Forage Yield and Quality of Binary Grass-Legume Mixtures of Tall Fescue, Orchardgrass, Meadow Brome, Alfalfa, Birdsfoot Trefoil, and Cicer Milkvetch

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FORAGE YIELD AND QUALITY OF BINARY GRASS-LEGUME MIXTURES OF TALL FESCUE, ORCHARDGRASS, MEADOW BROME, ALFALFA, BIRDSFOOT TREFOIL, AND CICER MILKVETCH

by

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ABSTRACT

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Rising fertilizer prices have led a return to the use of grass-legume mixtures to reduce N costs and improve pasture productivity. The objective of this study was to determine optimal species combinations of binary grass-legume mixtures to improve forage production and pasture nutritive value in irrigated pastures of the Intermountain West. The study was conducted at the Utah State University Intermountain Pasture Research Facility near Lewiston, UT. Tall fescue (TF), orchardgrass (OG), and meadow brome (MB) were grown with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) in legume-grass mixes and monocultures at planting ratios of 25:75, 50:50, 75:25. Grass monocultures were fertilized with 0 (0 N), 67 (67 N), or 134 kg N ha^{-1} (134 N). Forage was harvested four times each season during 2011-2012. Forage of the mixtures and monocultures from the first and third harvests was analyzed for crude protein (CP) and neutral-detergent fiber (NDF). Average forage production of the unfertilized TF, MB, and OG monocultures was 11.03, 9.76, and 8.10 Mg ha^{-1}, respectively. TF-ALF, OG-ALF, and MB-ALF grass-legume mixes averaged 24.0, 35.0, and 41.0% higher forage production than their respective unfertilized grass monocultures. The grass-legume mixtures with the highest CP were MB-ALF 159, TF-ALF 159, and TF-OG-159 g kg^{-1} and averaged 59, 43, and 51% higher than their respective unfertilized grass monocultures. Likewise, the mixtures with the lowest NDF were OG-ALF 453 g kg^{-1}, OG-BFTF 469 g kg^{-1}, and MB-ALF 480 g kg^{-1}. These mixtures had 10, 7, and 18% lower NDF than their respective unfertilized grass monocultures. Individual harvests had similarly higher yields and CP, with lower NDF for the mixtures than the unfertilized grass monocultures. The grass-legume mixtures with the 50:50 planting ratio were most productive and had high forage quality. The grass-legume mixtures had similar forage production as the grass monocultures at 134 kg N ha^{-1}. The grass-legume mixtures also had higher CP and lower NDF than the grass monocultures. Cicer milkvetch did not perform well in irrigated pastures. Grass-legume mixtures with ALF and BFTF can be used to replace commercial N while increasing forage nutritive value.

(117 pages)

PUBLIC ABSTRACT

Forage Yield and Quality of Binary Grass-Legume Mixtures of
Tall Fescue, Orchardgrass, Meadow brome, Alfalfa,
Birdsfoot Trefoil, and Cicer milkvetch

Managed pasture forms the foundation for much of the U.S. livestock production. Increased forage yield and quality can be achieved with nitrogen (N) fertilizer but increases the cost of pasture production. Rising prices of N have led to a return to the use of grass-legume pastures to reduce or replace commercial N fertilizer. There is a need to identify viable grass-legume mixtures and species planting ratios for the region of the Intermountain Western United States. The purpose of this study was to identify grass-legume combinations and planting ratios that maximize forage production and forage quality in irrigated pastures. The grass-legume mixtures produced more forage than their respective unfertilized grass monocultures by: 24% tall fescue (TF)-alfalfa (ALF), 19% TF-birdsfoot trefoil (BFTF), 35% meadow brome (MB)-ALF, 26% MB-BFTF, 41% orchardgrass (OG)-ALF, and 29% OG-BFTF. The CMV mixtures did not increase forage production compared to the unfertilized monoculture. The highest to lowest yielding grass mixtures were TF > MB > OG. The highest yielding legume mixtures were ALF > BFTF > CMV. The grass-legume mixtures had higher CP than the unfertilized mixtures by 37% TF-ALF, 21% TF-BFTF, 57% MB-ALF, 35% MB-BFTF, 47% OG-ALF, and 23% OG-BFTF. Cicer milkvetch only combined well with MB and may not be suitable for irrigated pastures. Individual harvests of the mixtures had similarly higher yields and CP, and lower NDF, than the unfertilized grass monocultures. Relative species composition had an effect on total forage yield, CP, and NDF. Additionally, the grass-legume mixtures of all species were most productive at the 50:50 planting ratio. In conclusion, the grass-legume mixtures were found to produce as much as a pasture fertilized at 134 kg N ha^{-1}. Additionally, a grass-legume pasture will have much higher CP and lower NDF than a fertilized grass pasture. As a result, using grass-legume pastures will reduce or eliminate N applications while providing higher quality forage for livestock.

Steven R Cox

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Steven R Cox

CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

Pastureland refers to land "devoted to the production of indigenous or introduced forage for grazing" (Barnes et al., 1995). In 2007, there were a total of 14.4 million hectares (ha) of pasture in the United States (US) and 163.2 thousand ha of pasture in Utah (NASS, 2007). Managed pasture is used for livestock grazing and forms the foundation of livestock production. With declining acreage of pasture and recent changes in federal grazing policy, there is an increased reliance on private pasture in the summer (Waldron et al., 2002). Ways are being sought to increase forage production in an environmentally sound manner.

In the Intermountain Western US, improved pastures are irrigated and consist, primarily, of one or more species of cool-season grass (Waldron et al., 2002). These irrigated pastures can produce between 900 and 5,500 kg ha of forage per year, depending on the climate and plant species in the pasture (Rinehart, 2006). A goal of pasture production is to optimize forage production for yield, nutritional quality, and pasture longevity while minimizing inputs such as fertilizer and labor. Increased forage yield and quality can be attributed mostly to nitrogen (N) fertilizer and is the most variable cost of pasture production

(Solomon et al., 2011). As commercial N prices continue to rise, an alternative means of increasing production without adding N to pastures is needed.

NITROGEN PRICES

Since the 1950's, commercial fertilizer, particularly N, has been considered the most effect way to increase pasture productivity. Nitrogen can be mobile in the soil profile and is a limiting nutrient in grass pastures (Rogers et al., 1983). Nitrogen deficiency has usually been addressed by the use of commercial fertilizers. However, fertilizer prices, in recent years, have been on the rise. Two main causes have contributed to this phenomenon; 1) recent increases in natural gas prices, and 2) rising global demand for commercial N. In a report written by the United States General Accounting Office, it was estimated that between 46 and 90% of the cost of nitrogen (depending on the type of N) is correlated with the cost of natural gas (GAO, 2003). There has been also been a reduction in domestic nitrogen fertilizer production due to production costs, causing a greater increase in the price of N (GAO, 2003). These conditions have created interest in finding alternative ways to reduce dependence on commercial fertilizer in the U.S. and to improve the economics of N fertilization (Huang, 2007).

GRASS-LEGUME PASTURES

Many studies have documented increases in forage yield and quality of grass-legume pastures over grass monocultures (Rumbaugh et al., 1982; Sleugh et al., 2000; Guldan et al., 2000; Gierus et al., 2012). The use of legumes in grass-legume pastures can increase forage yield and quality of pastures in two ways: 1) fixing N that can then be used by the grasses and 2) directly contributing to overall forage production in the pasture. Forage quality is enhanced as legumes included because they have higher crude protein and lower NDF content than grasses (Van Soest, 1982; Sleugh et al., 2000). As N is fixed, some of it is transferred to plants growing in association with the legume. N transfer to grasses can be through N excretions into the soil by the root of the legume (Ta et al., 1986) or by the decay of stems, roots and nodules (Ta and Faris, 1987b; Dubach and Russelle, 1994). As the neighboring grass absorbs soil N, the reduction in N concentration of the soil can stimulate the bacteria *Rhizobium* associated with legumes to increase the fixation of N_2 (Nyfeler et al., 2011). The amount of N_2 that is fixed by the R*hizobium* can increase as the legumes age (LaRue and Patterson, 1981; Ta and Faris, 1987ab). These actions can reduce or eliminate need for applications of N fertilizer by cool-season grasses to maximize growth. As a result, the production costs of buying and applying N can be minimized while optimizing pasture production (Sleugh et al., 2000).

Forage production of cool-season species is greatest in the spring, with some growth occurring in the fall. In the summer months when temperatures are hottest, a 'summer slump' or period of reduced growth or grass dormancy is exhibited. Some of the ways that have been found to reduce and evenly distribute the amount of forage in cool-season grass pastures include: the use of irrigation (Waldron et al., 2002), nitrogen applications as needed to maintain soil N levels (Sweeney et al., 1995), or by planting forage legumes which actively grow in July and August. These plants compensate for the 'summer slump' of cool-season grasses during this time period and can improve the seasonal distribution of pasture forage, thereby increasing the number of livestock that can by supported (Rumbaugh et al., 1982; Hoveland and Richardson, 1992; Sleugh et al., 2000).

The estimated total amount of N needed by a grass pasture in the Intermountain West is between 114 and 170 kg per ha (Koenig et al., 2002). Kroth et al. (1982) estimated that birdsfoot trefoil (*Lotus corniculatus* L.) (BFTF) and alfalfa (*Medicago sativa* L.) (ALF) annually fix 115 and 200 kg N ha^{-1} respectively and release it into the soil. This would be sufficient to meet all or most, if not all, of the needs described by Koenig et al. (2002). Similarly, Malhi et al. (2002) showed that the contribution of N by ALF to a smooth brome (*Bromus inermus* Leyss.) stand reduced needed applications of N fertilizer requirement by 100 kg ha^{-1} in a single growing season. Similar results of N transfer by ALF and BFTF to correlated grasses were found by Heichel and Henjum (1991).

When adequate water is available, forage legumes can compensate for the 'summer slump' when grown in combination with cool-season grasses. In a study conducted by Sleugh et al. (2000), ALF, and BFTF grown in binary mixtures with grasses, both showed 100% higher yields than the grass monocultures in the hot summer months. Furthermore, legumes raise the forage protein content of the grass-legume mixtures both because legumes inherently contain more protein, and because the fixed N transferred from the legumes to the grass can increase the protein of the grass (Tewari and Schmid, 1960). Forage quality of pasture mixes are directly correlated to the legume component (Gierus et al., 2012; Kleen et al., 2011; Mallarino and Wedin, 1990). Grass-legume mixtures reflect this by having higher forage quality than monocultures of grass species (Sleugh et al., 2000; Lauriault et al., 2006).

Persistence of forage legumes can be problematic in grass-legume mixes because of grazing effects and adverse growing conditions (Harmoney et al., 2001; Guretzky et al., 2004; Lauriault et al., 2006). Grazing management is the most important way to maintain a productive pasture. When pastures are grazed for an extended period of time, less palatable and more grazing-tolerant species can dominate, leading to a reduction of both the utility and nutritional value of the pasture (Skinner et al., 2004; Deak et al., 2007). This can risk can be reduced by limiting the time and area that livestock can access. This causes livestock to be less selective in the forage that is consumed (Senft et al., 1987). As a result, forage is uniformly utilized and overgrazing may be prevented.

The majority of the Intermountain West is a semi-arid climate with alkaline soil conditions. Phosphorous is a limiting nutrient in pastures, especially in alkaline soils with high concentrations of calcium carbonate with which it forms a precipitate that is unavailable for plant uptake. Legumes are especially susceptible to phosphorous deficiencies because of the tap root that is typical of most legumes is not as efficient at nutrient uptake as fibrous roots (Hill et al., 2006) Grass-legume competition can limit the legume component if not enough phosphorous is present in the soil (Hill et al., 2006). Species longevity and productivity in a plant mixture may be optimized by matching the species' used to the specific climatic and soil conditions of an area (Tracy and Sanderson, 2004). Well-adapted species mixes may also improve ecosystem functions in the stand by providing benefits such as increased persistence, resistance to fluctuating environmental conditions, and resistance to weed invasion (Sanderson et al., 2004; Picasso et al., 2008).

FORAGE SPECIES

Tall fescue (*Festuca arundinacea* Schreb.) (TF) is a cool-season bunchgrass that is deep-rooted and is one of the most competitive grasses when grown in the climatic conditions of the Intermountain Region (Jensen et al., 2001b; Waldron et al., 2002). When irrigated, TF is very grazing -tolerant and can show higher annual production than other grasses in irrigated conditions indicative of the Intermountain Region (Waldron et al., 2002). The lower palatability of TF in comparison to other forage species can cause TF to outcompete the other species in the pasture due to grazing pressure (Jensen et al., 2001a).

Tall fescue is often infected with a fungal endophyte. This can give the grass higher temperature tolerances, wider pH tolerances, increased water acquisition, and resistance to pests which are present in the humid conditions of the Southeastern U.S. (Malinowski and Belesky, 2000). Therefore, endophyte-free TF is preferred in the Intermountain West for two reasons: The first is that in a semi-arid climate, the benefits provided to the plant by the endophyte are negligible (Malinowski et al., 2009). The second reason is because of the negative health effects that the endophyte can cause in livestock. Some of these health problems include: increased respiration rates, nervousness, decreased weight gains, severe circulation problems, and reduced pregnancy rates in cows. (Hoveland et al., 1983; Stuedemann and Hoveland, 1988).

Meadow Brome (*Bromus biebersteinii* Roem. & Schult.) is a rhizomatous, perennial cool-season grass that is productive in pastures providing earlier spring forage than orchardgrass (OG). It regrows quickly and is palatable to livestock. Under irrigated conditions without grazing it may reach between 0.6 to 1.8 m in height and does well when grown with legumes (Ogle et al., 2003). Meadow brome was found to outyield OG at lower irrigation levels but produced a similar amount to OG at higher irrigation levels (Jensen et al., 2001b; Waldron et al., 2002). This grass is susceptible to damage from spring flooding (Ogle et al., 2003; Jensen et al., 2001a).

Orchardgrass (*Dactylis glomerata* L.) is a long-lived perennial bunchgrass. When grown under irrigated conditions can form dense stands and is palatable to livestock. This grass is widely used in grazing systems for forage production (Bush et al., 2000). Orchardgrass grows well with ALF and other legumes in irrigated conditions. Drawbacks of this grass include lack of drought and cold tolerance. In the winter, snow is required as insulation against the cold to prevent damage to an OG pasture (Jensen et al., 2001a).

Alfalfa is the most widely-used forage legume for hay-cropping and pastures. It is valued because of its forage quality, palatability and competitiveness and can consistently produce more forage annually than both cicer milkvetch (CMV) and BFTF (Jensen et al., 2001a). Its growth is evenly distributed from spring to early fall. Alfalfa can fix more nitrogen consistently than other forage legumes (Kroth et al., 1982). The biggest concern when using ALF in grass-legume mixtures is the potential that ALF can cause bloat in ruminants. It also has limited grazing resistance to intensive grazing (Van Keuren and Matches, 1988). This risk can be lowered when it is grazed with grass in a binary mixture (Guldan et al., 2000). Alfalfa persists best in rotationally grazed pastures, allowing it sufficient time to recover before being grazed again (Jensen et al., 2001a).

Birdsfoot trefoil is a non-bloating, highly palatable, short-lived perennial legume well-adapted for use in well managed pastures. It contains tannins which bind proteins in the rumen preventing bloat, and may also improve protein utilization (Min et al., 2003). Birdsfoot trefoil can tolerate somewhat heavy grazing. Because livestock favor this forage species over others, grazing management is crucial in maintaining a productive pasture of this species (Jensen et al., 2001a). Birdsfoot trefoil can be similar in forage quality to ALF although it is more palatable to livestock. Lauriault et al. (2006) found that TF mixtures containing BFTF during the four years of the study yielded consistently less than ALF but more than CMV. The only exception was the last year where CMV roughly equaled BFTF in yield.

Cicer milkvetch (*Astragolus cicer* L.) is a long-lived, non-bloating, rhizomatous, perennial legume. This plant's rhizomes make mature stands very grazing resistant and competitive with many grass species (Jensen et al., 2001a). It is compatible with OG, MB, and TF. The leaves of CMV cling to the plant a few weeks longer than other forages; this gives it higher forage quality later in the season, although ALF has higher forage quality than CMV for most of the year (Smoliak et al., 1990). The main disadvantage of this species is its longer establishment time in comparison to ALF and BFTF. Cicer milkvetch takes two years for a stand to establish itself, fully maturing in the third year after seeding (Monsen et al., 2004). Weed control and correct seeding techniques are very important for the survival of the legume component in the stand (Townsend et al., 1990). Scarification of the seed coat of CMV is required to ensure germination because of the inherently hard seed coat of this species (Acharya et al., 2006, Townsend, 2003).

Previous research on grass-legume mixtures has been conducted in Europe, the mid-western U.S., and Australia where the irrigation and grazing systems are not reflective of those used in the Intermountain Region of the Western U.S. The Intermountain West has a semi-arid climate and is known for hot dry summers and long cold winters with freezing temperatures that limit the growing season (lower than -8°C) to around 100-120 days. The majority of the annually precipitation occurs in the form of snow with limited rain in the summer. The distribution and amount of precipitation makes irrigation rotations necessary to optimize pasture forage production since water is limiting for plant growth during the summer (Waldron et al., 2002).

RESEARCH OBJECTIVES

There is not enough information about utilizing binary grass-legume mixtures in rotationally-grazed irrigated pastures to maximize forage production and quality in the Intermountain West. We hypothesized that grass-legume mixtures will produce more forage than unfertilized grass monocultures containing the same grass species. It is also expected that the most effective species ratio of each binary mixture at increasing forage production and yield will vary depending on the species of legume which is included. The objective of this study was to determine grass-legume mixtures and binary species ratios that optimize pasture productivity and forage nutritive value that are adapted for use in pastures of the Intermountain West.

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CHAPTER 2

YIELD EVALUATIONS OF GRASS-LEGUME MIXTURES OF TALL FESCUE, ORCHARDGRASS, MEADOW BROME, ALFALFA, BIRDSFOOT TREFOIL, AND CICER MILKVETCH

Rising fertilizer prices have led to increased interest in using grass-legume mixtures to reduce costs of supplementing pastures with N. Our objective was to determine optimal species combinations of binary grass-legume mixtures to maximize forage production in the Intermountain West. Tall fescue (TF), orchardgrass (OG), and meadow brome (MB) were grown with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) in grass-legume mixes at planting ratios of 25:75, 50:50, 75:25. Plots were harvested four times during 2011 and 2012. Seasonal forage production of unfertilized TF, MB, and OG monocultures was 11.03, 9.76, and 8.10 Mg ha^{-1}, respectively. TF, OG, and MB grass-legume mixes averaged 24.0, 35.0, and 41.0% higher forage production than their respective grass monocultures. The highest seasonal forage production was with TF mixes producing 14.78 Mg ha^{-1} TF:ALF (50:50), 14.16 Mg ha^{-1} TF:BFTF (50:50), and 11.65 Mg ha^{-1} TF:CMV (50:50). The highest forage production of MB mixes was 13.65 Mg ha^{-1} MB:ALF (50:50), 13.02 Mg ha^{-1} MB:BFTF (50:50), and 11.07 Mg ha^{-1} OG:CMV (50:50). Highest seasonal forage production of OG combinations was 12.34 Mg ha^{-1} OG:ALF (50:50), 10.88 Mg ha^{-1} OG:BFTF (50:50), and 8.76 Mg ha^{-1} OG:CMV (75:25). Individual harvests showed similarly higher yield of the mixtures over the monocultures.

Cicer milkvetch did not perform well in irrigated pastures. The 50:50 TF-ALF mixture was the highest yielding and should be used to maximize forage production. If a non-bloating legume is desired, BFTF is the best alternative with forage production near those of ALF.

INTRODUCTION

Rising prices for commercial nitrogen (N) and federal land policies which have reduced the availability of public lands for summer grazing have increased the need for production practices capable of supporting increased livestock use (Peel et al., 2004; Lauriault et al., 2006). Irrigated pastures in the Intermountain Region of the western USA consist, primarily, of one or more species of cool-season grasses (Waldron et al., 2002). These pastures produce the largest amount of forage in the spring with a forage deficit in the summer. The midsummer forage deficit, or summer slump, can be reduced by applying nitrogen (N) (Moser and Hoveland, 1996) or including a complementary forage legume to improve forage performance in the midsummer when cool-season grasses have reduced growth (Sleuth et al., 2000; Springer et al., 2001, 2007).

A goal of pasture production is to minimize inputs such as fertilizer applications and labor costs while maximizing forage production, quality and pasture longevity. Increased forage yield can be attributed mostly to N fertilizer and is the most variable cost of pasture production (Huang, 2007; Solomon et al., 2011). Research has been done on grass-legume mixtures in the past, but there is renewed interest with the increase in fossil fuel prices. As the prices of fossil fuel continue to increase the use of nitrogen-fixing legumes in grass-legume pastures mixes as an alternative source of N has become a viable alternative to applications of commercial N (Rumbaugh et al., 1982; Sleugh et al., 2000; Crews and Peoples, 2004; Butler et al., 2012; Interrante et al., 2012).

The positive effect that legumes can have on the yield of grass monocultures has been well-documented. Legumes have the potential to increase the yield of a grass pasture in two ways: 1) transfer of fixed N to the neighboring grasses (Ta et al., 1986; Ta and Faris, 1987; Heichel and Henjum, 1991; Malhi et al., 2002) and 2) contributing plant biomass to the overall forage yield of the pasture. This is especially important during the midsummer months when there is a forage deficit for livestock (Sleugh et al., 2000; Kopp et al., 2003).

The estimated total amount of N needed by a grass pasture in the Intermountain West is between 114 and 170 kg per ha (Koenig et al., 2002). Kroth et al. (1982) estimated that birdsfoot trefoil (*Lotus corniculatus* L.) (BFTF) and alfalfa (*Medicago sativa* L.) (ALF) annually fix 115 and 200 kg N ha^{-1}, respectively, that is then released into the soil. This is enough to satisfy the N requirements as stated by Kroth et al. (1982). The amount of N that can be fixed by a legume is species dependent on the legume proportion in the grass-legume mixture (Carlsson and Huss-Danell, 2003; Mallarino and Wedin, 1990; Nyfeler et al., 2011).

Forage legumes which are commonly used in grass-legume mixtures, such as ALF and BFTF, are most productive in the summer months when grass production slows. This added forage plays a critical role in increasing yields obtained in the summer months by compensating for the summer slump of the grasses (Moore et al., 2004). Yield compensation by the legumes can be instrumental in improving the seasonal distribution of forage and increasing the capacity of a pasture to support livestock grazing throughout the summer (Leep et al., 2002; Lauriault et al., 2006). The challenges that arise from trying to maintain a legume component in a grass-legume pasture include: 1) Environmental stressors (Harmoney et al., 2001), 2) interspecies competition (Sanderson et al., 2005), and 3) species selection (Skinner et al., 2004; Picasso et al., 2008).

The legumes ALF, BFTF, and cicer milkvetch (*Astragalus cicer* L.) (CMV) have shown potential for use in grass-legume mixtures in the Intermountain West (Townsend et al., 1990; Guldan et al., 2000; Rumbaugh et al., 1983). Alfalfa is the most commonly harvested forage in the Intermountain West and produces well under irrigation. It is often used as the standard for comparison for other legumes because it is the highest producing legume and is widely used (Jensen et al., 2001). Alfalfa's ability to increase production of grasses equal to that of commercial N has been well documented (Guldan et al., 2000; Ta and Faris, 1987; Lauriault et al., 2006; Sleugh et al., 2000). However, alfalfa can cause bloat in ruminant livestock if not grazed properly (Jensen et al., 2001).

Birdsfoot trefoil has been known to also produce well in a rotationally grazed pasture (Harmoney et al., 2001) and is very palatable to livestock. The tannins of this plant can prevent bloat in ruminants (Lees et al., 1984). Birdsfoot trefoil has been shown to increase forage production in pastures when used in grass-legume mixtures (Hoveland and Richardson, 1992; Sleugh et al., 2000; Lauriault et al., 2006).

Cicer milkvetch is a non-bloating, rhizomatous perennial legume that has shown potential in the climate of Utah to increase forage production of cool-season grass pastures (Rumbaugh et al., 1982; Townsend et al., 1990). Although CMV develops slowly and has been recorded to produce less forage than ALF, it is well-suited for use in pastures (Acharya et al., 2006; Townsend, 1993).

Studies in Europe, Canada, and the Midwest, South, Southwest, and Southeastern United States have demonstrated that the grass-legume mixtures have the potential to improve pasture forage production and distribution while minimizing N applications (Beuselinck et al., 1992; Guldan et al., 2000; Hoveland and Richardson, 1992; Kopp et al., 2002; Loeppky et al., 1996; Nyfeler et al., 2011; Townsend et al., 1990; Sleugh et al., 2000; Ta and Faris, 1987). While some work has been done in the Intermountain West on the benefits and use of grass-legume mixtures (Rumbaugh et al., 1982; Jensen et al., 2001), more information concerning the performance of specific species combinations and optimal mixture ratios is needed. The objective of this study was to determine which binary grass-legume mixtures and planting ratios of tall fescue (*Festuca arundinacea* Schreb.) (TF), meadow brome (*Bromus biebersteinii* Roem. & Schult.) (MB), and orchardgrass (*Dactylis glomerata* L.) (OG); with ALF, BFTF, and CMV, maximized productivity of pastures in the Intermountain Region of the Western United States.

MATERIALS AND METHODS

Research was conducted at the Utah State University Intermountain Irrigated Pasture Facility located near Lewiston, UT (41°56'.94" N, 111°51'14.12" W, elev. 2049 m above sea level). The soil is a Kidman fine sandy loam (Coarse-loamy, mixed, superactive, mesic Calcic Haploxerolls)(Soil Survey Staff, 2012). Average annual precipitation is 44.6 cm with the majority received as snow during the winter months (Fig. 2-1). There is an average of 114 frost-free days, during the growing season (April – Sept.), average night and daytime temperatures for 2011 were 8, and 23.5 °C, respectively; and 4.1 and 27.0 °C, respectively, for 2012 (Western Regional Climate Center, 2012)s(Fig. 2.2).

Tall fescue, MB, and OG were planted in binary mixtures with ALF, BFTF, and CMV. The grass-legume mixtures were planted for targeted plant population ratios of 0:100 (legume monoculture), 25:75, 50:50, 75:25, and 100:0 (grass monoculture) to determine optimum plant population ratios for forage yield and quality. The cultivars used were 'Fawn' TF, 'Cache' MB, 'Intensiv' OG, 'Rugged' ALF, 'Norcin' BFTF, and 'Monarch' CMV

Plots were planted August 10, 2010, using a cone seeder (Hegie Company, Waldenburg, Germany) and measured 1.5 m wide by 6.1 m long. A spacing of 0.3 m was left between plots for separation and ease of harvesting. To ensure that the grasses and legumes were not in the same row, grasses and legumes were planted in separate passes. The legume rows were offset from the grass rows six to eight centimeters to avoid planting the grass and the legumes in the same row. This was done to reduce interspecies competition during germination and establishment. Grass was planted in the alleyways running north and south to separate the plots from one another. Irrigation was applied until the soil was saturated after planting, and as needed afterwards to maintain needed soil-water for growth.

A seeding rate of 16.8 kg pure live seed (PLS) ha^{-1} was used for the TF, MB, and OG monocultures. The ALF and CMV monocultures were seeded at 13.4 kg PLS ha^{-1} and a seeding rate of 11.2 kg PLS ha^{-1} was used for the BFTF monocultures. The seeding rates for the grass-ALF and grass-CMV mixtures were 12.6:2.0 (75:25), 8.4:3.9 (50:50), and 4.2:9.8 kg PLS ha^{-1} (25:75). Seeding rates for the grass-BFTF mixtures were 12.6:1.7 (75:25), 8.4:4.2 (50:50), and 4.2:8.4 kg PLS ha^{-1} (25:75). Prior to planting, each legume was inoculated with the proper *Rhizobium* species. Sufficient monoammonium phosphate was applied prior to planting to supply phosphorus needs of the legumes for four years, as determined by soil tests taken prior to plot establishment.

Before the first harvest, plots were measured and the alleys were mowed using a push lawn mower to ensure that equal areas were being harvested. Alleyways were mowed approximately every two weeks, enough to visibly mark the edge of the plots.

Three monocultures were established for each grass species. The first was fertilized with N at 134 kg ha^{-1}, the second at 67 kg ha^{-1}, and the third was left unfertilized. Urea (46-0-0) was applied uniformly on the appropriate plots and incorporated immediately into the soil using irrigation to prevent volatilization. Nitrogen was split into three equal applications over the growing season. These occurred in April of 2011 and 2012 prior to plant growth and after the second and third harvest each year. The mixtures were not fertilized. Weeds were minimal but were removed by hand when necessary.

Plots were harvested June 6, July 8, Aug. 8, and Sept. 14, in 2011, and May 25, July 2, Aug. 6, and Sept. 13 in 2012. The first harvests of each year took place when the grasses were in the boot growth stage. A 28-day harvest interval, thereafter, was used to simulate a rotational grazing system. The plots were harvested with a Swift Current sickle-bar harvester (Swift Machine & Welding LTD, Swift Current, SK) to a stubble height of eight cm. At each harvest, a subsample of 400 g was obtained, weighed, and dried at a temperature of 60°C to a constant weight and used to calculate the plot total dry-weight, plant moisture content, and was used for subsequent forage quality analysis. Subsamples from twenty 50:50 grass-legume mixtures were separated into grass and legume components. These components were weighed and dried to determine the forage composition of the plot by weight. The dry weights of the components were added together to determine the dry matter yield (DMY) of the plots.

Legume forage content of each plot was visually estimated by two individuals immediately prior to each harvest. The amount of legume forage in the plot was rated on a scale of 0 to 10, 10 indicating that the forage of the plot was composed entirely of legume and 0 indicating that no legume was present. The accuracy of the visual estimates was verified using the weights of the selected subsamples.

Species plant composition was determined after each harvest using a frame measuring 84 cm by 122 cm that was subdivided into a five by eight grid. This frame was used to determine species presence/absence for both grasses and legumes in each square. These measurements were used to monitor the change in species composition during the duration of the study.

The study was arranged in a randomized complete block design. There were a total of 45 treatments, each replicated four times. Statistical analysis was performed with SAS statistical software (SAS Institute Inc., Cary, NC) using the General Linear Model procedure. Fisher's protected LSD at $P < 0.05$ was used to separate means.

RESULTS

Forage production of the unfertilized TF, MB, and OG monocultures was 11.03, 9.76, and 8.11 Mg ha^{-1}, respectively (Table 2-1). The unfertilized TF and MB monocultures produced 36 and 20% more annual forage, respectively, than the OG monocultures. Among treatments, the means of the grass-legume mixtures and N treatments were compared to their respective, unfertilized, grass monocultures. The 67 kg ha^{-1} N rate increased forage production of TF, MB, and OG by 19, 20, and 18%, respectively, and the 134 kg N ha^{-1} rate increased forage production of TF, MB, and OG by 29, 28, and 37%, respectively, over the unfertilized monocultures.

The average seasonal production of ALF, BFTF, and CMV was 11.14, 9.34, and 7.84 Mg ha^{-1}, respectively (Table 2-2). As well as being the highest yielding, the seasonal distribution of forage for the ALF monocultures was the most uniform of the legumes, producing 27, 22, 26, and 25% of its forage at the first, second, third, and fourth harvests, respectively (Table 2-3). Although the forage production of BFTF at the first harvest was 72% of the ALF, it increased to 122% of ALF at harvest two. At the third and fourth harvests the forage production of BFTF was lower, at 76 and 71% of ALF, respectively.

Cicer milkvetch had not established at the first harvest in 2011 and had no harvestable forage (Table 2-4). Growing plants were visible but small and still in the seedling stage. Starting with the second harvest in 2011, CMV yields were measurable, producing 1.40 Mg ha^{-1} but still lower than the second harvest in

2012 at 2.77 Mg ha^{-1}. By the fourth harvest of 2011 the forage production of CMV monoculture appeared to reach their potential when compared to the yield of the fourth harvest of 2012. The CMV monoculture yielded 39, 11, and 71% less forage than ALF during the first, third and fourth harvests, respectively, with no significant differences being observed during harvest two in 2012 (Table 2-4). The average seasonal production of the CMV mixtures in 2012 was 100, 51, and 69% more than the first, second, and third harvests in 2011, respectively. Because of the slow establishment of CMV, comparisons will focus on 2012 yields when the legume was fully established.

Grass-Legume Mixtures

Tall Fescue

Mean annual forage production of the TF-ALF mixtures was 13.70 Mg ha^{-1}, TF-BFTF mixtures were 13.12 Mg ha^{-1}, and the TF-CMV mixtures were 11.38 Mg ha^{-1} (Table 2-1). Forage production of the TF-ALF mixtures was 24% higher than the forage production of the unfertilized monoculture and similar to the TF monoculture fertilized at 134 kg ha^{-1}. The TF-BFTF mixtures were 20% higher than the unfertilized TF monoculture and were similar to the TF monoculture fertilized at 67 kg N ha^{-1}. The 50:50 TF-ALF mixture was the most productive planting ratio for TF-ALF, producing 33% more forage than the unfertilized TF monocultures (Table 2-2). Likewise, the 50:50 TF-BFTF mixture was most productive of the TF-BFTF mixtures, annually producing on average 28% more forage than the unfertilized TF monoculture. The 50:50 TF-BFTF mixture was similar to the TF monoculture fertilized at 134 kg ha^{-1}, which produced an average of 14.21 Mg ha^{-1} annually.

The forage production of the TF-CMV mixture was 7.35 Mg ha^{-1} in 2012, a similar amount to the unfertilized TF grass monoculture (Table 2-1). In the first year, the CMV in the mixtures was still establishing, and was a confounding factor (Table 2-4). In 2012, the 25:75 TF-CMV planting ratio produced the most forage at 7.97 Mg ha^{-1}. None of the TF-CMV mixtures were different from the unfertilized TF monocultures (Table 2.6)

The TF monoculture produced the majority of its forage early, with 46, 18, 17, and 17% of its forage being produced at harvest one through four, respectively (Table 2-3). When TF is grown in mixtures with ALF and BFTF, the forage production of the grass-legume mixtures compensated for the "summer slump" of TF. Forage production of the TF-ALF mixtures for the second, third, and fourth harvests was 25, 56, and 72% higher, respectively, than the unfertilized monoculture of TF. The TF-BFTF mixtures also had higher yields than the unfertilized monocultures by 7, 19, 42, and 40% for harvests one through four, respectively. The TF-CMV mixtures were no different than the unfertilized monocultures.

During 2012, the TF-CMV mixtures produced 22 and 25% more than the unfertilized TF monocultures during harvests three and four (Table 2-8). However, at the first and second harvests, yields were 9 and 12% less than the unfertilized TF monoculture, suggesting that CMV is less compatible with TF than ALF or BFTF (Table 2-8).

Meadow Brome

The average annual forage production of the MB mixtures with ALF and BFTF were higher than the unfertilized MB monocultures by 35 and 26%, respectively, and similar forage production as the monoculture fertilized at 134 kg N ha^{-1} (Table 2-1). The forage production of the MB-CMV mixtures was similar to the unfertilized MB monoculture (Table 2-5).

Forage production of the MB-ALF mixtures was 35% greater than the unfertilized MB monoculture, and was similar to the monoculture fertilized at 134 kg N ha^{-1} (Table 2-1). At 13.02 Mg ha^{-1} the 50:50 MB-ALF mixture was numerically the most productive, but not statistically different from the 75:25 MB-ALF mixture (Table 2-2). Forage production of both the 75:25 and 50:50 MB-ALF planting ratios were comparable to the MB fertilized monoculture at 134 kg ha^{-1} and out-produced the unfertilized MB monoculture by 36 and 40%, respectively.

The annual forage production of the MB-BFTF mixtures averaged 12.33 Mg ha^{-1}, or 35% more forage than the unfertilized monoculture (Table 2-1). The 50:50 MB-BFTF mixture was numerically the most productive, but not statistically different than the 75:25 MB-BFTF mixture and produced 13.02 Mg ha^{-1}, out-producing the unfertilized monoculture of MB by 38% with production similar to the MB monoculture fertilized at 134 kg ha^{-1} N (Table 2-2). The 75:25 MB-BFTF mixture had 18% higher yield than the unfertilized monoculture and was similar in size to the monoculture fertilized at 67 kg N ha^{-1}. The average production of the 25:75 MB-BFTF mixture was similar to the unfertilized MB monoculture.

The mean forage production of the MB-CMV 50:50 mixture was 22% higher than the unfertilized MB monoculture and was intermediate to the 67 kg N ha^{-1} and 134 kg N ha^{-1} fertilized monocultures (Table 2-6). The 25:75 MB-CMV mixture also produced more than the unfertilized MB monoculture by 12% and was similar to the MB monoculture fertilized at 67 kg ha^{-1}. The 75:25 MB-CMV mixture was similar in yield to the unfertilized MB monoculture.

When grown in monocultures, MB produced 52% of its annual production at the first harvest. ALF, BFTF, and CMV compensated for the summer slump seen in the monocultures of MB during the second, third, and fourth harvests. MB-ALF yielded 78, 70, and 90% more forage than the unfertilized MB monoculture for the second, third, and fourth harvests, respectively (Table 2-9). The MB-BFTF mixtures were 49, 57, and 45% higher yielding than the unfertilized monocultures at the second, third, and fourth harvests, respectively. Forage production of the MB-CMV mixtures was 22, 31, and 60% higher for the second through the fourth harvests, respectively, than for the unfertilized MB monocultures (Table 2-10).

Orchardgrass

The mean annual forage production of the OG-ALF mixtures was 11.40

Mg ha^{-1}, OG-BFTF mixtures 10.50 Mg ha^{-1}, and the OG-CMV mixtures 8.33 Mg ha^{-1} (Table 2-1). The OG-ALF mixtures produced 41% more forage than the unfertilized OG monoculture and had similar production to the OG monoculture fertilized at 134 kg ha^{-1}.

In the OG-ALF mixtures, the 50:50 planting ratio produced 12.34 Mg ha^{-1} and was numerically higher but statistically similar to the 75:25 mix at 11.45 Mg ha^{-1}, but was significantly higher than the 25:75 mix which produced 10.39 Mg ha^{-1} (Table 2-2). The 50:50 OG-ALF mixture produced 52% more forage than the unfertilized OG monoculture and was similar to the forage production of the monoculture fertilized at 134 kg ha^{-1}. The 75:25 and 25:75 OG-ALF mixtures produced 28 and 39% more forage, respectively, than the unfertilized OG monoculture.

The forage production of the OG-BFTF mixtures at 10.50 Mg ha^{-1} was 29% higher than the unfertilized OG monoculture (Table 2-1). The 75:25, 25:75, and 50:50 planting ratio had 24, 30, and 34% higher forage production, respectively, than the unfertilized OG monoculture and were all similar to the OG monoculture fertilized at 134 kg ha^{-1} of N (Table 2-2). The 50:50 planting ratio was numerically the highest producing of the OG-BFTF mixtures and produced 10.88 Mg ha^{-1}, producing an intermediate amount of forage to the fertilized OG monocultures at 67 and 134 kg ha^{-1}. The 75:25 and 25:75 OG-BFTF mixtures while numerically lower, were not statistically different from the 50:50 OG-BFTF mixture.

The OG-CMV mixtures were no different than the unfertilized OG monoculture in 2011 or 2012 (Table 2-5). The production of the OG-CMV mixtures was lower than OG monoculture fertilized at 67 kg ha^{-1}. The, 25:75, 50:50, and 75:25 OG-CMV mixtures were higher producing than the unfertilized OG monoculture by 8, 11, and 14%, respectively, but were less productive than the fertilized OG monocultures (Table 2-6). The 75:25 OG-CMV mixture had the highest production in 2012 at 7.56 Mg ha^{-1}.

Although the OG-legume mixtures were similar to the unfertilized OG monocultures at the first harvest, all of the OG-legume mixtures were effective at improving the seasonal distribution as evidenced by higher forage production at the second, third, and fourth harvests (Table 2-11). The production of the OG-ALF mixture was higher than the unfertilized OG monoculture by 37, 76, and 79% for the first, second, and third harvests, respectively (Table 2-11). OG-birdsfoot mixtures, similarly, had higher production than the unfertilized monoculture by 40, 63, and 38% for the second, third, and fourth harvests, respectively. The OG-CMV mixtures were similar to the unfertilized monoculture when both years were combined; however, in 2012, the OG-CMV mixtures produced 10, 39, and 32% more forage than the unfertilized OG monocultures for harvests two through four (Table 2-12).

Comparisons of the Forage Legume Component

The forage production of the grass-legume mixtures was correlated with the legume component which varied by planting ratio. Visually the MB-ALF mixtures had the highest concentration of legumes in any of the grass-legume mixtures at 63 and 60% for the 25:75 and 50:50 planting ratios respectively (Table 2-13). The MB-BFTF mixture had the most BFTF at the 25:75 planting ratio at 49%. The forage of the 50:50 MB-BFTF mixture had 41% BFTF, with the 75:25 planting ratio having the least BFTF at 39%. The CMV component of the MB-CMV mixtures did not change between the planting ratios (Table 2-14).

The 25:75 TF-ALF mixture contained 49% ALF and had 16 and 48% more ALF than the 50:50 and 75:25 planting ratios, respectively (Table 2-13). The TF-BFTF mixtures contained a similar amount of BFTF at the 50:50 and 25:75 planting ratios, maximizing the BFTF content of the mixtures at 33%. The 25:75 TF-CMV mixture had the highest concentration of CMV in the TF mixtures at 26% (Table 2-14).

The 50:50 and 25:75 planting ratios for the OG-legume mixtures had similar amounts of forage legumes. The 50:50 and 25:75 OG-ALF mixtures contained the highest legume component at 47 and 48%, respectively. The 50:50 and 25:75 OG-BFTF mixture contained 38 and 39% BFTF in the mixtures. The OG-CMV mixtures were similar across the planting ratio; however, the 25:75 OG-CMV mixture contained 28% CMV.

DISCUSSION

In agreement with past literature, forage production of TF-, MB-, and OG-, in mixtures containing ALF or BFTF was greater than the respective unfertilized grass monocultures (Harmoney et al., 2001; Heichel and Henjum, 1991; Mallarino et al., 1990; Rumbaugh et al., 1982) and equal to the fertilized grass monocultures at 67 kg N ha^{-1}(Sleugh et al., 2000) and 134 kg N ha^{-1}(Guldan et al., 2000).

The grass-legume mixtures with the highest average forage production and their optimal planting ratio from the highest producing to the least were: TF-ALF 50:50 at 14.78 Mg ha^{-1}, TF-BFTF 50:50 at 14.16 Mg ha^{-1}, MB-ALF 50:50 at 13.65 Mg ha^{-1}, MB-BFTF 50:50 at 13.02 Mg ha^{-1}, OG-ALF 50:50 at 12.34 Mg ha^{-1}, and OG-BFTF 50:50 at 10.88 Mg ha^{-1} (Table 2-5).

The forage production of the grass-legume mixtures containing CMV were similar to the unfertilized grass monocultures and less than the grass monocultures fertilized at 67 and 134 kg N ha^{-1} (Table 2-1). This observation agrees with others (Acharya et al., 2006; Guldan et al., 2000; Townsend, 1993), and can be primarily attributed to the slow establishment of CMV. Because of the slow establishment of CMV relative to the other legumes, the average 2012 mixtures with CMV were more representative of the production potential of CMV than the two year average (Table 2-4). In 2012, the most productive CMV mixtures the 50:50 MB-CMV mixture which produced 11.39 Mg ha^{-1}, the TF-CMV 25:75 mixture yielded at 7.93 Mg ha^{-1}, and the 75:25 OG-CMV mixture produced 7.57 Mg ha^{-1} (Table 2-6).

The planting ratios were correlated with the forage production of the grass-legume mixtures. The grass-legume mixtures with the exception of the CMV mixture had the highest forage production at the 50:50 planting ratio (Tables 2-2 and 2-6). The MB mixtures consistently had higher proportions of legume in the forage than the other grass-legume mixtures (Fig. 2-3). The 25:75 MB-ALF mixtures had the highest legume component of the grass-legume mixtures at 63%, followed by 25:75 MB-BFTF at 49%, and the 25:75 TF-ALF at 49%. As might be expected, the 25:75 planting ratio had the largest legume component in the mixtures, however, the highest yielding mixtures appeared to be those with a slightly higher grass or legume component with a planting ratio of 50:50 supporting the results of Springer et al., (2001) who suggested a plant community ratio of 1:1 would maximize plant productivity. Mallarino and Wedin (1990) found that the optimal planting ratios for forage production occurred when the TF component was larger than the legume component. The single exception in our study to the findings of Mallarion and Wedin (1990) was the MB-ALF mixture which maximized forage production when ALF was estimated make up 60% of the harvestable forage (Tables 2-13 and 2-14).

The distribution of seasonal forage for the grass-legume mixtures was more uniform than their respective unfertilized grass monocultures. The forage production of the grass-legume mixtures was higher than the unfertilized grass monocultures because the legume component of the mixtures was largest during the midsummer months; complement for the lack of forage production by the grass (Fig 2-3). The first harvest of the mixtures was similar to the unfertilized grass monocultures. At the second through fourth harvests the TF-ALF mixtures had 25, 56, and 72% higher forage yield, respectively, than the unfertilized TF monocultures (Table 2.3). The TF-BFTF mixtures produced 19, 42, and 40% more forage than the unfertilized TF monoculture. Both the TF-ALF and TF-BFTF mixtures were similar in yield to the TF monocultures fertilized at 134 kg N ha^{-1}, with the exception of the TF-BFTF mixture at harvest four which was similar to the TF monoculture fertilized at 67 kg N ha^{-1}.

The increase of forage production of the MB-legume mixtures compared to the unfertilized MB monocultures during harvests two, three, and four was as follows: MB-ALF; 78, 70, and 90%; MB-BFTF: 79, 56, and 45%; and MB-CMV; 20, 23, and 45% (Table 2-9).

The OG-ALF mixture produced 37, 76, and 79% respectively more forage than the unfertilized grass monocultures at the second through fourth harvests. Likewise, the OG-BFTF mixture produced 40, 63 and 38% more than the unfertilized OG monoculture at harvests two through four, respectively (Table 2-11). The OG-ALF and BFTF mixtures, like those of the TF- and MB- mixtures were similar to the OG monocultures fertilized at 134 kg N ha^{-1}. The single exception was the OG-BFTF mixture at harvest four, which was similar to the half rate of N (67 kg ha^{-1}). The legume benefit to the OG-ALF, and OG-BFTF mixtures observed by Sleugh et al. (2000) was similar to our observations (Fig 2-3).

The TF-CMV and OG-CMV mixtures did not improve seasonal distribution.

This is likely an artifact of slow establishment where two or three more years may produce different results. This is consistent with Townsend et al. (1990) who reported that CMV which consisted of 45% or less of the mixtures reached its maximum density in the grass-legume mixtures of approximately 80% in the TF-OG and TF-MB mixtures by the end of the third year. Studies done by Guldan et al. (2000), and Dobson et al. (1976) confirm that the low productivity of the TF-CMV mixtures in comparison with unfertilized TF monocultures indicate that this species mixture does not significantly improve forage production compared to the TF monocultures. Moreover, CMV in these studies was observed to compete poorly with TF, evidenced by slow establishment of the CMV component, which was evidenced in our study by consisting less than 20% of the mixtures (Fig 2-3).

In conclusion, the grass-legume mixtures with the highest forage production and their optimal planting ratio from the greatest to least were TF-ALF 50:50, TF-BFTF 50:50, MB-ALF 50:50, MB-BFTF 50:50, OG-ALF 50:50, and OG-BFTF 50:50. These mixtures out-yielded their respective unfertilized grass monocultures and were similar to the grass monocultures fertilized at 134 kg N ha^{-1}. CMV takes 2 years to establish and does not combine well with TF. The TF- and OG-CMV mixtures were similar to their respective unfertilized grass monocultures. The MB-CMV mixture, however, was larger than the unfertilized MB monoculture. This would further suggest that CMV does not mix well with TF and is better adapted for use on drier or minimally irrigated pastures.

The grass-legume mixtures containing ALF and BFTF had improved forage seasonal distribution when compared with grass monocultures. The 50:50 TF-ALF mixture was the highest yielding and should be used to maximize forage production in the Intermountain West. If a non-bloating legume is desired, BFTF is the best alternative with forage production near those of ALF. The MB-legume mixtures contained the highest percentage of legumes of the grasses and can be used if a high concentration of legumes or if a grass other than TF is desired. Cicer milkvetch did the best when grown with MB suggesting they are most compatible. The grass-legume mixtures that had forage production similar to the fertilized grass monocultures could be used to replace commercial N use on irrigated pastures in the Intermountain West. Future research is needed to address the performance and persistence of ALF and BFTF in combination with TF or MB under grazing in the Intermountain West.

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Table 2-1. Mean dry matter yield (2011-2012) of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in fertilized and unfertilized monocultures and mixtures with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV).

	Legumes			Monocultures N Rate (kg ha^{-1})			
Grass Species	ALF	BFTF	CMV	0 N	62 N	134 N	LSD (0.05)
	Mg ha^{-1}						
TF	13.70	13.12	11.38	11.03	13.18	14.21	2.05
MB	13.21	12.33	10.50	9.76	11.75	12.86	1.43
OG	11.40	10.50	8.33	8.11	9.61	11.09	1.60
LSD (0.05)	0.86	1.06	1.11	2.09	2.21	1.41	--

Table 2-2. Mean dry matter yield (2011-2012) of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in monocultures and mixtures with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV). Each legume was grown with each grass in legume-grass ratios of 25:75, 50:50, 75:25. The grass monocultures were fertilized at 0, 67, and 134 kg N ha^{-1}, mixtures were not fertilized.

	Tall Fescue			Meadow Brome			Orchardgrass		
Treatments	ALF	BFTF	CMV	ALF	BFTF	CMV	ALF	BFTF	CMV
	Mg ha^{-1}								
Legume:Grass Mixtures									
25:75	13.24	13.04	11.55	13.23	12.41	10.51	10.39	10.08	8.76
50:50	14.78	14.16	11.56	13.65	13.02	11.07	12.34	10.88	8.11
75:25	13.10	12.16	11.02	12.75	11.55	9.91	11.45	10.53	8.12
100:0	11.14	9.34	7.85	11.14	9.34	7.85	11.14	9.34	7.85
Grass Monocultures N Rate (kg ha^{-1})									
0 N	11.03	11.03	11.03	9.76	9.76	9.76	8.11	8.11	8.11
62 N	13.18	13.18	13.18	11.75	11.75	11.75	9.61	9.61	9.61
134 N	14.21	14.21	14.21	12.86	12.86	12.86	11.09	11.09	11.09
LSD (0.05)	1.58	1.89	1.57	1.22	1.28	1.19	1.13	1.33	1.62

Table 2-3. Mean dry matter yield (2011- 2012) at four harvests of tall fescue (TF) mixtures with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV).

	Harvest				
Treatments	1	2	3	4	LSD (0.05)
	Mg ha^{-1}				
Grass-Legume Mixtures					
TF - ALF	4.99	2.51	2.90	3.30	0.19
TF - BFTF	5.38	2.40	2.64	2.69	0.29
TF - CMV	4.86	1.96	2.24	2.32	0.25
Grass Monocultures N rate (kg ha^{-1})					
TF 0 N	5.24	2.01	1.86	1.92	0.70
TF 67 N	5.57	2.37	2.33	2.90	0.69
TF 134 N	5.77	2.64	2.59	3.21	0.54
Legume Monocultures					
ALF	3.02	2.45	2.86	2.81	0.17
BFTF	2.17	3.00	2.18	1.99	0.18
CMV	1.71	2.03	2.10	2.00	0.20
LSD (0.05)	0.74	0.4	0.36	0.48	--

Table 2-4. Mean dry matter yield (2011-2012) of cicer milkvetch at four harvests.

	Harvest				
Year	1	2	3	4	LSD (0.05)
	Mg ha^{-1}				
2011	0.04	1.36	1.67	2.31	0.26
2012	3.37	2.71	2.53	1.70	0.26
LSD (0.05)	0.32	0.30	0.23	0.22	--

Table 2-5. Mean dry matter yield (2012) of monocultures and mixtures of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in mixtures with cicer milkvetch (CMV).

Grass	CMV	0 N†	67 N	134 N	LSD (0.05)
	Mg ha^{-1}				
TF	7.35	7.60	9.48	10.93	ns‡
MB	10.58	9.36	11.91	12.21	1.81
OG	7.36	6.65	8.66	10.03	1.62
LSD (0.05)	1.25	ns	ns	ns	--

† kg ha^{-1}

‡ Not significant

Table 2-6. Mean dry matter yield (2012) of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in monocultures and mixtures with cicer milkvetch. CMV was grown with each grass in legume:grass ratios of 25:75, 50:50, 75:25. The grass monocultures were fertilized at 0, 67, and 134 kg N ha^{-1}, mixtures were not fertilized.

Treatments	TF	MB	OG
	Mg ha^{-1}		
Legume:Grass Mixtures			
25:75	6.76	9.91	7.56
50:50	7.37	11.39	7.16
75:25	7.93	10.46	7.37
100:0	10.31	10.31	10.31
Grass Monoculture N Rate (kg ha^{-1})			
0 N	7.60	9.36	6.65
67 N	9.48	11.91	8.66
134 N	10.92	12.21	10.03
LSD (0.05)	2.39	1.73	1.42

Table 2-7. Mean forage yield (2012) at four harvests of alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) monocultures.

	Harvest				
Legumes	1	2	3	4	LSD (0.05)
	Mg ha^{-1}				
ALF	4.69	2.74	2.81	2.90	0.23
BFTF	3.48	2.85	2.20	1.85	0.34
CMV	3.37	2.71	2.53	1.70	0.26
LSD (0.05)	0.32	ns†	0.21	0.28	--

† Not significant

Table 2-8. Mean dry matter yield (2012) at four harvests of the tall fescue (TF) and cicer milkvetch (CMV) grass-legume mixture and tall fescue grass monocultures at 0, 67, and 134 kg N ha^{-1}.

	Harvest				
Treatments	1	2	3	4	LSD (0.05)
	Mg ha^{-1}				
Grass-Legume Mixture					
TF - CMV	3.97	1.54	0.95	0.90	0.39
Grass Monoculture N rate (kg ha^{-1})					
TF 0 N	4.34	1.76	0.78	0.71	0.84
TF 67 N	4.57	2.20	1.26	1.45	0.51
TF 134 N	4.72	2.51	1.64	2.05	0.78
Legume Monoculture					
CMV	3.37	2.71	2.53	1.70	0.25
LSD (0.05)	0.94	0.39	0.42	0.56	--

Table 2-9. Mean dry matter yield (2011- 2012) at four harvests of meadow brome (MB) mixtures with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV).

	Harvest				
Treatments	1	2	3	4	LSD (0.05)
	Mg ha^{-1}				
Grass-Legume Mixtures					
MB - ALF	4.86	2.55	2.86	2.94	0.15
MB - BFTF	4.90	2.56	2.63	2.24	0.30
MB - CMV	4.72	1.71	2.06	2.01	0.19
Grass Monoculture N rate (kg ha^{-1})					
MB 0 N	5.11	1.43	1.68	1.55	0.70
MB 67 N	5.57	1.72	2.20	2.26	0.69
MB 134 N	5.69	1.94	2.70	2.53	0.49
Legume Monocultures					
ALF	3.02	2.45	2.86	2.81	0.17
BFTF	2.17	3.00	2.18	1.99	0.18
CMV	1.71	2.03	2.10	2.00	0.20
LSD (0.05)	0.78	0.34	0.29	0.33	--

Table 2-10. Mean dry matter yield (2012) at four harvests of meadow brome (MB) and cicer milkvetch (CMV) grass-legume mixture and fertilized and unfertilized meadow brome monocultures.

	Harvest				
Treatment	1	2	3	4	LSD (0.05)
	Mg ha^{-1}				
Grass-Legume Mixtures					
MB - CMV	6.11	1.78	1.49	1.21	0.67
Grass Monoculture N rate (kg ha^{-1})					
MB 0 N	6.00	1.45	1.15	0.77	1.59
MB 67 N	6.71	1.93	1.73	1.54	1.16
MB 134 N	6.10	2.02	2.18	1.90	0.68
Legume Monocultures					
CMV	3.37	2.71	2.53	1.70	0.25
LSD (0.05)	1.37	0.30	0.33	0.39	--

Table 2-11. Mean dry matter yield (2011- 2012) at four harvests of orchardgrass (OG) mixtures with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV).

	Harvest				
Treatment	1	2	3	4	LSD (0.05)
			$Mg\ ha^{-1}$		
Grass-Legume Mixtures					
OG - ALF	3.78	2.43	2.62	2.56	0.27
OG - BFTF	3.63	2.47	2.43	1.97	0.29
OG - CMV	3.43	1.79	1.61	1.49	0.39
Grass Monoculture N rate ($kg\ ha^{-1}$)					
OG 0 N	3.42	1.77	1.49	1.43	0.42
OG 67 N	3.71	2.03	1.93	1.95	0.81
OG 134 N	3.99	2.24	2.32	2.54	0.28
Legume Monocultures					
ALF	3.02	2.45	2.86	2.81	0.14
BFTF	2.17	3.00	2.18	1.99	0.19
CMV	1.71	2.03	2.10	2.00	0.20
LSD (0.05)	0.78	0.34	0.31	0.33	--

Table 2-12. Mean dry matter yield (2012) at four harvests of orchardgrass (OG) and cicer milkvetch (CMV) grass-legume mixture and fertilized and unfertilized orchardgrass monocultures.

	Harvest				
Treatment	1	2	3	4	LSD (0.05)
	Mg ha^{-1}				
Grass-Legume Mixtures					
OG - CMV	3.26	1.75	1.32	1.03	0.33
Grass Monoculture N rate (kg ha^{-1})					
OG 0 N	3.28	1.64	0.95	0.78	0.55
OG 67 N	3.75	1.94	1.51	1.47	0.47
OG 134 N	3.80	2.29	1.96	1.98	0.62
Legume Monocultures					
CMV	3.37	2.71	2.53	1.70	0.25
LSD (0.05)	0.78	0.29	0.36	0.27	--

Table 2-13. Mean visual estimates (2011- 2012) of the forage legume content of the legume (Leg):grass mixtures of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) with alfalfa (ALF) and birdsfoot trefoil (BFTF).

	TF		MB		OG	
Leg:Grass	ALF	BFTF	ALF	BFTF	ALF	BFTF
	%					
25:75	33	23	47	39	37	32
50:50	42	27	60	41	47	38
75:25	49	33	63	49	48	39
LSD (0.05)	8	8	7	7	5	6

Table 2-14. Mean visual estimates (2012) of the forage legume content of the legume (Leg)-grass mixtures of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) with cicer milkvetch (CMV).

Leg:Grass	TF-	MB	OG
	%		
25:75	10	21	18
50:50	16	21	21
75:25	26	30	28
LSD (0.05)	9	7	ns†

† Not significant

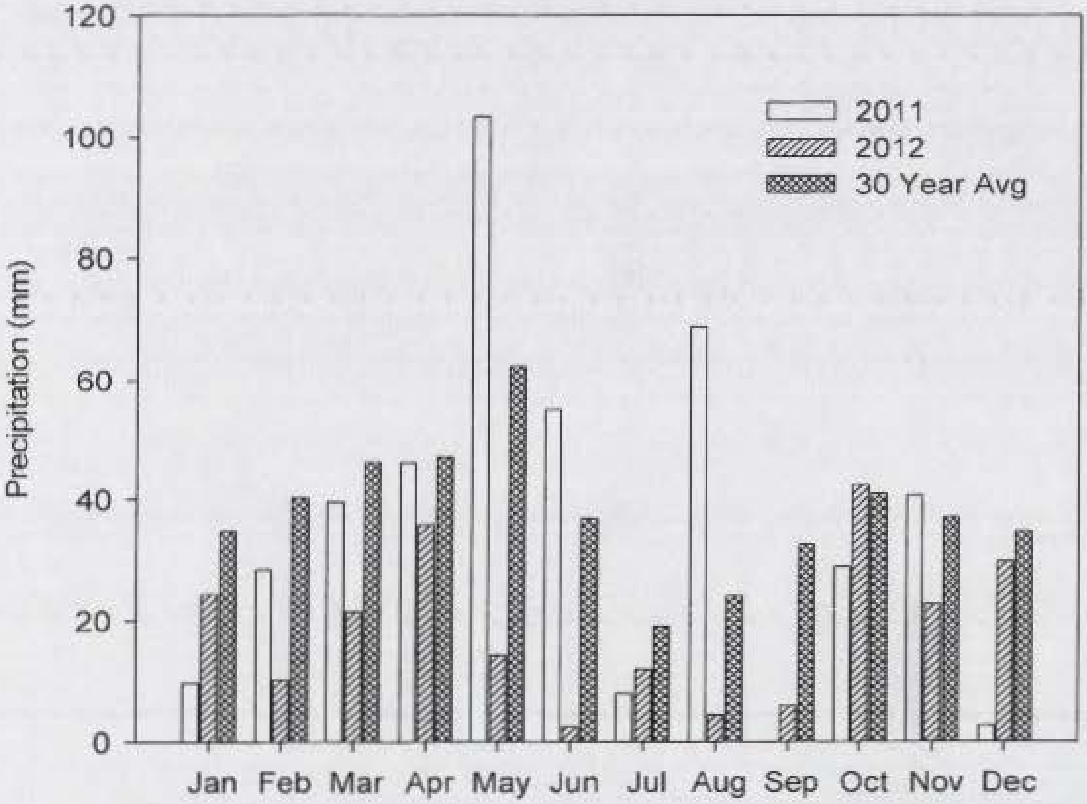

Fig. 2-1. Total precipitation by month for 2011 and 2012 and the 30 year average recorded near Lewiston, UT.

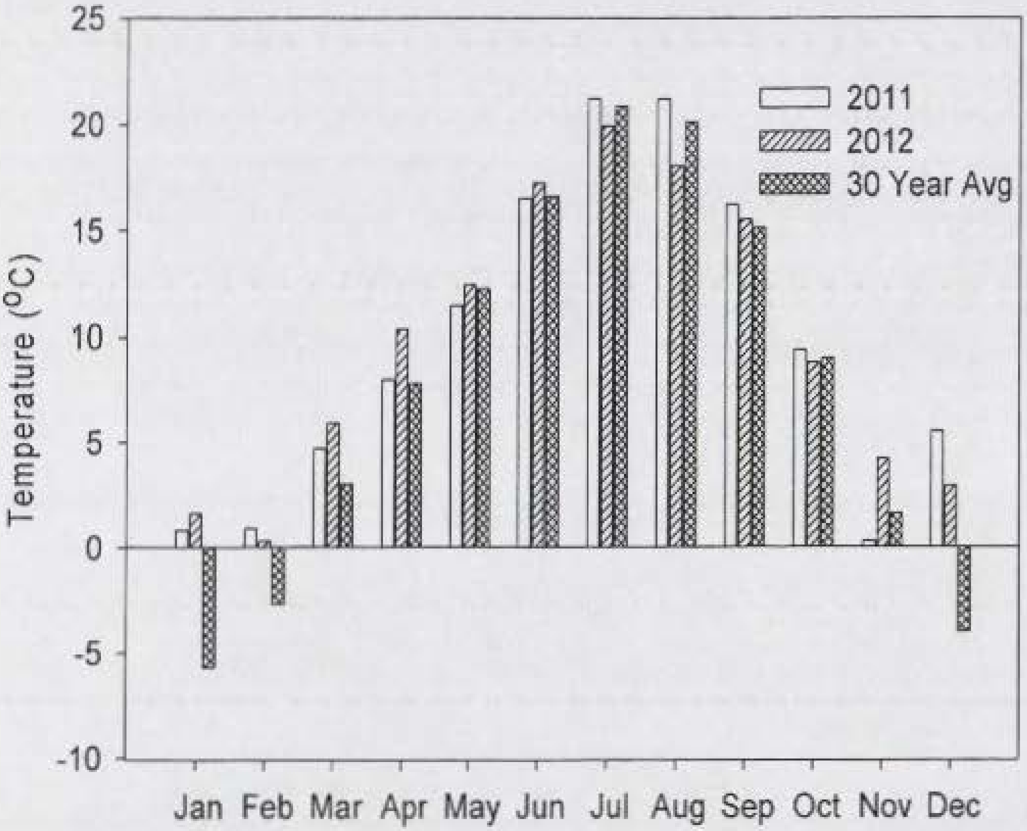

Fig. 2-2. Average temperature by month in 2011 and 2012 and the 30 year average recorded near Lewiston, UT.

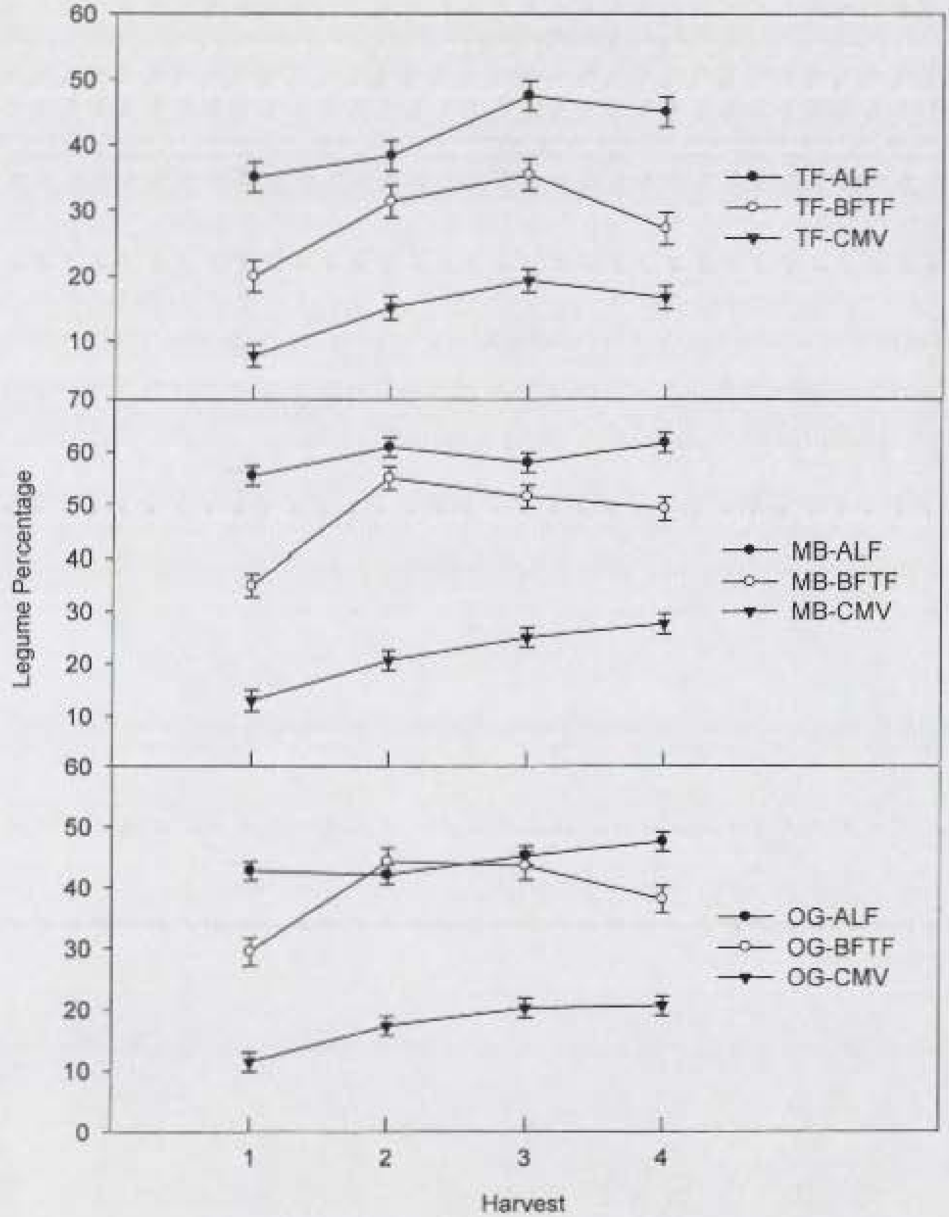

Fig. 2-3. Mean legume forage composition of alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) averaged over 2 years with tall fescue (TF), meadow brome (MB), and orchardgrass (OG). Whiskers represent standard error (*n* = 24) of the mean.

CHAPTER 3

FORAGE NUTRITIVE VALUE OF TALL FESCUE, ORCHARDGRASS, MEADOW BROME, IN BINARY MIXTURES WITH ALFALFA, BIRDSFOOT TREFOIL, AND CICER MILKVETCH

High nitrogen (N) prices have decreased the economic viability of irrigated pastures. In an effort to reduce input costs from N fertilization, forage legumes are being used to reduce N requirements and enhance forage quality of irrigated pastures. Our objective was to determine the species combinations of binary grass-legume mixtures that optimize forage quality for irrigated pastures of the Intermountain West. Tall fescue (TF), orchardgrass (OG), and meadow brome (MB), were grown with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CM) in grass-legume mixes at planting ratios of 25:75, 50:50, 75:25 percent. Plots were harvested four times during the growing seasons of 2011 and 2012. Each mixture and monoculture from the first and third harvests was analyzed for crude protein (CP) and neutral detergent fiber (NDF). Crude protein of the unfertilized TF, OG, and MB monocultures were 116, 108, and 104 g kg^{-1}, respectively. TF, OG, and MB legume-grass mixes averaged 43, 51, and 59% higher CP than their respective grass monocultures. The CP of TF mixtures were 171 g kg^{-1} TF:ALF (75:25), 147 g kg^{-1} TF:BFTF (75:25), and 130 g kg^{-1} TF:CM (50:50). CP of MB mixtures were 177 g kg^{-1} MB:ALF (75:25), 150 g kg^{-1} MB:BFTF (75:25), and 127 g kg^{-1} MB:CM (50:50). The CP of OG mixtures were 167 g kg^{-1} OG:ALF (75:25), 138 g kg^{-1} OG:BFTF (50:50), and 127 g kg^{-1}

OG:CMV (75:25). The NDF of TF mixtures were: 465 g kg^{-1} TF:ALF (75:25), 482 g kg^{-1} TF:BFTF (75:25), and 525 g kg^{-1} TF:CM (50:50). NDF of MB mixtures were: 448 g kg^{-1} MB:ALF (75:25), 492 g kg^{-1} MB:BFTF (75:25), and 539 g kg^{-1} MB:CM (50:50). The NDF of OG mixtures were 447 g kg^{-1} OG:ALF (75:25), 464 g kg^{-1} OG:BFTF (50:50), and 473 g kg^{-1} OG:CMV (75:25). Both harvests of the mixtures showed a similarly higher nutritive quality of the mixtures over the monocultures. Mixtures with ALF and BFTF had the highest CP and lowest NDF at the 75:25 planting ratio and CMV at 50:50. While all forage legumes increased the nutritive value of irrigated pasture. Alfalfa improved forage quality the most, followed by BFTF.

INTRODUCTION

Irrigated pastures in the Intermountain West region of the United States primarily are cool-season grass monocultures often fertilized with commercial nitrogen (N) (Waldron et al., 2002). As the price of N has steadily increased, it has become one of the main expenses of pasture production (Huang, 2007; Solomon et al., 2011). In addition, changes to federal land policies have reduced the availability of public lands for summer livestock grazing in many areas increasing the reliance on private pastures (Waldron et al., 2002; Lauriault et al., 2006). The loss of summer rangeland grazing areas, together with rising N prices, has prompted use of grass-legume mixtures to increase productivity of irrigated pastures.

Two measures of forage quality is commonly measured using neutral detergent fiber (NDF) and crude protein (CP) concentrations and is commonly associated with a plant's stem-to-leaf ratio, plant maturity, and soil nutrient and water availability (Buxton, 1996; Mertens, 2007). Grasses typically have lower feed quality than legumes because grasses have higher concentrations (less desirable) of neutral detergent fiber (NDF) and lower concentrations of crude protein (CP) than legumes such as alfalfa (*Medicago sativa* L.) (ALF) and birdsfoot trefoil (*Lotus corniculatus* L.) (BFTF), although this is not always true (Buxton, 1996; Mertens, 2007).

Legumes have been shown to increase the forage quality of a grass-legume mixture over a monoculture of grass in two ways. The first is through N_2 fixation and subsequent transfer of the N to the grasses (Ta and Faris, 1987; Ta et al., 1986; Heichel and Henjum, 1991; Malhi et al., 2002). Crude protein is increased by N fertilizer, while NDF doesn't change when N is applied (Buxton, 1996; Valk et al., 1996). The second way that legumes improve forage quality is by contributing plant biomass to the forage. Sleugh et al. (2000) found that CP and NDF of the grass-legume mixtures were intermediate to the grass and legume monocultures. Sleugh et al. attributed the higher CP and lower NDF of the grass-legume mixtures compared to the grass monocultures to the forage legumes in the mixtures. Studies have been conducted in the U.S. and Canada and found that grass-legume mixtures improve CP and NDF in the forage compared to the grass monocultures (Rumbaugh et al., 1982; Beuselinck et al., 1992; Malhi et al., 2002; Zemenchik et al., 2002; Kopp et al., 2003; Deak et al., 2007; Kleen et al., 2011).

The persistence of legumes in grass-legume pastures has been problematic and is considered to be one of the biggest challenges of using grass-legume mixtures (Solomon et al., 2011). Environmental conditions (Harmoney et al., 2001), interspecies competition (Skinner et al., 2004; Springer et al., 2001; Springer et al., 2007), and grazing selection pressure from livestock (Sanderson et al., 2005), are some suggested reasons why legumes fail to persist.

Alfalfa is the most widely-used forage legume for hay-cropping and pasture systems. It is valued because of its forage quality, palatability and competitiveness in comparison to BFTF and cicer milkvetch (*Astragalus cicer* L.) (CMV) (Kephart et al., 1990; Guldan et al., 2000; Jensen et al., 2001; Acharya et al., 2006). Fixation of N_2 by ALF and transfer to the neighboring grasses can be equal to an application of commercial N (Ledgard and Steele, 1992; Koenig et al., 2002). However, ALF causes bloat in ruminant livestock (Jensen et al., 2001).

Birdsfoot trefoil also been produces well in a rotationally grazed pasture (Harmoney et al., 2001). Its forage quality is similar to ALF during the midsummer months with similar nutritive value as ALF (M.D. Peel, USDA Research Geneticist, personal communication; Sleugh et al., 2000). Birdsfoot trefoil does not cause bloat due to tannins which can also increase rumen bypass protein (Min et al., 2003). New plant recruitment of BFTF in pastures mixes is possible because of high seed production where a grazing interval of 60 d or longer is allowed (Sheaffer and Evers 2007; Zemenchik et al., 2002).

Cicer milkvetch is a non-bloating legume that has shown potential under semi-arid Utah climatic conditions to increase forage production of cool-season grass pastures (Rumbaugh et al., 1982). Cicer milkvetch has been shown to have lower NDF and similar amounts of CP to both ALF and BFTF when management is similar (Kephart et al., 1990; Acharya et al., 2006).

Studies in Europe, Canada, and the United States have shown that grass-legume mixtures have potential to improve the nutritive value of irrigated pastures (Beuselinck et al., 1992; Deak et al., 2007; Guldan et al., 2000; Kleen et al., 2001, Kopp et al., 2003; Townsend et al., 1990; Ta and Faris, 1987). While some work has been done in the Intermountain West detailing the nutritive benefits and use of grass-legume mixtures (Rumbaugh et al., 1982; Jensen et al., 2001; Peel et al., 2011), more information concerning the performance of specific species combinations and optimal planting ratios to maximize forage quality of pastures is needed. The objective of this study was to identify binary grass-legume mixtures and planting ratios of tall fescue (*Festuca arundinacea* Schreb.) (TF), meadow brome (*Bromus biebersteinii* Roem. & Schult.) (MB), and orchardgrass (*Dactylis glomerata* L.) (OG); in mixtures with ALF, BFTF, and CMV, that maximized forage quality in the Intermountain Region of the Western United States.

MATERIALS AND METHODS

Data for this experiment was collected simultaneously with the forage yield experiment discussed in Chapter 2. For specifics concerning Utah State University's Intermountain Irrigated Pasture Facility and the materials and methods used for the field study, site, plot establishment, N application rates, and harvest dates, refer to Chapter 2 Materials and Methods.

Forage quality was determined using subsamples from the first and third harvests. Samples were limited to two harvests due to resource limitations. The subsamples were dried in a forced-air dryer at 60°C to a constant weight. Forage quality samples were ground using a Thomas Wiley Laboratory Model 4 mill (Swedesboro, NJ) to pass through a 1 mm screen. Ground samples were scanned using a Near Infrared Reflectance Spectroscopy (NIRS) Instrument Foss Rapid Content Analyzer (XM-1100 series) (Eden, Prairie, MN) to estimate crude protein (CP) and neutral-detergent fiber (NDF).

Twenty five samples per harvest were selected to be analyzed using wet chemistry to validate the USDA-ARS Forage and Range Laboratory's NIRS pasture equation used to determine the CP and NDF content. To prepare samples for the validation, ground samples weighing 120 - 150 mg and 490 - 510 mg were used for CP and NDF, respectively. The CP samples were placed in foil cups and analyzed using a LECO CHN-2000 series Elemental Analyzer (LECO Corp, St. Joseph, MI) to find total N content. These values were than multiplied by 6.25 to convert N to CP content. For the NDF analysis, ground samples weighing 490 - 510 mg were placed in F57 filter bags (ANKOM Technology Corporation, Macedon, NY) in preparation for NDF analysis. Analysis for NDF content was completed using an ANKOM 2000 Fiber Analyzer (ANKOM Technology Corporation, Macedon, NY) using the procedures of Georing and Van Soest, (1970). The R^2 values of the NIRS CP and NDF equations were 0.985 and 0.975, respectively.

The data was analyzed as a randomized complete block design. There were a total of 45 treatments used, with four replicates per treatment. Data was analyzed using SAS software (SAS Institute Inc., Cary, NC) using the General Linear Model procedure. The fixed factor in the analysis was treatment. Random factors consisted of harvest, year, and rep. A Fisher's protected LSD ($P < 0.05$) was used for mean separation.

Cicer milkvetch had not completely established at harvest one in 2011 and had no harvestable forage. Growing plants were visible but small and still in the seedling stage. Starting with the third harvest in 2011, measurable forage growth was present. Due to the lack of growth in 2011, only means from 2012 harvests are presented for CMV.

RESULTS

Crude Protein

Significant effects for CP were observed for legume ($P \leq 0.0001$), percent legume ($P \leq 0.0001$), and harvest ($P \leq 0.001$). An interaction between legume and percent legume ($P \leq 0.01$) was also observed. The two year mean of CP for the unfertilized TF, MB, and OG monocultures was 116, 104, and 108 g kg^{-1}, respectively (Table 3.1). To show differences among the treatments, the means of the grass-legume mixtures and N treatments were compared to their respective unfertilized grass monocultures. At 67 kg N ha^{-1}, the CP content of the fertilized grass monocultures was higher than the unfertilized monocultures by 14% in TF, 19% in MB, and 16% in OG. Similarly, the highest N rate (134 kg ha^{-1}) had 28, 24, and 32% more CP than the respective unfertilized TF, MB, and OG monocultures.

At the first harvest, CP content of the grass monocultures fertilized at the highest rate of N (134 kg ha^{-1}) was 26, 23, and 41% higher than their respective unfertilized TF, MB, and OG monocultures, and 31, 24, and 26% higher than their respective unfertilized grass monocultures at the third harvest (Table 3.2). Likewise the grass monocultures fertilized with the half rate of N (67 kg ha^{-1}) had 19, 25, and 27% higher CP than the respective unfertilized TF, MB, and OG monocultures during the first harvest. At harvest three the TF, MB, and OG monocultures fertilized at 67 kg N ha^{-1} had 11, 14, and 9% more CP than the unfertilized grass monocultures.

The ALF monoculture had the highest amount of CP at 226 g kg^{-1}. The CP of the BFTF and CMV monocultures was 95 and 94% of ALF, respectively (Table 3-1). The legume monocultures had higher CP than the unfertilized grass monocultures and grass-legume mixtures (Table 3-2). The ALF monoculture had 210 g kg^{-1} CP during the first harvest and 240 g kg^{-1} during the third harvest. The

BFTF monoculture consistently had 96% the CP of ALF at both the first and third harvests. During 2012, CMV CP was 89 and 92% of the ALF during the first and third harvests, respectively (Table 3-3). Although the grass-legume mixtures had lower CP than the legume monocultures, the mixtures had more CP than the unfertilized grass monocultures and were sufficient for livestock needs as listed by Jurgens (2002).

Tall Fescue

The TF-ALF and TF-BFTF mixtures had the highest CP content of the mixtures, the TF-ALF mixture averaged 159 g kg^{-1}; the TF-BFTF mixtures averaged 140 g kg^{-1} and the TF-CMV mixtures at 121 g kg^{-1} (2012) (Tables 3-1 and 3-4). The TF-ALF and TF-BFTF mixtures had 37 and 21% more CP, respectively, than the unfertilized TF monoculture and were similar to the monoculture fertilized at 134 kg N ha^{-1} (Table 3-1). The CP content of the TF-CMV mixtures was similar to the unfertilized TF monoculture ($P \leq 0.34$) (Table 3-4).

The 25:75 TF-ALF and 25:75 BFTF mixtures contained 171 and 147 g kg^{-1} CP, respectively (Table 3-5). These grass-legume mixtures had 47 and 27% more CP, respectively, than the unfertilized TF monocultures and were similar to the TF monoculture fertilized with 134 kg N ha^{-1} (Table 3-7). CP of the TF-BFTF planting ratios were not statistically different at $P = 0.05$. However, at the 0.07 level, the 25:75 planting ratio was higher than the other planting ratios. The CP of the TF-CMV mixtures were not different from the unfertilized TF monoculture (Table 3-6)

At the first harvest the TF-ALF mixtures contained 28% more CP than the unfertilized TF monoculture and was similar to the fertilized (134 kg ha^{-1}) TF monoculture (Table 3-2). The two-year mean TF-BFTF mixture CP and the CP of 2012 TF-CMV mixture were similar to the unfertilized TF monoculture (Tables 3-2 and 3-3). However, at the third harvest the TF-ALF, TF-BFTF, and 2012 TF-CMV mixtures contained 45, 28, and 15% more CP, respectively, than the unfertilized monocultures and, with the exception of the TF-CMV mixtures, were similar to the TF monoculture fertilized at 134 kg ha^{-1} (Tables 3-2 and 3-3). The TF-CMV mixtures were similar to the fertilized TF monoculture at 67 kg N ha^{-1}. This was caused by the increase in the legume content in the TF mixtures. The same trend happened in the MB and OG mixtures (Fig. 3-1).

Meadow Brome

The MB-ALF, MB-BFTF, and MB-CMV mixtures averaged 163, 140, and 122 g kg^{-1} CP, respectively (Tables 3-1 and 3-4). The MB-ALF and MB-BFTF mixtures both contained 57 and 35% more CP, respectively, than the unfertilized MB monoculture (Table 3-1). The MB-ALF mixtures had 26% more CP than the MB monoculture fertilized at 134 kg N ha^{-1}. The CP of the MB-BFTF mixtures were similar to the MB monoculture fertilized at 67 and 134 kg ha^{-1}, respectively. The 2012 MB-CMV mixture contained 127 g kg^{-1} CP in 2012, 28% more CP than the unfertilized MB monoculture and was similar to the grass monoculture fertilized at 134 kg N ha^{-1} (Table 3-4).

The MB-ALF and MB-BFTF mixtures had the highest CP at the 25:75 planting ratio with 70 and 44% more CP, respectively, than the unfertilized MB monoculture (Table 3-5). The MB-ALF mixtures had 37% more CP than the MB monoculture fertilized with 134 kg N ha^{-1}, while the CP content of the MB-BFTF mixtures was similar to the fertilized monoculture at 134 kg N ha^{-1}. Crude protein was numerically higher in the 25:75 MB-BFTF and the 50:50 MB-CMV mixtures although the differences between planting ratios were not significant at $P = 0.05$ (Tables 3-5 and 3-6). However, the planting ratios of the MB-BFTF mixtures were significant at $P = 0.07$. The MB-CMV planting ratios were did not differ (Table 3-6).

At the first harvest, the MB-ALF mixtures contained 60% more CP than the unfertilized MB monocultures and 31 and 28% more than the MB monocultures fertilized at 134 and 67 kg N ha^{-1}, respectively (Table 3-9). The MB-BFTF mixtures averaged 26% more CP than the unfertilized MB monoculture and was similar to both the fertilized MB monocultures. The MB-CMV mixtures during harvest one of 2012 contained 27% more CP than the unfertilized MB monocultures, and was similar to the fertilized MB monocultures (Table 3-10).

At the third harvest the MB-ALF and MB-BFTF mixtures contained 54 and 40% more CP content, respectively, than the unfertilized MB monocultures

(Table 3-9). Additionally, these mixtures contained 24 and 13% more CP, respectively, than the MB monocultures fertilized at 134 kg N ha^{-1}.

Orchardgrass

The CP of the OG-ALF, OG-BFTF, and OG-CMV mixtures was 159, 133, and 119 g kg^{-1}, respectively (Table 3-1). The OG-ALF mixtures had the highest protein content of the OG mixtures with 47% higher CP than the unfertilized monoculture and with a similar concentration of CP as the OG monoculture fertilized with 134 kg N ha^{-1}. Likewise, the OG-BFTF mixtures contained 23% more CP than the unfertilized grass monocultures and were similar to the OG monoculture fertilized at 134 kg N ha^{-1}. The mean OG-CMV mixture in 2012 had 12% more CP than the unfertilized OG monoculture and was similar to the monoculture fertilized at 67 kg N ha^{-1}.

The 50:50 and 25:75 planting ratios were similar and had the highest CP content for both the OG-ALF and OG-BFTF mixtures (Tables 3-3 and 3-6). Although the planting ratios were similar for the OG-CMV mixtures, the CP of the 25:75 planting ratio was numerically higher than the others. The 25:75 OG-ALF mixture had 55 and 17% more CP than the unfertilized monoculture and the monoculture fertilized at 134 kg N ha^{-1}, respectively. The 50:50 BFTF-OG planting ratio had 28% more CP than the OG monocultures and was similar to the OG fertilized at 134 kg N ha-1. The CP content of the 2012 25:75 OG-CMV mixture was similar to the unfertilized OG-CMV monoculture. The planting ratios of the OG-ALF mixtures were significantly different at $P = 0.05$, the OG-BFTF mixtures at $P = 0.06$, and the OG-CMV planting ratios for 2012 were not different.

At the first harvest, the OG-ALF mixtures had 52% more CP than the unfertilized grass monoculture and was similar to the monoculture fertilized at 134 kg N ha^{-1} (Table 3-11). The OG-BFTF and OG-CMV mixtures were similar to the unfertilized OG monoculture at harvest one (Tables 3-11 and 3-12). At the third harvest, the CP of the OG-ALF mixtures increased, and had 43 and 13% more than the unfertilized OG monoculture and the OG monocultures fertliilized at 134 kg N ha^{-1}, respectively (Table 3-11). Likewise, the OG-BFTF mixtures CP was 27% higher than the unfertilized OG monocultures and were similar to the OG monoculture fertilized at 134 kg N ha^{-1}. The 2012 OG-CMV mixtures were similar to the unfertilized OG monoculture (Table 3-12).

Neutral Detergent Fiber

Significant effects for neutral detergent fiber (NDF) were observed for legume ($P \leq 0.0001$) grass ($P \leq 0.0001$), harvest ($P \leq 0.0001$) and year ($P \leq 0.0001$). Intake of forage by livestock is inversely related to the NDF content (i.e., low numbers are better) representing higher nutritional value (Mertens, 2007). The unfertilized TF, MB, and OG monocultures had NDF content of 552, 583, and 503 g kg^{-1} respectively (Table 3-13). The grass monoculture fertilized at 67 kg N ha^{-1} had similar NDF contents as the unfertilized grass monocultures

(Table 3-13). The NDF content of the TF, MB, and OG fertilized at 134 kg N ha^{-1} were similar to their respective unfertilized monocultures.

The NDF of the ALF, BFTF, and CMV monocultures averaged 310, 289, and 277 g kg^{-1}, respectively (Table 3-14). The NDF of the legume monocultures was much less than the grass monocultures. For example, the ALF monocultures had at least 44% less NDF than the unfertilized TF monoculture, 47% less than the unfertilized MB monoculture, and 38% less than the unfertilized OG monoculture. BFTF and CMV also had lower NDF content than the grass monocultures. The grass-legume mixtures had at least 7% less NDF than the grass monocultures but were still higher than the legume monocultures. At harvest one, the NDF of the ALF monocultures averaged 291 g kg^{-1} and the BFTF monocultures had a similar amount as ALF at 271 g kg^{-1} (Table 3.2). In 2012, the CMV monoculture had 271 g kg^{-1} NDF; 14 and 15% less NDF than either the ALF and BFTF monocultures (Table 3-3). During harvest three the ALF monoculture averaged 330 g kg^{-1} NDF (Table 3-2). The BFTF monocultures contained a similar amount of NDF at 306 g kg^{-1}. The average NDF of CMV during the second year (2012) was similar to the ALF and BFTF monocultures at 296 g kg^{-1} (Table 3-3).

Tall Fescue

The NDF of TF-ALF, -BFTF, and -CMV mixtures averaged 490, 508, and 534 g kg^{-1}, respectively (Table 3.13). The TF-ALF mixture had 11% less NDF than the unfertilized TF monoculture and 9% less than the TF monoculture fertilized at 134 kg N ha^{-1}. The TF-BFTF mixture had 8% lower NDF than the unfertilized TF monocultures and was similar to the fertilized TF monoculture (134 kg N ha^{-1}). The TF-BFTF mixture had 6% less NDF than the unfertilized TF monoculture and was similar to the fertilized TF monoculture at 134 kg ha^{-1}. The NDF of the TF-CMV mixture was similar to the TF monoculture fertilized at 134 kg N ha^{-1}.

The 25:75 planting ratio had the lowest NDF in the TF-ALF and -BFTF mixtures at 465 and 482 g kg^{-1}, respectively (Table 3-14). The NDF of the 2012 25:75 CMV mixture was the lowest at 487 g kg^{-1} (Table 3-6). The TF-ALF mixture had 16% lower NDF than the unfertilized TF monoculture and 14% lower NDF than the TF monoculture fertilized at 134 kg ha^{-1}. Similarly, the 25:75 TF-BFTF mixture had 13, 13, and 11% lower NDF than the TF monocultures at 0, 67, and 134 kg N ha^{-1}, respectively. The 25:75 TF-CMV mixture had the lowest NDF at 487 g kg^{-1} and was similar to the TF monoculture fertilized at 67 kg N ha^{-1} (Table 3-6).

The NDF at the first harvest was similar for the TF-legume mixtures and monocultures. At the third harvest the NDF of the TF-ALF mixtures was 19 and 14% lower than the unfertilized and fertilized (134 kg N ha^{-1}) TF monocultures (Table 3-2). Similarly, the TF-BFTF mixtures had 14 and 9% lower NDF than the unfertilized and fertilized (134 kg N ha^{-1}) TF monocultures. The NDF of the 2012

TF-CMV mixture was 17% less NDF than the unfertilized TF monocultures and was similar to the TF monoculture fertilized at 134 kg N ha^{-1} (Table 3-3).

Meadow Brome

The average NDF of the MB-ALF, MB-BFTF, and MB-CMV mixtures was 480, 512, and 550 g kg^{-1}, respectively (Table 3-13). The MB-ALF and -BFTF mixtures had 18 and 12% lower NDF, respectively, than the unfertilized MB monocultures and had 16 and 10% lower NDF, than the MB monocultures fertilized at 134 kg ha^{-1}. The 2012 MB-CMV mixtures were similar in NDF content to the unfertilized MB monoculture (Table 3-4). The NDF of the 25:75 MB-ALF mixture was 23 and 21%, respectively lower than the unfertilized and 134 kg ha^{-1} MB monocultures (Table 3-14). Likewise, NDF of the 25:75 MB-BFTF mixtures was 16 and 15% , respectively lower than the unfertilized and 134 kg ha^{-1} monocultures. This suggests that the reduction in NDF of the MB mixtures was due to the legume component of the mixture (Table 3.7). During 2012, the NDF of the MB-CMV was lowest at the 50:50 planting ratio and 6% less than the unfertilized MB monoculture (Table 3-6).

When they were measured, the MB-ALF and -BFTF mixtures at both harvests had similar NDF content as one another (Table 3-9). The NDF of the MB-ALF mixture was at least 15% lower than the NDF of the unfertilized and fertilized (67 and 134 kg N ha^{-1}). The MB-BFTF mixture was similar to the unfertilized and MB monocultures fertilized at 134 kg N ha^{-1}. The NDF content of the 2012 MB-CMV mixtures was also similar to the unfertilized MB mixtures but 7% lower than the MB monoculture fertilized at 134 kg N ha^{-1}(Table 3-10).

Both the MB-ALF and MB-BFTF mixtures had lower NDF than the MB monocultures at harvest three (Table 3-9). The MB-ALF mixture had 18 and 15% lower NDF than the unfertilized and fertilized (134 kg N ha^{-1}) MB monoculture, respectively. The MB-BFTF mixtures had 16 and 13% lower NDF than the unfertilized and fertilized (134 kg N ha^{-1}) MB monocultures, respectively. The 2012 MB-CMV mixtures also had 14 and 9% lower NDF than the unfertilized and fertilized (134 kg ha^{-1}) MB monocultures, respectively (Table 3-10). The 2012 MB-CMV mixtures had 10% lower NDF than the unfertilized MB mixtures and was similar to the MB monoculture fertilized at 134 kg N ha^{-1}.

Orchardgrass

The average NDF content of the OG mixtures was 453, 469, and 445 g kg^{-1} for the OG-ALF, OG-BFTF, and 2012 OG-CMV mixtures, respectively (Tables 3-4 and 3-13). The OG-ALF and OG-BFTF mixtures contained higher NDF than the unfertilized OG monocultures by 10 and 7%, respectively. The NDF of the 2012 OG-CMV mixtures were similar to the unfertilized OG monocultures (Table 3-4).

The planting ratios for the OG-legume mixtures did not have a strong influence on NDF and were not statistically different; however, there were small numerical differences. The 25:75 OG-ALF mixtures numerically contained the lowest amount of NDF OG-ALF planting ratios at 447 g kg^{-1} (Table 3-14). The OG-BFTF mixtures contained the lowest amount of NDF at the 25:75 planting ratio at 436 g kg^{-1}. The NDF of the OG-CMV mixtures did not change between planting ratios; however, the 25:75 mixture had the lowest NDF of the mixtures (Table 3-6). The OG-ALF and OG-BFTF mixtures contained 24, and 8% lower NDF, respectively, than the unfertilized OG monocultures (Table 3-14). The OG-CMV NDF was similar to the unfertilized OG monocultures (Table 3-6).

At harvest one, the OG-ALF mixtures contained 9% lower NDF than the unfertilized OG mixtures and 13 and 16% lower NDF than the fertilized monocultures at 67 and 134 kg N ha^{-1} (Table 3-11). At the third harvest the OG-ALF mixture had 11, 13, and 13% lower NDF than the unfertilized, 67, and 134 kg N ha^{-1} OG monocultures, respectively.

The NDF content of the OG-BFTF mixtures during harvest one was 464 g kg^{-1} (Table 3-11). The NDF content of this mixture was not different from the unfertilized and the OG monoculture fertilized at 67 kg N ha^{-1}. At harvest three, the OG-BFTF mixture contained 10, 12, and 12% lower NDF than the OG monocultures at 0, 67, and 134 kg N ha^{-1}, respectively. During 2012, the OG-ALF mixtures had 9% lower NDF than the OG-CMV mixtures at harvest one (Table 3-12).

The OG-BFTF mixtures were intermediate to the OG-ALF and OG-CMV mixtures during harvest one. (Table 3-11) There was no difference in NDF between the three OG-legume mixtures during harvest three. The OG CMV monocultures during 2012 were no different from the unfertilized OG monocultures but contained 12 and 11% less NDF than the OG monocultures fertilized at 67 and 134 kg N ha^{-1} respectively during harvest one (Table 3-12). The NDF content of the OG-CMV mixtures during harvest three was also not different from the unfertilized OG monoculture and was 14 and 15% lower than the OG monocultures fertilized at 67 and 134 kg N ha^{-1}, respectively.

DISCUSSION

The use of grass-legume mixtures improved both the CP and NDF of pastures. The CP of the grass-legume mixtures with TF, MB, and OG with ALF and BFTF were similar to or higher than, the CP of the grass monocultures fertilized at 134 kg N ha^{-1} (Tables 3-1 and 3-5). CP increased with increasing legumes. Kleen et al. (2011) also noticed that the legume component of the grass-legume mixture was important for CP and that different species combinations had varying amounts of CP, with ALF containing the most.

The NDF of the mixtures of TF, MB, and OG with ALF and BFTF were much lower than their respective grass monocultures (Table 3-13). NDF of cool-season grasses is not affected by N fertilizer applications consistent with past studies (Buxton, 1996; Valk et al., 1996). The low NDF content of the mixtures in comparison with the grass monocultures was by the legume component; NDF decreased (improved) as the legume component increased (Table 3-14).

CP and NDF of the mixtures and fertilized grass monocultures improved between the first and third harvests. For the grass-legume mixtures this was caused by: 1) Increase of the legume component of the mixtures during the third harvest (Fig 3-1); and 2) because the grasses were in the vegetative stage during the third harvest. This was especially important for NDF because it is primarily affected by plant maturity (Buxton, 1996). At the first harvest, the grasses were heading, with the exception of OG which never matured. This caused the NDF of orchardgrass mixtures to be lower than those of the other grass species. All of the mixtures were sufficient to provide the proper CP for the needs of livestock as reported by Jurgens (2002).

The forage quality (CP, NDF) reported in our study was lower than those listed by Sleugh et al. (2000). However, the CP and NDF content of the mixtures during the four harvests recorded by Sleugh et al. (2000) was informative and comparable to the values obtained for the OG-legume mixtures for the two harvests which we analyzed and would have been similar if all four harvests had been analyzed. Sleugh et al. (2000) found that in a four harvest system, the OG-ALF had higher CP than the OG-BFTF mixture. The CP of the OG-ALF and OG-BFTF mixtures were similar through July (second harvest) with the CP of OG-BFTF declining in relation to ALF during the late summer and early fall months. Our findings are in agreement with Sleugh et al. (2000) that forage quality (CP and NDF) of a grass-legume pasture can be higher at midsummer when the legume component is most productive than during late spring and early summer.

As would be expected, the 25:75 grass-legume planting ratio resulted in plant populations with the highest legume component in the mixtures at 63% for the MB-ALF mixtures, with the CMV component of the TF-CMV having the least legume forage at 26%. This agreed with the results of Mallarino and Wedin (1990) who planted legumes at five planting ratios. It was observed that the resulting plant populations were different from the target planting ratios because of interspecies competition. They also observed that the optimal planting ratios for forage yield and quality were not the same.

The 25:75 grass-legume mixtures had the highest CP and lowest NDF of the grass-ALF and -BFTF mixtures (Table 3-5). In contrast, the 50:50 grass-legume mixtures were the most productive, and because of plant competition, the most competitive (highest forage producing component) species in the mixture consisted of more of the forage. For example, the 50:50 TF-ALF mixture was the highest producing and averaged 42% ALF during 2011-2012. The MB-ALF mixture averaged 60% ALF and was the third highest yielding mixture but contained higher CP compared to lower quality grass-legume mixtures. As a result the 50:50 planting ratio could be used to maximize pasture production with only a small reduction of the nutritive value of the mixture.

In our study, only the MB-CMV mixture of the CMV mixtures had higher CP than their respective, unfertilized grass monoculture. The MB-CMV mixture had 23% more CP than the unfertilized MB monoculture (Table 3-4). The TF-CMV and OG-CMV mixtures were similar in CP to the unfertilized grass monocultures. The similarities between the mixtures containing CMV and the grass monocultures were caused by a low amount of CMV in the TF- and OG-CMV mixtures; with CMV estimated to make up less than 30% of the forage of those mixtures. This trend in the MB- and OG-CMV mixtures may change with stand age. Townsend et al. (1990) recorded that CMV was estimated to make up the majority of the harvested forage during the third and fourth years in MB- and OG-CMV mixtures. In contrast, Lauriault et al. (2003) reported that while CMV was still found in the mixtures of TF-CMV after five years, it was not plentiful enough to be beneficial in irrigated pasture agreeing with earlier conclusions of Guldan et al. (2000) who reported the results of the first four years of the same study. Our results support these conclusions that CMV does not compete with TF and is not the best choice for irrigated pasture.

In conclusion, grass-legume mixtures increased CP and reduced NDF in comparison to unfertilized grass monocultures. The 25:75 TF-ALF, 25:75 MB-ALF, and 25:75 OG-ALF had the most CP of the grass-legume mixtures. The amount of CP found in the ALF mixtures was similar to, or exceeded the CP found in the grass mixtures fertilized at 134 kg N ha^{-1}. The BFTF mixtures also contained similar amounts of CP as the grass monocultures fertilized at 134 kg N ha^{-1}. The CP of the CMV mixtures was equivalent to the grass monocultures fertilized at 67 kg N ha^{-1}. The legumes in the grass-legume mixtures were the reason for the improved forage quality compared to the grass monocultures and the grass did not influence the CP content of the mixtures.

The 25:75 OG-ALF, 25:75 OG-BFTF, and 25:75 MB-ALF mixtures had the lowest NDF of the grass-legume mixtures and had much lower NDF than the grass monocultures fertilized at 134 kg N ha^{-1}. The grass-legume mixtures all contained lower NDF that the fertilized grass monocultures. The legume component was the reason both CP and NDF was lower in the grass-legume mixtures compared to the grass monocultures. The grass component had an effect on the NDF content with OG having the lowest NDF of the grasses. The 25:75 OG-ALF mixture had the best forage quality of the mixtures and could be used as a high quality forage in pasture. Because the OG-ALF mixture was one of the lowest producing mixtures, a 50:50 TF or MB grass-legume mixture with ALF should be used as to balance forage production and quality. Birdsfoot trefoil was similar to ALF in forage production, CP, and NDF, and should be used as a non-bloat alternative to ALF in irrigated pastures in the Intermountain West.

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Table 3-1. Mean crude protein (CP) (2011- 2012) of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in monocultures and mixtures with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV).

	Grass-Legume Mixtures			Grass Monoculture N rates ($kg\ ha^{-1}$)			
Grass Species	ALF	BFTF	CMV	0 N	67 N	134 N	LSD (0.05)
				$g\ kg^{-1}$			
TF	159	140	126	116	133	149	24
MB	163	140	123	104	124	129	22
OG	159	133	119	108	125	143	21
LSD (0.05)	ns†	ns	ns	ns	ns	ns	--

† Not significant

Table 3-2. Mean crude protein (CP) and neutral-detergent fiber (NDF) (2011-2012) of tall fescue (TF) mixtures with alfalfa (AF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) at two harvests.

	Harvest					
	CP			NDF		
Treatment	1	3	LSD(0.05)	1	3	LSD(0.05)
	g kg^{-1}					
Grass-Legume Mixtures						
TF - ALF	127	192	11	530	450	16
TF - BFTF	112	169	14	544	473	ns
TF - CMV	100	152	8	561	506	12
Grass Monocultures N Rate (kg ha^{-1})						
TF - 0 N	99	132	ns†	554	550	ns
TF - 67N	118	147	ns	572	538	20
TF - 134 N	125	173	17	556	522	20
Legume Monocultures						
ALF	210	240	8	290	330	9
BFTF	201	231	11	271	306	25
CMV	188	227	ns	271	280	ns
LSD (0.05)	19	15	--	39	41	--

† Not significant

Table 3-3. Mean crude protein (CP) and neutral-detergent fiber (NDF) (2011-2012) of tall fescue (TF) mixtures with alfalfa (AF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) at two harvests.

	Harvest					
	CP			NDF		
Treatment	1	3	LSD (0.05)	1	3	LSD (0.05)
	g kg^{-1}					
Grass-Legume Mixtures						
TF - ALF	136	197	20	522	396	36
TF- BFTF	112	169	23	532	421	43
TF- CMV	93	149	12	546	449	29
Grass Monocultures N Rates (kg ha^{-1})						
TF - 0 N	99	113	ns[†]	532	535	ns
TF - 67 N	122	138	ns	554	507	ns
TF - 134 N	136	171	ns	541	493	ns
Legume Monocultures						
ALF	211	229	ns	315	322	ns
BFTF	190	216	13	320	312	ns
CMV	188	211	ns	271	296	ns
LSD (0.05)	14	13	--	27	27	--

[†] Not significant

Table 3-4. Mean crude protein (CP) and neutral detergent fiber (NDF) (2012) of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in mixtures with cicer milkvetch (CMV) and grass monocultures fertilized at 0, 67, and 134 kg ha^{-1} nitrogen (N).

	CP				NDF			
Treatment	TF	MB	OG	LSD (0.05)	TF	MB	OG	LSD (0.05)
	g kg^{-1}							
Grass-Legume Mixture								
CMV	121	122	127	ns†	497	521	445	32
Grass Monocultures N Rate (kg ha^{-1})								
0 N†	106	99	114	ns	483	494	435	40
67 N	130	115	120	ns	530	562	511	ns
134 N	154	120	143	26	517	562	513	ns
LSD (0.05)	ns	17	18	--	27	ns	27	--

† Not significant

Table 3-5. Mean crude protein (CP) (2011- 2012) of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in monocultures and mixtures with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) at planting ratios of 25:75, 50:50, 75:25 and grass monocultures fertilized at 0, 67, and 134 kg N ha^{-1}, mixtures were not fertilized.

	Tall Fescue			Meadow Brome			Orchardgrass		
Treatment	ALF	BFTF	CMV	ALF	BFTF	CMV	ALF	BFTF	CMV
					g kg^{-1}				
Legume:Grass Planting Ratios									
25:75	144	135	122	147	130	118	147	124	119
50:50	161	138	130	165	139	127	162	138	112
75:25	171	147	127	177	150	123	167	136	127
100:0	226	216	213	226	216	213	226	216	213
Grass Monoculture N Rate (kg ha^{-1})									
0 N	116	116	116	104	104	104	108	108	108
67 N	133	133	133	124	124	124	125	125	125
134 N	149	149	149	129	129	129	143	143	143
LSD (0.05)	22	22	20	18	21	16	19	20	17

Table 3-6. Mean crude protein (CP) and neutral detergent fiber (NDF) (2012) of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in monocultures and mixtures with cicer milkvetch (CMV) at planting ratios of 25:75, 50:50, and 75:25, and grass monocultures fertilized at 0, 67, and 134 kg N ha^{-1}.

	CP			NDF		
Treatment	TF	MB	OG	TF	MB	OG
	g kg^{-1}					
Legume:Grass Planting Ratios						
25:75	117	115	128	503	520	458
50:50	125	127	123	503	526	442
75:25	122	125	130	487	518	436
100:0	202	200	195	263	288	301
Grass Monoculture N Rate (kg ha^{-1})						
0 N	106	99	114	533	557	472
67 N	130	115	120	530	562	511
134 N	154	120	143	517	562	513
LSD(0.05)	28	25	24	46	58	38

Table 3-7. Mean visual estimates (2011- 2012) of the forage legume content of the grass-legume mixtures consisting of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) with alfalfa (ALF) and birdsfoot trefoil (BFTF).

	TF		MB		OG	
Legume:Grass	ALF	BFTF	ALF	BFTF	ALF	BFTF
	%					
25:75	33	23	47	39	37	32
50:50	42	27	60	41	47	38
75:25	49	33	63	49	48	39
LSD (0.05)	8	8	7	7	5	6

Table 3-8. Mean visual estimates (2012) of the forage legume content of the grass-legume mixtures consisting of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) with cicer milkvetch (CMV).

	CMV		
Legume:Grass	TF-	MB	OG
	%		
25:75	10	21	18
50:50	16	21	21
75:25	26	30	28
LSD (0.05)	9	7	ns†

† Not Significant

Table 3-9. Mean crude protein (CP) and neutral-detergent fiber (NDF) (2011-2012) of meadow brome (MB) mixtures with alfalfa (AF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) at two harvests.

	Harvest Date					
	CP			NDF		
Treatment	1	3	LSD (0.05)	1	3	LSD (0.05)
	g kg^{-1}					
Grass-Legume Mixtures						
MB – ALF	141	185	ns†	501	460	ns
MB - BFTF	111	168	ns	553	471	ns
MB - CMV	108	138	9	576	524	21
Grass Monoculture N Rates (kg ha^{-1})						
MB - 0 N	88	120	13	603	563	32
MB - 67 N	110	137	ns	590	559	ns
MB - 134 N	108	149	10	598	540	ns
Legume Monocultures						
ALF	210	240	8	290	330	9
BFTF	201	231	11	271	306	25
CMV	188	227	ns	271	280	ns
LSD (0.05)	24	17	--	56	43	--

† Not Significant

Table 3-10. Mean crude protein (CP) and neutral-detergent fiber (NDF) (2012) of meadow brome (MB) mixtures with alfalfa (AF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) at two harvests.

	Harvest Date					
	CP			NDF		
Treatments	1	3	LSD (0.05)	1	3	LSD (0.05)
	g kg^{-1}					
Grass-Legume Mixtures						
MB - ALF	148	183	18	472	433	ns
MB - BFTF	117	166	20	544	432	58
MB - CMV	107	138	18	568	474	38
Grass Monoculture N Rates (kg ha^{-1})						
0 N	84	114	11	585	529	ns
67 N	103	127	ns†	596	528	ns
134 N	96	144	18	609	515	ns
Legume Monocultures						
ALF	211	229	ns	315	322	ns
BFTF	190	216	13	320	312	ns
CMV	188	211	ns	271	296	ns
LSD (0.05)	21	20	--	40	53	--

† Not Significant

Table 3-11. Mean crude protein (CP) and neutral-detergent fiber (NDF) (2011-2012) of orchardgrass (OG) mixtures with alfalfa (AF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) at two harvests.

	Harvest Date					
	CP			NDF		
Treatments	1	3	LSD (0.05)	1	3	LSD (0.05)
	g kg^{-1}					
Grass-Legume Mixtures						
OG - ALF	137	180	13	435	471	ns
OG - BFTF	105	160	13	464	474	ns
OG - CMV	100	138	7	468	500	19
Grass Monoculture N Rates (kg ha^{-1})						
OG - 0 N	90	126	ns†	477	528	ns
OG - 67 N	114	137	ns	498	541	ns
OG - 134 N	127	159	ns	516	536	ns
Legume Monocultures						
ALF	210	240	8	290	330	9
BFTF	201	231	110	271	306	25
CMV	188	227	ns	271	280	ns
LSD (0.05)	18	18	--	41	43	--

† Not significant

Table 3-12. Mean Crude Protein (CP) and neutral-detergent fiber (NDF) (2012) of orchardgrass (OG) mixtures with alfalfa (AF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) at two harvests.

	Harvest					
	CP			NDF		
Treatments	1	3	LSD(0.05)	1	3	LSD (0.05)
	g kg^{-1}					
Grass-Legume Mixtures						
OG - ALF	162	187	16	400	441	35
OG - BFTF	116	171	18	425	429	ns
OG - CMV	109	145	13	442	449	ns
Grass Monoculture N Rate (kg ha^{-1})						
OG - 0 N	96	132	ns†	461	483	ns
OG - 67 N	104	135	ns	500	523	ns
OG - 134 N	137	150	ns	495	530	ns
Legume Monocultures						
ALF	211	229	ns	315	322	ns
BFTF	190	216	13	320	312	ns
CMV	188	211	ns	271	296	ns
LSD (0.05)	16	19	—	30	54	--

† Not significant

Table 3-13. Mean neutral detergent fiber (NDF) (2011- 2012) of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in monocultures and mixtures with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV), mixtures were not fertilized.

	Grass-Legume Mixtures			Grass Monoculture N rates (kg ha^{-1})			
Grass	ALF	BFTF	CMV	0 N	67 N	134 N	LSD (0.05)
	g kg^{-1}						
TF	490	508	534	552	555	539	38
MB	480	512	550	583	574	569	44
OG	453	469	484	503	519	526	33
LSD (0.05)	25	28	19	26	24	ns†	--

† Not significant

Table 3-14. Mean of neutral detergent fiber (NDF) (2011- 2012) of tall fescue (TF), meadow brome (MB), and orchardgrass (OG) in monocultures and mixtures with alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) at planting ratios of 25:75, 50:50, 75:25 and grass monocultures fertilized at 0, 67, and 134 kg N ha^{-1}, mixtures were not fertilized.

	Tall Fescue			Meadow Brome			Orchardgrass		
Treatments	ALF	BFTF	CMV	ALF	BFTF	CMV	ALF	BFTF	CMV
	g kg^{-1}								
Legume:Grass Planting Ratios									
25:75	503	521	540	524	536	560	462	493	492
50:50	504	523	535	470	507	551	452	452	488
75:25	465	482	525	448	492	539	447	464	473
100:0	310	289	277	310	289	277	310	289	277
Grass Monoculture N Rates (kg ha^{-1})									
0 N‡	552	552	552	583	583	583	503	503	503
67 N	555	555	555	574	574	574	519	519	519
134 N	539	539	539	569	569	569	526	526	526
LSD (0.05)	34	37	28	35	42	33	29	36	28

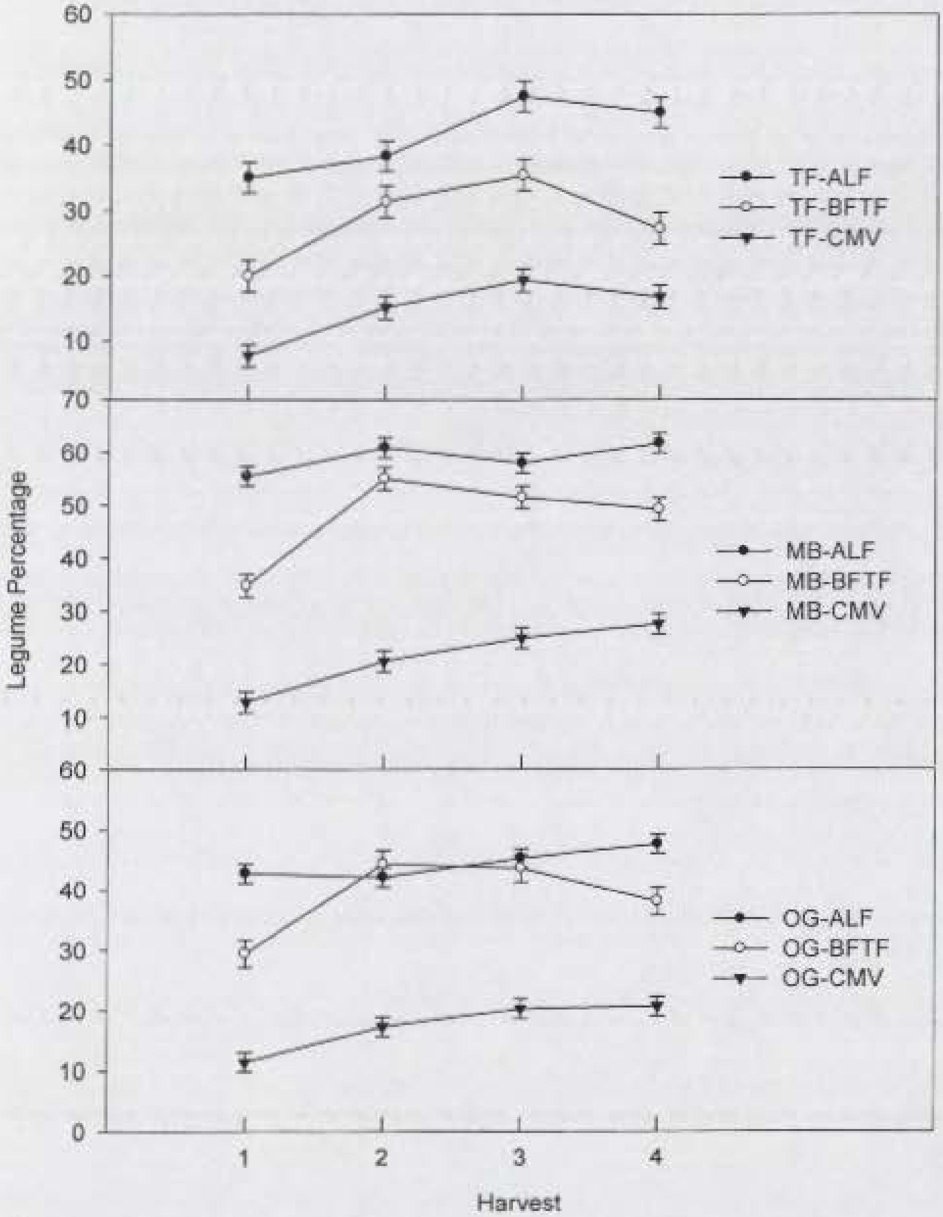

Fig. 2-3. Mean legume forage composition of alfalfa (ALF), birdsfoot trefoil (BFTF), and cicer milkvetch (CMV) averaged over 2 years with tall fescue (TF), meadow brome (MB), and orchardgrass (OG). Whiskers represent standard error (n = 24) of the mean.

CHAPTER 4

SUMMARY AND CONCLUSIONS

Improved forage yield and quality of irrigated pastures is attributed to nitrogen (N) fertilizer and is a constant cost of irrigated pasture production (Solomon et al., 2011). The rising cost of nitrogen (N) has increased the need for pasture management methods to increase forage production while lowering costs. Studies have documented the potential for grass-legume pastures to be used instead of fertilized grass pastures to improve forage yield and quality (Sleugh et al., 2000; Guldan et al., 2000, Gierus et al., 2012). The purpose of this study was to identify grass-legume mixtures for use in the Intermountain West to maximize forage production and quality of irrigated pastures. Another objective was to identify planting ratios which optimized pasture production.

Three grass species common to pasture of the Intermountain West were used, including: tall fescue (*Festuca arundinacea* Schreb.) (TF), meadow brome (*Bromus biebersteinii* Roem. & Schult.) (MB), and orchardgrass (*Dactylis glomerata* L.) (OG). They were grown in mixtures with: alfalfa (*Medicago sativa* L.) (ALF), birdsfoot trefoil (*Lotus corniculatus* L.) (BFTF), and cicer milkvetch (*Astragalus cicer* L.) (CMV). The forage production and quality of the grass-legume mixtures were compared to grass monocultures fertilized at 0, 67, or 134 kg N ha^{-1}, and the legume monocultures. These comparisons have identified possible grass-legumes mixtures that have similar production as pastures fertilized with 134 kg N ha^{-1} and increase forage quality for livestock production.

In addition, planting ratios that optimize forage production and quality for each grass-legume mixture have been identified for livestock producers to realize optimal forage yield and quality for irrigated pasture.

Chapter two reported the forage production of the grass-legume mixtures and their optimal planting ratio. The seasonal distribution of forage for each grass-legume mixture was also reported and compared to the production of the grass monocultures.

The TF-ALF (50:50), TF-BFTF (50:50), and MB-ALF (50:50) mixtures were the three highest yielding and produced 34, 28, and 40% more than their respective unfertilized grass monocultures. The 50:50 planting ratio was found to maximize forage yield compared to the 75:25 and 25:75 grass-legume planting ratios. The MB and OG in mixtures with ALF and BFTF showed similarly higher forage production compared to the unfertilized and fertilized (134 kg N ha^{-1}) grass monocultures.

Cicer milkvetch is known to take two years to establish (Acharya et al., 2006), and only the MB-CMV mixture had higher forage production than the unfertilized MB monoculture. CMV in particular did not combine well with TF in agreement with studies by Guldan et al. (2000) and Dobson et al. (1976). Other literature suggests that forage production of the OG-CMV mixture may increase as the stand ages (Townsend et al., 1990).

The grass-legume mixtures and their optimal planting ratio from greatest to least were: TF-ALF 50:50 > TF-BFTF 50:50 > MB-ALF 50:50 > MB-BFTF

50:50 > OG-ALF 50:50 > OG-BFTF 50:50, MB-CMV 50:50 > TF-CMV 25:75 > OG-CMV 75:25.

The grass-legume mixtures had more uniform seasonal forage distribution than the unfertilized grass legume mixtures and were similar to the grass monocultures fertilized at 134 kg N ha^{-1}, with the exception of the CMV mixtures. The forage legumes compensated for lack of summer growth of the cool-season grasses during the second through the fourth harvests thereby improving the seasonal forage distribution. The forage seasonal distribution for each grass-legume mixture changed depending on which legume was in the mixture. The grass-ALF mixtures yielded most consistently throughout the year. The -BFTF mixtures yielded the highest at the second and third harvests. During 2012, the CMV mixture had the highest forage yield at the first harvest but only improved the seasonal distribution of the MB- and OG-CMV mixtures compared to their respective unfertilized grass monocultures during the last two harvests.

Chapter three reported the forage quality of the of grass-legume mixtures in comparison with the grass and legume monocultures. The forage quality parameters that were measured were crude protein (CP) and neutral detergent fiber (NDF). It was found that the grass-legume mixtures had higher CP and lower NDF, therefore better forage quality than the unfertilized grass monocutlures. This agreed with the results of other studies (Lauriault et al., 2006; Rumbaugh et al., 1982; Sanderson et al., 2005; Sleugh et al., 2000).

Increased legume content in the grass-legume mixtures was correlated with improved CP. The highest legume component had the highest CP and the lowest NDF.

Overall, MB, TF, and OG in combination with ALF had the highest crude CP of the legumes at 177, 171, and 167 g kg^{-1}, respectively. Each of these mixtures contained at least 55 g kg^{-1} more than the unfertilized monocultures. The CP of the grass-legume mixtures from greatest to least were: MB-ALF 25:75 > TF-ALF 25:75 > OG-ALF 25:75 > MB-BFTF 25:75 > TF-BFTF 25:75 a> OG-BFTF 50:50. In 2012, the CMV mixtures with the most CP from greatest to least was the OG-CMV 25:75 > MB-CMV 50:50 > TF-CMV mixtures 50:50.

The OG-ALF mixture had the lowest NDF of the mixtures with 453 g kg^{-1}. The other OG mixtures had similarly lower NDF content as the TF and MB mixtures. The OG-BFTF and CMV mixtures were 469, and 484 g kg^{-1} NDF respectively. The CMV mixture in combination with MB and TF had the highest NDF content of the mixtures of 534 and 550 g kg^{-1} respectively. The maturity of the grass component and the legumes in the mixtures had an influence on the NDF of the mixtures. The NDF of the fertilized grass monocultures was similar to the unfertilized grass monocultures. This indicates that the NDF content of the grass-legume mixtures was because of the forage legumes. The grass-legume mixtures and the optimal planting ratio from least NDF to the most were: OG-ALF 25:75 < MB-ALF 25:75 < OG-BFTF 50:50 < TF-ALF 25:75 < TF-BFTF 25:75 < MB-BFTF and the 2012 25:75 OG-CMV 25:75 > TF-CMV 25:75 > MB-CMV 25:75.

The CP and NDF improved uniformly between the first and third harvests for the grass-legume mixtures and the grass monocultures. This effect was due 1) the grass maturity at the time of the first harvest. MB and TF were both heading at the first harvest while OG was not, therefore causing the lower NDF of OG. 2) The legume component was largest during the midsummer months causing more legume forage (with higher CP and lower NDF) to be harvested.

Irrigated grass-legume pasture containing TF, MB or OG in mixtures with ALF or BFTF produced similar amounts of forage as a pasture fertilized with 134 kg N ha^{-1}. The 50:50 TF-ALF mixture produced the most forage of the grass-legume mixtures. The grass-legume mixtures also had more uniform seasonal forage distribution than the unfertilized grass monocultures and were similar to the grass monocultures fertilized at 134 kg N ha^{-1}, and can be used to eliminate the need for N applications in irrigated pasture.

The grass-legume mixtures had similar CP and lower NDF than a pasture fertilized with 134 kg N ha^{-1}. Because CP and NDF are affected by the legume species and quantity, a planting ratio of 25:75 has the highest CP and lowest NDF of the planting ratios tested. Of the legumes, the OG-ALF mixtures had the highest CP and lowest NDF of the mixtures. Cicer milkvetch is not suited for use in irrigated pasture although use of CMV in dry-land or low irrigation grass-legume mixtures with MB or OG may be used.

Because forage yield is thought to be of higher importance by producers, the 50:50 TF-ALF mixture should be used to achieve the optimal balance between forage quality and yield. MB could be substituted for TF if desired. BFTF had comparable forage production and quality as ALF and could be used as an alternative to ALF if a non-bloating legume is desired. If the highest forage quality is desired, the OG-ALF mixture should be used.

The results of this study will be used to correct to the Utah State University Cooperative Extension publication AG-FG-03 written by Koenig et al. (2002), titled Fertilizer Management for Grass and Grass-Legume Mixtures. Specifically, table 2 will be modified to reflect the results from this study. The timings of N applications may also be changed to recommend three equal N applications for irrigated pasture. In addition the table will show no needed N for the grass-legume mixtures with 25:75 and 50:50 grass-legume mixtures with desired yield potential being 3.6 - 5.4 Mg and under. Another Extension publication on the establishment and production of grass-legume pastures will also be written. These changes will be used by producers to improve the economics and current pasture establishment and fertilization practices of grass-legume pastures in the Intermountain West.

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