24	13.6
	Weed	248 A	4 B	9 B	242 A	52 B	18 B	109 A	97	52.9
3	Grass	531 AB	797 AB	545 AB	288 B	1016 A	281 B	620 AB	583	258.1
	Legume	16 A	1 A	1 A	1 A	1 A	20 A	1 A	6	9.7
	Weed	88 A	1 B	44 B	107 A	36 B	5 B	44 B	46	21.2
4	Grass	1539 A	1047 B	918 B	439 C	1572 A	981 B	926 B	932	102.3
	Legume	38 B	2 B	45 B	62 B	3 B	229 A	40 B	60	30.0
	Weed	212 A	41 B	204 A	313 A	1 B	134 AB	132 AB	148	90.5

[†] Abbreviations are as follows: dPR = diploid perennial ryegrass, tPR = tetraploid perennial ryegrass, TF = tall fescue, Fest = festulolium, and OR = orchardgrass.

[‡] Means in a row followed by the same capital letter are not significantly different within a harvest ($p \leq 0.05$).

Appendix Table 19A. Co-culture palatability scores (n=9) at the first, second, third, and fifth harvests. Scores are averaged across years and location where 1 is least palatable and 5 is most palatable.

Cultivar (species)[†]	Cut 1	Cut 2	Cut 3	Cut 5
Aries (dPR)	5.0 A	4.4 A	4.8 A	5.0 A
Mara (dPR)	4.9 A	4.4 A	4.7 A	5.0 A
Barfort (tPR)	4.9 A	4.3 A	4.1 A	5.0 A
Quartet (tPR)	4.7 A	4.6 A	4.8 A	5.0 A
Bronson (TF)	3.9 B	3.9 A	4.0 A	5.0 A
Duo (Fest)	4.8 A	4.5 A	4.4 A	5.0 A
Tekapo (OR)	4.6 A	4.7 A	4.6 A	5.0 A
Mean	4.7	4.4	4.5	5.0
S.E.	0.2	0.4	0.4	0.1

Appendix Table 20A. Grass palatability scores (n=9) at the first, second, third, and fifth harvests. Scores are averaged across years and location where 1 is least palatable and 5 is most palatable.

Cultivar (species)[†]	Cut 1	Cut 2	Cut 3	Cut 5
Aries (dPR)	4.6 A	4.2 A	4.2 A	5.0 A
Mara (dPR)	4.6 A	4.4 A	3.6 A	5.0 A
Barfort (tPR)	4.7 A	4.4 A	4.0 A	5.0 A
Quartet (tPR)	4.6 A	4.4 A	4.2 A	5.0 A
Bronson (TF)	4.4 A	4.0 A	3.9 A	5.0 A
Duo (Fest)	4.7 A	4.3 A	4.1 A	5.0 A
Tekapo (OR)	4.8 A	4.5 A	4.2 A	5.0 A
Mean	4.6	4.3	4.0	5.0
S.E.	0.2	0.3	0.3	0.1

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