FORAGE QUALITY CHARACTERISTICS OF BARLEY IRRIGATED WITH COALBED METHANE DISCHARGE WATER.

by

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ABSTRACT

Two experiments were conducted to determine the effects of coalbed methane (CBM) discharge water as an irrigation source in comparison with the use of well water. Three plot trials were conducted in two consecutive growing seasons with three replicates of 14 barley cultivars under each water treatment.

Barley cultivars were grown under covered greenhouses to prevent uncontrolled precipitation. Each greenhouse received one of two water treatments: either well water (EC = 0.43 dS m^{-1}, SAR = 0.25) or synthesized CBM discharge water (EC = 1.6 dS m^{-1}, SAR = 35). Plots were irrigated with 5.1 cm of respective treatment water on the day of seeding and flood irrigated with treatment water on a weekly basis.

Cultivars were sampled on three cutting dates within each trial, when the majority of the entries were in the boot, anthesis, and milk stages of maturity. Barley forage was analyzed for yield, height, and forage quality with relation to livestock requirements. Cultivars were dried, ground and analyzed for yield, dry matter (DM), acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), nitrate (NO_3-N) concentrations, *in vitro* dry matter digestibility (IVDMD), and mineral concentrations.

Coalbed methane discharge water significantly reduced ($P<0.10$) barley forage yield, height, and NO_3-N concentrations. Forages irrigated with well water yielded higher ($P<0.10$) than those irrigated with CBM water (6499 vs 4937 kg ha^{-1}) and were taller (49 vs 36 cm). Nitrate concentrations were lower ($P<.010$) in forages irrigated with CBM water than well water (0.66 vs 3.3 mg g^{-1}). No differences ($P>0.10$) were seen between water treatments for the remaining parameters.

Use of CBM discharge water as an irrigation source reduced yield, had a negative impact on height, and CP concentrations and reduced nitrate concentrations. Few differences were detected in mineral concentrations between water treatments. More research is necessary to determine the long term impacts of CBM discharge water on soil and plant quality.

CHAPTER 1

INTRODUCTION

Livestock producers in southeastern Montana are dependent upon range use, irrigated hay production, and purchased hay. Significant year to year variation in forage production and quality exists due to dependency upon the climate and inadequate water for irrigation. In 2004, southeastern Montana produced 140,769 harvested hectares of non-irrigated crops vs. 25,975 harvested hectares of irrigated crops (Montana Agricultural Statistics, 2004). Needs of livestock producers in southeastern Montana are not met with locally produced forage alone. Producers are required to purchase feed sources from outside of their region. Additionally, there are inadequate amounts of irrigation water available in southeastern Montana to meet potential crop yields.

Coalbed methane (CBM) discharge water, a by-product of CBM extraction, could be available at large volumes and possibly reduce this variability and increase production potentials for irrigated producers in this region.

Coalbed methane water is known to have elevated salinity and sodium levels. Salinity and sodium are common sources of stress to plant environments. Plants growing in soils which are high in saline and sodium will often have stunted growth and reduced yields. As salt concentrations increase above a threshold level, growth rate and size of the plant decrease (Maas and Hoffman, 1977). Barley (*Hordeum vulgare*) is know to be adapted to saline conditions and has a high threshold or salt tolerance level. Barley grain production is maintained up to an EC of 7 dS m^{-1} and has a maximum salt tolerance of EC 17dS m^{-1}. (Majerus,1996).

Many studies have addressed the effects of salinity and sodium on the agronomic qualities of barley, such as growth and yield. Few studies have evaluated the effects of salinity and sodium on forage quality. In order for the forage to be of value to livestock producers it must also be a feedstuff of adequate quality with regards to fiber, protein, energy, nitrate, and mineral concentrations. Livestock performance depends upon these nutrients and forage quality is generally measured against performance such as growth or gain and reproductive efficiency. Usually species, stage of maturity at harvest, and growing conditions will determine the concentrations of these nutrients (Blunt, 2001). Feeding costs are the single largest expense to livestock producers. It is important that they can produce the highest quality forage possible in order to minimize feed costs through reduced need for supplementation.

The objectives of this research were to determine the effects of CBM discharge water on barley forage yield, quality, and mineral concentrations with regards to livestock requirements.

CHAPTER 2

LITERATURE REVIEW

Livestock producers in southeastern Montana are dependent upon range use, irrigated hay production, and purchased hay. Significant year to year variation in forage production and quality exists due to dependency upon the climate and inadequate water for irrigation. Coal bed methane (CBM) discharge water, a by-product of CBM extraction, could reduce this variability and increase production potentials for irrigated producers in this region.

CBM Water

Methane makes up a large portion of available natural gas. When coal is formed from organic materials, methane is a by-product. During the process of converting the organic materials into coal and the formation of methane, the coal may become saturated with water and trap the methane, resulting in CBM (Robinson et al., 2001). With rising fuel prices, CBM is gaining attention. The Powder River Basin (PRB) of Wyoming contains roughly 15,000 active wells. The majority of the wells in MT are currently pilot project wells (WOGCC, 2006). The PRB has been recognized as one of the largest CBM regions in North America (Bauder and Blake, 2001). Methane is considered a cleaner source of energy than traditional coal and oil with low exploration costs (Robinson et al., 2001). However, extracting CBM requires pumping water from the ground to release the pressure that traps the gas in the coal. An average well produces roughly 69,120 liters of water per day with a range of 27, 216 to 108,000 liters (Robinson et al., 2001). This amount of water could lead to a dramatic increase in available irrigation water and subsequently a dramatic increase in the number of irrigated hectares in eastern Montana.

Coalbed methane water has high salinity and sodium hazards (Robinson et al., 2001). Use of it as an irrigation source could alter physical and chemical properties of the soil and limit the long term potential of sensitive forage or crop species. However if proper management practices can be established, CBM water could prove to be a substantial irrigation source for producers in southeastern Montana (Robinson et al., 2001). Currently in Wyoming, in existing wells CBM water can be permitted for discharge into surface waters during high flows. Any wells which are being developed are required to impound the water in reservoirs for irrigation or later discharge.

Coalbed methane water from the Powder River drainage has high levels of salinity and sodicity (Phelps, 2003). Irrigating with water which has moderate salinity and sodicty levels (EC <2 dS m^{-1}, [Phelps, 2003] and SAR < 15, [Swift, 2003]) would help prevent salt accumulation in the soils, mainly through increased leaching. Irrigating with saline-sodic water adds more salt and sodium (Na) to the soil contributing to the accumulation of salt and Na (Woodbury, 1993).

Since CBM water is known to be high in salts and Na, consideration must be given to the potential effects on soil properties and plant growth. Soils of the PRB are mainly silts, clays, silt loams, and sandy clays. The predominance of clay creates an environment for increased dispersion due to the highly sodic water. In arid areas such as the PRB, leaching is less likely to occur and salts are more likely to accumulate (Phelps, 2003).

With CBM water, salinity and sodicity are the main factors of concern. Salinity can have an adverse effect on plant growth and yield. Sodicity, the amount of Na present in the irrigation water, can have an adverse effect on soil structure altering plant growth. Sodium and the types and concentrations of salts present, soil type and plant species determine how severely the saline-sodic water will affect the soil. Use of water with a high sodium adsorption ratio (SAR) may affect irrigation use downstream of the CBM water discharge sites. The SAR is the proportion of Na ions compared to the concentration of calcium (Ca) and magnesium (Mg). An excess of SAR will result in excess Na adsorption which can cause soil to be hard and reduce water infiltration (Swift, 2003). The higher the SAR, the less suitable that water is for irrigation use.

Salinity

When soluble salts are present in amounts that cause harm to the plants, the soil is considered saline. Salinity creates an osmotic potential which creates water stress and toxicity from high amounts of non essential ions (Na and others) and low amounts of essential ions such as potassium (K) (Franklin-McEvoy et al., 2004) This is due in part to the plants inability to uptake water and nutrients, caused by the interference of excess salt (Franzen, 2003).

Horpestad (2001) stated that in areas with little precipitation (i.e. eastern Montana), salts may accumulate and be present in high concentrations in the soil and in the surface water and ground water. This is due to the lack of non saline-sodic irrigation water or rain water that would be required to flush the excess salts from the soil. The quality of irrigation water is of significant importance. Without dilution from rainwater, the salinity of the soil solution will be equal to or greater than that of the irrigation water. Generally, the salinity of the soil is at least two or three times that of the irrigation water. The amount of water applied, drainage, and the height of the water table will affect the amount of salt accumulation in the soil. Higher levels of water and drainage result in less salt accumulation (Bernstein, 1964). Rengasamy and Olsson (1993) stated that irrigating with saline water will increase the salinity and sodicity of soils. This is due to the higher levels of Na than Ca in the water. Irrigating with high saline water (EC 2 to 4 dS m-1) or very sodic water (SAR>25) will increase salinity and alkalinity to hazardous levels after 10 to 14 years (Anderson et al., 1972).

According to Dodds and Vasey (1985) plants may produce well on moderately salty soils if the soil moisture stays high enough to flush the salt out. In dry soils, where the salt is more concentrated, water and mineral uptake by plants is limited.

Currently, the most common criteria for determining salt tolerance of a cereal plant are agronomic yields. Vegetative growth is rarely considered since its response does not always match the response seen in grain yield. For instance, in barley crops the seed production decreases much less than the vegetative growth under saline conditions.

The reduced seed production is estimated at a 5 unit decrease per unit increase above the salinity threshold (Maas and Hoffman., 1977). Maas and Hoffman (1977) also stated that the decrease seen in barley forage is estimated at a 7.1 unit decrease per unit increase above the salinity threshold of 6 dS m^{-1}. Steppuhn et al. (1996a) also found that increasing levels of root-zone salinity above 2 dS m^{-1} reduced the amount of grain produced in wheat.

Salinity can also interfere with plant nutrition. Excess Ca ions can prevent the plant from absorbing enough K. Similarly, excess amounts of other ions can prevent the uptake of Ca. Certain cultivars of a crop may be more adapted to nutritional disturbances than other cultivars within the same species and therefore may be better able to withstand saline conditions (Bernstein, 1964).

Stage of maturity can also have an effect on a plant's tolerance to salinity. Plants react to saline conditions at all stages of maturity. There is a high amount of variability in salt tolerance from one stage of maturity to the next, particularly with cereal crops. For example, barley is more sensitive to salinity during emergence and seedling growth than during later growth and grain development (Maas and Hoffman, 1977). Steppuhn et al. (1996a) found that wheat (*Triticum aestivum* L.) plants have different sensitivities to saline conditions at different growth periods. Seeded wheat will germinate at a slower rate in saline soil but as the stage of maturity increases it becomes less sensitive to the saline conditions. Therefore, well established plants are generally more tolerant than young plants. Early exposure is thought to reduce a plant's salt tolerance. Climate also plays a role in plant tolerance to salinity. Hot, dry conditions are more harmful than cool, humid conditions.

The most common affect of salinity is stunted plant growth. Plants develop dark green leaves, but defoliation and necrosis may occur is some species (Maas et al., 1993). Salinity stress will lower the amount of water potential in the soil leading to plant dehydration stress.

Plants which are sensitive to salt quickly decline in growth and yield as the salinity increases. This is often displayed by a reduction in the amount of leaves and stems or an overall reduction in the plant size. As salt concentrations increase above a threshold level, growth rate and size of the plant decrease (Maas and Hoffman, 1977). Growth is not suppressed equally throughout the plant, with top growth being more affected than root growth (Maas and Hoffman., 1977). Some plants, such as barley, may not show a decline in grain yield even when there is as much as a 50% reduction in plant size (Bernstein, 1964).

Steppuhn and Wall (1996b) found that plant height in wheat cultivars declined linearly with increasing salinity. This response was seen in all cultivars at EC 2 dS m $^{-1}$or greater. In addition to this, it was found that salt reduces the development of the primordia which determines the number of tillers that the plant will have. This correlates with additional data Steppuhn et al. (1996a) reported where grain yield declined at EC levels of 2 dS m $^{-1}$.

Generally, the leaves and stems accumulate more salt than the grain. Salt tolerant grasses like bermudagrass (*Cynodon dactylon*) and tall wheatgrass (*Agropyron elongatum*) are resistant to salt uptake and can produce good quality hay or forage on saline sites. Grasses that are not as salt tolerant may display increased toughness (through increased lignification) under saline conditions, thereby reducing palatability for livestock. Toughness increases in proportion to the amount of growth inhibited (Bernstein, 1964). Bauder et al. (1992) found that salinity of irrigation water had more effect on alfalfa germination and seedling survival than did sodicity. Seedling mortality was increased up to 60% by irrigating with saline-sodic water. Salinity has been found to reduce stand establishment and productivity of grasses on rangeland sites.

Steppuhn et al. (1998) found that in Russian wild rye (*Elymus junceus*) as the salinity levels increased, time to emergence increased, the emergence rate decreased, and the total emergence decreased. Hay produced on saline soils can accumulate salt and will cause scours and changes in intake in cattle (Bernstein, 1964).

Sodium

Sodium can change specific soil characteristics which will directly affect plant growth. If a soil high in Ca and Mg is irrigated with water high in Na some of the Ca and Mg will be replaced by Na. When soil Na levels reach concentrations of 150 mg g^{-1} and higher, the structure of the soil begins to break down. The soil becomes dispersed while having reduced permeability to air and water. Excess Na will directly affect plant nutrition due to the Mg and Ca deficiencies it will impose. Root growth is very sensitive to Ca deficiencies (Gardner, 2004). With high levels of exchangeable Na, the soil structure can deteriorate either through dispersion of clay and ultimately the blocking of water-conducting pores by the lodging of clay particles. Sodium will also cause the swelling of clays which will lead to a reduction in pore size (Curtin et al., 1993a). Curtin et al. (1993a) stated that the high levels of Na is only a problem if salt concentration is low. He also stated that fine textured soils have poor Na stability and are therefore especially unsuited to irrigation with sodic water. As the clay content of the soil increases, the SAR of the irrigation water should decrease.

High levels of Na restrict the soil's water holding capacity by preventing clay soil particles from growing into aggregates. This prevents water from getting between the soil and from providing moisture at deeper depths (Franzen et al., 2003). This is supported by Curtin et al. (1994a) who stated that prairie soils have high smectite contents and so thus clay swelling could be a common cause of soil instability when sodium occupies more than 10 to 15% of the exchange site. Furthermore, use of an irrigation source high in SAR can create sodic conditions in the soil which can in turn change the chemical behavior of the soil. This can lead to a compromised ability on the soil's part to supply nutrients to plants (Curtin et al., 1994a). Levels of SAR <10 should result in little risk of clay dispersion in Canadian soils if the electrolyte concentration is 0.5 to 1 dS m^{-1}. It is the ratio of salt to sodium which impacts the dispersion rates (Curtin et al., 1994b). Elimination of Na by replacement with Ca (through gypsum amendments or acid forming amendments which release the Ca from insoluble lime) is necessary for the soil to be productive again (Bernstein, 1964).

The presence of Mg in irrigation water could increase the sodicity hazard. High ratios of Mg:Ca could result in increases in exchangeable Mg and Na levels (Curtin et al., 1994c). The higher the exchangeable Na levels the greater the increase in sodicity. Soils examined accumulated more exchangeable Na when Mg levels were higher than Ca. However, the direct effects are small. Using water that is high in Mg would likely result in soils that have exchangeable Na levels which are less than 10% higher than soils which are irrigated with low Mg water (Curtin et al., 1994c).

With high Na levels the soil will dry out and form hard structures which prevent roots from penetrating deep into the soil. The roots can then only access water and nutrients located in the small area around them (Franzen, 2003). Overall infiltration and hydraulic conductivity are reduced and the amount of crusting increases when Na concentrations are high. Surface crusting reduces water infiltration and plant emergence of most crop species. The effects of sodicity are a major concern for CBM discharge water due to the high Na levels.

Powder River

Water from the Powder River is higher in dissolved Ca, Mg, chloride (Cl), and sulfate (SO_4) than CBM water. Coalbed methane water is generally higher in dissolved Na and bicarbonate than Powder River water (Clark et al., 2001). Powder River water has Ca levels of 350 ppm while CBM water has levels of 150 ppm. Magnesium levels are close to this same ratio, 300 ppm vs. 100 ppm in PRB water and CBM water respectively. Sodium levels are much higher in CBM water as mentioned above, 750 ppm vs. 500 ppm in PRB water. Bicarbonates are much higher in CBM water than PRB, 950 ppm vs. 200 ppm, respectively. Powder River water typically has EC 2-3 dS m^{-1}, SAR >20 and a pH of 8.0. In contrast, CBM discharge water has an EC 3 to 4 dS m^{-1}, SAR >35, and pH 7.5 (Kirkpatrick, 2004). Based on the levels mentioned above, water from the PRB would be considered a poor source of irrigation water and CBM even worse.

Soils in eastern Montana are generally high in pH, salinity, and sodicity (Robinson et al., 2001), so irrigation water quality is of concern. However, given that water from the PRB could already be considered a poor source of irrigation water it is the damage that would be done by CBM water above and beyond that of PRB water that must be considered.

Halophytes

The use of halophytes (salt tolerant plants) may help reduce some of the negative effects of CBM water when it is used as an irrigation source (Oster, 2001). Halophytes growing in saline conditions are able to regulate osmotic pressure throughout ion accumulation. The excess amount of ions does not significantly affect plant metabolism. However, the high concentration of salt ions may reduce the palatability of the forage and thereby reduce intake (Franklin-McEvoy et al., 2004).

Two components of salt resistance are avoidance and tolerance. Salt tolerance is a plant's ability to both establish and survive the effects of salt in the root zone. Tolerance indicates that a plant takes up salt ions while resisting tissue ion toxicity. Flowers (2003), stated that tolerant plants can control the ion uptake at the root level and secrete excess ions from the leaves through salt secreting glands. With avoidance, the plants are able to exclude salt or flush toxic ions from the internal plant tissue (Johnson, 1991).

There are a number of perennial or annual forages produced such as barley, sorghum (*Sorghum bicolor L.*) and several *Agropyron* species like tall wheatgrass, standard crested wheatgrass (*A. desertorum*), and Altai wildrye (*Leymus angustus*) that have been produced on soils with moderate salinity or sodicity problems, with or without irrigation water. Tall wheatgrass displays a 25% yield reduction at EC 15 dS m^{-1}, and crested wheatgrass displays a 25% yield reduction at EC 11 dS m^{-1}(Majerus, 1996). Tall wheatgrass is considered a saline resistant plant since it restricts accumulation of Na, Cl, and Ca in the shoots (Johnson, 1991). Dewey (1962) found that lines of crested wheatgrass selected under high levels of salinity produced progenies more resistant to salinity at germination. High forage production was seen for crested wheatgrass under both saline and non-saline conditions (Johnson, 1991). Production of Altai wildrye began to decline at 10 dS m $^{-1}$. Productivity of barley began to decline at 7 dS m $^{-1}$ and sorghum declined at 5 dS m $^{-1}$ (Majerus, 1996). These are crops that have been tested for possible use in bio-remediation of saline-sodic sites. Salt and Na can be leached beyond the roots through excessive irrigation of these crops (Bauder and Blake, 2001).

High producing crested wheatgrass and tall wheatgrass are both able to maintain their turgor pressure under a wide range of NaCl solutions. Tall wheatgrass and high producing crested wheatgrass had higher concentrations of K, lower concentrations of Na, and lower ratios of Na:K in their leaves than did lower producing crested wheatgrass. Tall wheatgrass had higher concentrations of K, Na, and Cl and lower ratios of Na:K in the root systems than did the higher and lower producing crested wheatgrass. The higher forage production for the high producing crested wheatgrass and the tall wheatgrass under saline conditions was due to the maintained turgor pressure and the lower Na:K ratios.

Altai wildrye is winter hardy with good drought potential, characteristics suited to eastern Montana. It has been found to be tolerant of saline conditions and is well adapted to the prairies as a pasture grass. It has a long growth period from early in the spring continuing late into fall. Cattle and sheep find Altai wildrye to be very palatable. It can maintain adequate nutrition concentrations through summer and fall and into winter (Smoliak et al., 2000).

The proven adaptation and tolerance of these species to saline conditions makes them a practical option for crop rotations in southeastern Montana where CBM water may be available for irrigation.

Barley

Since barley is adapted to saline conditions it could efficiently be used as a model to measure the effects of CBM water. Salt tolerant barley that is grown as forage can be a very useful tool in managing salinity while benefiting cattle production at the same time (Dadshani et al., 2004). Barley grain production was maintained up to an EC of 7 dS m^{-1} and had a maximum salt tolerance of EC 17 dS m^{-1} (Majerus, 1996). Previous work by Majerus (1996) stated EC threshold levels for barley grain but not forage. Maas and Hoffman (1977) found that forage production decreased by 7.1 units per unit increase above the salinity threshold of 6 EC dS m^{-1}. Curtin et al. (1993b) reported that some barley cultivars had greater tolerance of salt due to their ability to maintain high tissue levels of Ca under saline conditions. Furthermore, declines in barley yields on sites which are high in sulfate salts are usually due to Ca deficiency.

Forage Quality

Much is known about the adaptation and production potential of different forages. However, very little is known about the impact of salt or sodicity on forage quality. Forage quality consists of protein, fiber (influences intake and digestibility), nitrate, and vitamin and mineral concentrations. Livestock performance depends upon these nutrients and forage quality is generally measured against performance such as growth or gain and reproductive efficiency. Usually forage species, stage of maturity at harvest, and growing conditions will determine the concentrations of these nutrients in forages (Blunt, 2001). Cherney and Marten (1982) stated that stage of maturity at harvest had a large impact on forage quality of cereal forages. Forage quality of small grains, such as barley, was affected by stage of growth with quality declining as the plant matures (Surber et al., 2003a; Ditsch and Bitzer, 2005). Crude protein of small grains drops significantly with stem elongation and seed formation. Crude fiber is found to be low until the seed begins to develop and then increases significantly. However, as the seed head develops, the carbohydrate concentration increases. Barley has been found to have higher dry matter digestibility and lower cell wall contents, acid detergent fiber (ADF), and lignin than other small grains making it a suitable forage source (Cherney and Marten, 1982).

Cherney and Marten (1982) compared barley, oat (*Avena sativa L*), triticale (*Triticale hexaploide* Lart.), and spring wheat and found that barley had the highest CP of the four species. They found that forage yield increased as the plants matured, however there were significant reductions in the concentrations of CP and macro minerals, specifically K, Ca, phosphorous (P), and Mg. Acid detergent fiber (ADF) and cell wall constituents all increased as the plant matured and *in vitro* dry matter digestibility (IVDMD) decreased.

Khorasani et al. (1997) did a similar study looking at the influence of stage of maturity on the quality of cereal grain silage. The DM concentrations increased as plants matured from 130 mg g $^{-1}$ in the boot stage to 419 mg g $^{-1}$ in the soft dough stage. The CP concentrations declined from 250 mg g $^{-1}$ in the boot stage to 120 mg g $^{-1}$ at soft dough. Concentrations of NDF increased from 500 mg g $^{-1}$ at boot to 600 mg g $^{-1}$ at boot three weeks later but declined back down to 500 mg g $^{-1}$ at soft dough. The concentrations of ADF followed the same pattern going from 260, 320 mg g $^{-1}$, and 250 mg g $^{-1}$ at the same maturity stages respectively. Since the NDF content is higher in the stem portion of the plant than the leaves of the plant, the digestibility of the stems is lower than the digestibility of the leaves (Buxton, 1996). Buxton (1996) also stated that the maximum cell wall level in forages that will not hinder intake and performance is 700 to 750 mg g $^{-1}$NDF for mature beef cattle and 150 to 200 mg g $^{-1}$NDF for growing and finishing cattle.

Acosta et al. (1991) studied barley cultivars used for silage at different maturities. It was found that DM, CP, and total digestible nutrients (TDN) levels were greater in soft dough stages when compared to the boot stage. However, when the barley silage was fed to heifers it was more digestible in the boot stage than in the soft dough stage.

Nitrate-N

Nitrate (NO_3) level is a very important factor in forage quality. When NO_3 accumulates at high levels, NO_3 poisoning can occur in livestock consuming the affected forage. Nitrate is absorbed from the soil into the plant. Plant NO_3 is ingested into the rumen and converted to nitrite (NO_2) and converted into ammonia which is absorbed into the blood stream. When NO_3 is present in excess amounts, the ammonia in the blood stream combines with hemoglobin to form methemoglobin which essentially causes the animal to die of suffocation since the blood is unable to carry oxygen to cell tissues (Wright and Davison, 1964). Gul and Kolp (1960) stated that oat grown under certain conditions will accumulate NO_3 which when fed to cattle can cause abortion or death. Signs of acute toxicity include muscle tremors, staggering, and cyanosis. Levels of <3,000 ppm NO_3 are considered safe for all classes of livestock (Cash et al., 2002).

Cereal grains, such as barley, are known to accumulate toxic levels of NO_3 under certain conditions. Abnormal growing conditions, or “stressed growing conditions”, including soil mineral deficiencies and drought or a lack of water uptake, can cause the accumulation of NO_3. Nitrate concentrations are known to be the highest in the morning and during cloudy periods when the normal photosynthetic activities of the plant are disrupted (Wright and Davison, 1964). Accumulation of NO_3 is negatively correlated with stage of plant maturity. Levels generally decrease as the plant matures (Murphy and Smith, 1967). Gul and Kolp (1960) found that oat in the 25% flower stage showed NO_3

levels of approximately 280 mg g $^{-1}$. This level dropped to 10 mg g $^{-1}$ in the hard dough stage. Another of his sites showed similar results with nitrate levels of 60 mg g $^{-1}$ at the 25% flower stage and then dropping to 30 mg g $^{-1}$ in the hard dough stage. They also found that amounts accumulated by different cultivars differed, accumulation at different locations was very different, and there was no relationship between plant height or yield and the amount of NO_3 accumulated. Khorasani et al. (1997) found NO_3 levels to decrease as the plant matured, from 25 mg g $^{-1}$ at boot to10 mg g $^{-1}$ at soft dough. Oat samples from Wyoming which were analyzed showed the straw to have higher nitrate concentrations than the grain. Wright and Davison (1964) explained this as the NO_3 in transit to the site of reduction (the photosynthetic part of the leaves) but somehow its passage has been halted. Gul and Kolp (1960) concluded that factors associated with the accumulation of NO_3 include high amounts of nitrogen in the soil during drought conditions, the soil lacking adequate amounts of minor elements such as copper (Cu), manganese (Mn), and molybdenum (Mo), and shading.

Fertilizer

Soder and Stout (2003) measured fertilizer effects on mineral concentration of pasture and related it to ruminant performance. Slurry (urine and feces) fertilizer was used at levels of 168, 336, and 672 N, 124, 248, and 496 K, 34, 68, and 136 P, 73, 146, and 292 Ca, and 21, 42, and 84 Mg, kg ha^{-1}. As fertilizer level increased, N and K increased in the forages No change was seen in P concentrations and Ca and Mg concentrations decreased in the forages evaluated. The reduced levels of Ca and Mg were due to large amounts of K being added to the soil which reduced the plant's uptake of Ca and Mg. The soil concentrations of N, P, K, Ca, and Mg increased with increased level of fertilizer. This study demonstrated the large variability in mineral concentration of the forage based on minerals in the soil and the type and level of fertilizer and additions to the soil.

Forage Mineral Concentrations in Montana

The main source of nutrition in most cow-calf operations is range and hay forage. According to the National Animal Health Monitoring System (NAHMS, 1997) only 9% of cow-calf producers evaluated their forages (Mortimer et al., 1999). The NAHMS selected producers from 23 states to contribute forage samples which were tested for forage quality. Forty-six cereal forage samples were analyzed from these voluntary samples. Cereal samples were found to have an average of 89 ± 61 mg g^{-1} CP, 396 ± 9.8 mg g^{-1} ADF, and 576 ± 7.8 mg g^{-1} TDN. Mineral analysis results displayed even more variability. Approximately 80% of the samples were found to be deficient in zinc (Zn). The Cu: Mo ratio was deficient in 8% of the samples. Iron (Fe), Mo, and sulfur (S) concentrations were at antagonistic levels which could lower the amount of Cu available. Copper concentrations were slightly to largely deficient in 76% of the samples. Only 20% of the samples contained adequate levels of selenium (Se). Manganese was found to be adequate in 80% of the samples (Mortimer et al., 1999). This vast difference in adequacies and deficiencies displays the large variability in mineral concentrations of cereal forages.

Montana has such a wide variety of soil chemistry and characteristics that mineral concentrations can vary widely across the state naturally without the interference from irrigation water high in total dissolved solutes (TDS).

Importance of Minerals in Livestock

Extreme levels of trace minerals can lead to deficiencies, toxicities, imbalances, or interactions which can cause an assortment of nutritional problems. Mineral requirements are affected by breed of livestock and stage of production. Minerals are required for vitamin synthesis, hormone production, enzyme activity, and synthesis of tissue as well as many other physiological processes which relate to growth, health, and production (Greene et al., 1998). Small grain forages often display mineral deficiencies (Ditsch and Bitzer, 2005).

Copper and Zn are two minerals of concern in southeastern MT (the main site for CBM development in MT). Copper requirements for beef cattle are .01 mg g^{-1} and Zn requirements are .03 mg g^{-1} (NRC, Nutrient Requirements of Beef Cattle, 2000). Southeastern Montana produces deficient grass hay with levels of Cu at .003 mg g^{-1} and Zn at .015 mg g^{-1} (Ansotegui, personal communication) which are at least 50% below the NRC requirements.

It has been found that Cu and Zn supplementation will improve performance and health, as well as average daily gains (ADG) of livestock. Copper also showed strong immune system benefits (Lee, 1991). Signs of Cu deficiency are anemia, reduced growth, de-pigmentation of the hair, cardiac failure, fragile bones, and low reproduction through delayed or depressed estrus. The presence of S is known to reduce the absorption rate of Cu, possibly through formation of copper-sulfide in the gut. Sulfur and Mo together will form thiomolybdates in the rumen which complex Cu and leave it unavailable to the animal (Suttle, 1991). Molybdenum, S, and Fe are all antagonists that form insoluble Cu complexes in the digestive tract, bloodstream, and tissues of ruminants. This induces hypocuprosis. There is reported increased availability in amino acid-complexed trace minerals. When Cu antagonists are absent, it would be much simpler to meet requirements (NRC, 2000).

Zinc is essential for proper functioning of the immune system and is found to be beneficial when the animal is subjected to environmental stress (Greene et al., 1998). Zinc is an essential component of several important enzymes including those that metabolize carbohydrates. A deficiency in Zn can result in reduced growth, intake and feed efficiency of livestock. Listlessness, salivation, reduced testicular growth, and swollen feet are also signs of Zn deficiencies (NRC, 2000). Insufficient intake and poor absorption due to dietary antagonists are factors that contribute to low Cu consumption and utilization in beef cattle.

Copper is often below dietary requirements in all forages except legumes, while Zn is borderline deficient. Iron is usually above requirements in forages which will have a negative effect on Cu (Greene et al., 1998). Eastern Montana forages are typically deficient in Cu and Zn (Ansotegui, personal communication). Soils and waters high in sulfates, salt, and/or sodium could potentially compound this problem.

Smart et al. (1986) showed that levels of Cu in the liver of beef cows were decreased with excess S intake. Zinn et al. (1997) found that dietary levels of S above 0.2% DM had negative impacts on forage digestion in ruminants.

Calcium and S are required for normal blood coagulation. Beef cows require 1.5 mg g^{-1} S and no more than 4 mg g^{-1} S (NRC, 1996). Sulfur toxicity is generally considered uncommon because absorption of inorganic sulfur is low. Whanger and Matrone (1970) and Rumsey (1978) found that a diet lacking in S leads to decreased microbial protein synthesis, microbial numbers, organic matter digestibility, and lactate utilization. Occasionally cattle will consume greater amounts of salt than required but S toxicity is rare (Manske, 2002). The maximum tolerable allowance for salt is 9.0% dietary dry matter (NRC, 1996). Salt in drinking water is considered more toxic than dry matter salt in the diet. Intake of excess amounts of Mg, K, Na, or Cl rarely leads to toxicity because excess amounts are readily excreted through the kidneys (Manske, 2002). When drinking water is restricted or very high in salt, or when the kidneys are malfunctioning, S toxicity could occur (Church and Pond, 1975).

Very little research on mineral availability or utilization from forages has been conducted (Emanuele et al., 1990). Utilization of a mineral by an animal is dependent on release of the mineral from the feedstuff and absorption of the released mineral. Minerals which are associated with the plant cell wall have lower availability than those which are not (Emanuele et al., 1989).

Mineral release from hays after 12h of rumen incubation, ranked high to low, showed K>Mg>Na>P>Ca. Therefore a smaller percentage of Ca and P will be immediately released (Emanuele et al., 1989). Emanuele et al. (1989) also stated that some forages, such as dwarf elephant grass (*Pennisetum purpureum*), have a strong affinity for binding Ca in the rumen and that Ca concentrations increased 20% from original samples. The Ca binding effect would reduce the release rate of Ca further. Emanuele summarizes that up to 33% of Ca in alfalfa is tied to oxalate which surrounds vascular bunds and is unavailable to the ruminant. Maximum Ca release requires longer incubation time due to its function in the stability of cell walls and membranes. Calcium makes up from 34 to 61% of the total mineral found in the cell wall. Therefore, digestion of the cell wall is necessary before the Ca can be released. Minerals which are more rapidly released may be located in the more digestible portions of the cell wall such as the mesophyll and phloem or not associated with the cell wall at all (i.e. Mg, K, P, Cu, and Zn) (Emanuele et al., 1989).

Emanuele et al. (1989) stated that indigestible cell walls may contain negatively charged groups such as uronic groups and phenolic groups which have a strong affinity for Ca. Other possible contributors of the increased Ca concentrations may include Ca oxalates and silicates. Emanuele also hypothesized that if ruminal pH is lower than 6.5 (as in a high concentrate diet) a higher amount of Ca may be released than in a high forage diet.

Soil mineral level, soil pH, climatic conditions, and stage of maturity are all factors which will influence mineral bioavailability in forages (Swenson et al., 2000). As forages mature, the mineral digestibility decreases, more so in macro mineral concentrations than micro mineral concentrations. This is due to dilution processes and translocation of the minerals to the root zone (Machen, 2005). Within the digestive system, interactions may occur that will alter the utilization of one or more minerals. Generally, 85 to 90% of P, K, and Mn are available, 50 to 65% of Ca and Cu is available, and 40 to 70% of Zn is available (Rasby et al., 1998).

Several studies were conducted in the San Joaquin Valley of California using drainage water from the San Joaquin Basin (SJB) as an irrigation source for grasses and legumes (Gratten et al., 2004). Water from the SJB contains a high mixture of salts, among them Na and sulfate (dS m^{-1}15 and SAR=25). Legumes showed increased levels of K which may reduce Mg availability to ruminants. They also found a low Cu:Mo ratio in forages which were irrigated with this water as well as ion imbalances (K:Mg). Most importantly, they found that the S concentration in the forages were either close to or exceeded the maximum tolerable limits. They concluded that livestock fed exclusively forages irrigated with drainage water from the SJB would be at risk of malnutrition and metabolic disorders due to mineral deficiencies, toxicities, and ion imbalances (Gratten et al., 2004).

Sulfur and Forage Quality

Many soils are deficient in S and fertilizing with S can increase forage yield and improve ruminant use of the grazed forage. Moir (1970) found that response to S in beef cattle diets is a function of the N:S ratio and the availability of S (Glenn and Ely, 1981). Fertilizing with S can alter the nutrient content of forages. Small grain forages usually have a high content of N and adding S as a fertilizer to small grains would therefore reduce the N to S ratio which would improve ruminant usage of forage (Hardt et al., 1991). However, fertilizing with S can quickly lead to an imbalance since high levels of dietary S can decrease the availability of other ingested essential minerals.

In preliminary studies Hardt et al., (1991) found that heifers grazing pasture which was fertilized with urea gained 20% more than those grazing pasture fertilized with ammonia sulfate (both treatments contained equal amounts of N). Hardt et al. (1991) found that fertilizing with ammonia sulfate increased levels of S in the forage (wheat and oat) by 27%. They found no improvement in weight gain among heifers grazing forages fertilized with elevated levels of S, due to feed refusal of forages with S concentrations greater than 40 mg g^{-1} DM.

Arthington et al. (2002) found that fertilizing with ammonia sulfate elevated the forage S concentrations from 1.9 mg g^{-1} to 4.8 mg g^{-1} and 2.5 mg g^{-1} to 5.1 mg g^{-1} in years

1 and 2, respectively. Sulfur combines with Mo to form thiomolybdates, therefore fertilizing with S can increase the antagonism of S on Cu. Fertilizing with S reduces Cu availability to the ruminant. Liver Cu levels of 72 ppm were seen in animals consuming S fertilized forages vs. 204 ppm seen in those consuming control forages. Iron levels in the liver were also lower on forages fertilized with S compared to control (332 vs. 438 ppm, respectively). Manganese and Zn levels were also lower on forages fertilized with S compared to control (9.1 vs. 9.9 and 119 vs. 126, ppm respectively) (Arthington et al., 2002). Heifers grazing ammonia sulfate fertilized pastures were provided 142 $mg \cdot day^{-1}$ Cu supplement and were still found to have reduced Cu liver concentrations. The heifers were able to quickly increase their Cu liver status once removed from the pastures high in S (Arthington et al., 2002).

Halophytes as Forage

Salt tolerant forages have been shown to be an adequate diet source, providing adequate nutrition levels for lambs. Swingle et al. (1996) found that at 30% of the diet, halophyte forages supported the same weight gain of lambs as bermudagrass. When used as a sole diet source, results were less favorable. Lambs fed halophytes consumed up to 110% more water per day and 50% more water per kg of dry matter intake (DMI) than lambs on control diets. Lambs on the halophyte diet had slightly higher dressing percentages at slaughter than those on the control diet.

Halophytes often have higher levels of minerals, particularly NaCl, which can create mineral imbalances (Benjamin et al., 1992). Overall, Swingle et al. (1996) found that halophytes had higher mineral content, lower CP content, and higher fiber levels than the control hay. The halophytes used were a combination of forage from a natural stand grown on saline soil and crops grown under seawater irrigation. When they looked at artificial halophyte diets, the animals were able to sort the salt from the feed whereas with the actual halophytes, the majority of the salt was in the stem and leaf tissues and thus unavoidable by the animals (Swingle et al., 1996). In a trial in southwestern Australia, Norman et al. (2002) found that sheep grazing saltland pastures consisting of a mixture of halophytes and underlying pasture maintained weight and condition.

Franklin-McEvoy et al. (2004) studied sheep grazing halophytes, particularly saltbush (*Atriplex canescens*) and found that when they were initially exposed to the forage there is a rapid weight gain which quickly slowed down and eventually turned to weight loss. The initial weight gain was explained by water retention associated with the high salt intake. They stated that grazing only saltbush prevented maximum animal performance but when used as part of ration (thereby diluting the salt) animals could maintain and improve their performance. This was partly due to the high amounts of non-protein nitrogen found in saltbush. They also reported that intakes of 10 $g \cdot kg^{-1}$ Na, had no side effects, 27 $g \cdot kg^{-1}$ Na, reduced intake, and over 40 $g \cdot kg^{-1}$ Na, had negative impacts on rumen microflora which in turn reduced digestion. Gihad and El Shaer

(1994) pointed out that animals on halophyte diets may have lower meat quality than those consuming normal forages.

Saline-Sodic Water and its Effect on Livestock

A great deal of research has been done on the effects of water high in salts and Na when consumed by livestock. Quality of water available to cattle can have a large impact on their productivity. Much of the water available in the United States is not of high enough quality to maintain performance and health (high salt content).

Surface and sub-surface water can be high in TDS. Water high in salt content can reduce water and feed intake, create toxic levels of S ingestion, and induce trace mineral deficiencies. Beef cattle will often voluntarily reduce their intake of poor quality water which will result in a reduced dry matter intake. Lowered intake leads to lowered nutrient intake which reduces productivity.

Sulfur Toxicity in Livestock

Sulfate concentrations of greater than 1000 ppm in drinking water have been shown to cause diarrhea in young calves. Sulfur concentrations of greater than 1,500 ppm have been shown to cause a reduction in weight gain with beef heifers. The recommendation for water sulfate concentrations is generally <1,000 ppm (Grooms, 2005).

Sodium sulfate (Na_2S0_4) is commonly the cause of elevated levels of TDS in water. Sulfates can have greater effects on water intake and performance than other salts. Toxic ingestion of sulfates can occur when cattle consume water high in sulfates. Again, the requirement for S according to the NRC is 1.5 mg g $^{-1}$ and the maximum tolerable level is 4.0 mg g $^{-1}$ of dry matter (NRC, 2000). Diets greater than 2.0 mg g $^{-1}$ S have been shown to reduce performance of finishing steers. Ingestion of high levels of S from water can cause polioencephalomalacia (PEM). Symptoms include lethargy, anorexia, blindness, muscle tremors, in-coordination, staggering, weakness, convulsions, and death. Dietary S levels of 9.0 mg g $^{-1}$ of DM have been linked to PEM (Loneragan et al., 2001). Weeth and Hunter (1971) compared cattle consuming water with 5,000 ppm Na_2S0_4 and 4,110 ppm NaCl. Cattle on the high sulfate-water treatment reduced their water consumption by 35% and feed consumption by 30% while those on the low sodium-water treatment increased their water intake by 19% and their feed intake was unaffected. Embry et al. (1959) found 10,000 ppm Na_2SO_4 water to be toxic in growing cattle yet 7,000 ppm Na_2SO_4 showed no adverse effect.

Patterson et al. (2002) evaluated sulfate levels in three different water sources which contained 400 ppm (1000 TDS), 3,100 ppm (6200 TDS), and 3,900 ppm (6200 TDS). The first two treatments were obtained from a well while the third treatment was obtained from a stock dam. Cattle were on diets of grass hay and wheat middlings. The average diet S intake was 2.7 mg g $^{-1}$, 7.4 mg g $^{-1}$, and 7.3 mg g $^{-1}$, respectively. They found that ADG declined from 0.63 to 0.46 kg day^{-1} as sulfates increased from 400 ppm to 3,100 ppm. Gain did not fall further with the highest sulfate levels of 3,600 ppm but water intake, DMI, and gain/feed were all reduced. Steers consuming water high in TDS and high in sulfates had greater than 12% PEM occurrences and 5% mortality rates. Cattle on 3100 to 3900 ppm sulfate levels also had increased incidences of PEM (Patterson et al., 2002). Livestock production (ADG and DMI) was reduced in animals drinking water with sulfate levels as low as 1,700 ppm. Performance, such as ADG, was reduced when cattle consumer water high in sulfates even in instances where no PEM was seen. It is unknown if there is any adaptation, physiological or behavioral, in cattle drinking water with high levels of sulfate (Patterson et al., 2003).

In a similar study, ADG was again reduced with increasing sulfate levels (Patterson et al., 2003). The four water treatment levels were 1,000 TDS, 3,000 TDS, 5,000 TDS, and 7,000 TDS. Steers were fed grass hay and wheat middlings, limestone, and free-choice salt. Sulfate levels of 400 ppm showed ADG of 0.81 kg d^{-1} while steers consuming water with sulfate levels of 4600 ppm showed an ADG of 0.28 kg day^{-1}. Again, DMI and water intake declined as the sulfate level in the drinking water increased. Feed efficiency was reduced 48% with the highest level of sulfates. Steers on the highest sulfate level had a higher rate of PEM (47.6%) and higher mortality rate (33%) due to PEM.

Studies were also conducted on steers and cows grazing native range. Cows on high sulfate water lost 36 pounds on average and those on low sulfate water gained 10 pounds. Calf average daily gain did not differ between treatments, nor did milk production. The PEM rates and pregnancy rates did not differ (Patterson et al., 2003).

While the elevated sulfate levels reduced the performance of cattle grazing native range it was not as extreme as the reduced performance of cattle in confinement. This may be due to moisture levels in forage being higher than in dry feed, less heat stress (able to find shade), and the ability to consume standing water after rain (Patterson et al., 2003). Patterson et al. (2003) stated that dietary S levels of 7mg g^{-1} and greater may cause PEM in growing cattle. While the main source of excess salt is commonly from drinking water, it would be possible to ingest this excess salt or sulfates through diet.

Hay Barley

Hay barley is a significant source of winter feed for livestock producers in Montana. It can be an inexpensive feed source with high yield. It has been found that barley has higher nutritive value and lower fiber concentrations than many other small grains (Cherney and Marten,1982). Feeding awned varieties has not been shown to impact DMI, ADG, or feed efficiency. In a backgrounding trial where four different hay barley varieties were fed, steers gained an average of 1.37 kg d^{-1} and an average feed efficiency of 0.145 kg gain·kg^{-1} feed (Todd et al., 2003). Feed barley has been found to have equal feeding value to corn in finishing diets (Kincheloe et al., 2003). Boles et al. (2004) found that using barley as a diet source for finishing steers when compared to the more traditional diet of corn had little effect on carcass quality or yield grade. Hay and feed barley are adequate diet sources and increased production of these feeds could have a positive impact on livestock producers.

Summary

The major issues regarding use of CBM discharge water as an irrigation source are the elevated levels of salt and sodium that it contains. Southeastern MT already experiences production cycles of drought and low forage quality (mineral imbalances). The use of CBM discharge water as irrigation water would increase the levels of salt and sodium in the soil and disrupt the chemical balances in the soil. These disruptions could be passed along to the forage being grown on these sites. This would only exaggerate the issue of poor forage quality and poor growing conditions in southeastern MT. The use of cereal forages such as barley which has been proven to be adapted to saline conditions and tolerant of sodium could provide an alternative which would maintain a high level of forage quality for livestock operations.

The objectives of this research were to determine the effects of utilizing a highly saline-sodic water source, CBM discharge water, on the yield, forage quality, and mineral content of barley cultivars in a two year period.

CHAPTER 3

MATERIALS AND METHODS

Site Description

Three field trials were conducted under two covered greenhouses at the MSU Horticulture Farm, Bozeman, MT. Soil was excavated in 2003 to 1.3m, lined with a polyethylene sheet, and replaced with soil similar to soil found along the Powder River. It is a well drained, fine soil with smectitic mineralogy, pH=7.85, EC= 0.93 dS m $^{-1}$, and SAR= 1.31(Kirkpatrick, 2004). Each greenhouse was 4 X 10 m, subdivided into three 3 X 3 m repetitions (blocks). Each greenhouse was covered with a canopy over the top and sides with the ends left open in order to prevent any uncontrolled precipitation. Plots were hand-seeded into single 3 m rows. All barley cultivars were seeded at the recommended rate of 340 seeds m^{-2}. Rows were spaced 0.3 m apart.

Each greenhouse received one of two water treatments. One greenhouse received well water (EC = 0.43 dS m^{-1}, SAR = 0.25) and the other greenhouse received synthesized CBM treatment water (EC = 1.6 dS m^{-1}, SAR = 35) (Kirkpatrick, 2004). A water tank was placed at the west end of each greenhouse in which the water was synthesized and stored. Water was mixed on a weekly basis and a circulating pump was immersed in each tank to keep the water mixed. Tanks connected to PVC pipe which ran down alternate rows of the plots, running west to east. When plots were irrigated, valves on the pipe were opened and the plots were flood irrigated.

Fertilizer containing N, P, and K, was provided equivalently to both greenhouses twice during the season. The fertilizer rate was 1.36 kg of 20-27-5; N-P-K. This is equivalent to 98 kg ha^{-1} of N, 131 kg ha^{-1} of P, and 22 kg ha^{-1} of K. At the appropriate growth stage 2, 4-D was applied to control weeds.

Trial 1 (2004)

Trial 1 was conducted between 15 April and 12 July, 2004. Fourteen adapted barley cultivars were chosen based on known performance or adaptation in MT. Hays, Westford, Baronesse, Moravian 37, Conlon, Hector, MT960100, Valier, Haybet, BA 1202, Robust, Morex, Bowman, and Haxby were tested. Cultivar descriptions are presented in Table 1. Plots were seeded 15 April. Plots were irrigated with 5 cm of respective treatment water on the day of seeding. Greenhouses were flood irrigated on a weekly basis with 1.5 to 2.5 cm of treatment water. Both greenhouses received the same amount of respective treatment water at each application.

Sample clippings of 30 cm were taken per block. Sample clippings were taken when the majority of the entries were in the boot, heading, and milk stages of maturity, 6 June, 7 July, and 12 July respectively.

Table 1. Description of 18 barley cultivars evaluated in forage quality testing, irrigated with CBM or well water in 2004 and 2005.

Cultivar	Type	End Use	Source	Date Released	Source
BA 1202	2-row, awned	Malt	Busch Agriculture Servies	1989	U.S. Grains Council
Baronesse	2-row, awned	Feed	Western Plant Breeders	1991	U.S. Grains Council
Bowman	2-row, awned	Feed	North Dakota Ag Experiment Station	1984	U.S. Grains Council
Conlon	2-row, awned	Malt	North Dakota Ag Experiment Station	1996	U.S. Grains Council
Eslick	2-row, awned	Feed	Montana Ag Experiment Station	2005	Montana Agriculture Experiment Station
Harrington	2-row, awned	Malt	University of Saskatchewan, Canada	1981	U.S. Grains Council
Haxby	2-row, awned	Feed	Montana State University	2002	Montana Agriculture Experiment Station
Haybet	2-row, hooded	Forage	Montana State University	1989	U.S. Grains Council
Hays	2-row, hooded	Forage	Montana State University	2004	Montana Agriculture Experiment Station
Hector	2-row, awned	Feed	University of Alberta, Canada	1983	U.S. Grains Council
AC Metcalf	2-row, awned	Malt	Ag. Canada	1994	U.S. Grains Council
Morex	6-row, awned	Malt	Minnesota Ag. Experiment Station	1978	U.S. Grains Council
Moravian 37	2-row, awned	Malt	Coors Brewing Co.	2000	U.S. Grains Council
MT 960100	2-row, awned	Malt	Experimental Line, Montana State University		P.Hensleigh, Personal Communication
Robust	6-row, awned	Malt	Minnesota Ag. Experiment Station	1983	U.S. Grains Council
Tradition	6-row, awned	Malt	Busch Ag.	2003	U.S. Grains Council
Valier	2-row, awned	Feed	Montana Ag Exp.Station	1999	Montana Agriculture Experiment Station
Westford	6-row, hooded	Forage	Western Plant Breeders	1988	Montana Agriculture Experiment Station

Maturity scores were recorded for each individual cultivar using the Zadok's numbering scale. The Zadok's growth staging system is a two digit code where the first digit refers to the actual stage of development (germination to kernel ripening). The second digit is a subdivision of each growth stage. A 50 on the Zadok's scale refers to the first stages of heading, 55 is midway through the heading process, with one half of the head emerged. A score of 60 is the first stages of flowering, a 65 is midway through flowering (half of the florets have flowered). A score of 70 indicated the beginning of milk development (Anderson et al., 2002). Maturity scores by cutting date are presented in Table 2.

Table 2. Maturity stages of nine barley cultivars irrigated with well or CBM discharge water in Trial 1 (2004).

Cultivar	28, June		3, July		12, July	
	Well	CBM	Well	CBM	Well	CBM
Conlon	Early Anthesis	Early Anthesis	Early Anthesis*	Anthesis *	Milk	Soft Dough
Haxby	Boot	Early Anthesis	Early Anthesis	Anthesis*	Anthesis*	Soft Dough
Haybet	Vegetative	Late Boot	Anthesis	Anthesis*	Late Anthesis*	Anthesis
Hays	Vegetative	Boot	Early Anthesis	Early Anthesis	Anthesis*	Anthesis*
Moravian37	Early Boot	Boot	Early Anthesis*	Anthesis *	Water	Soft Dough
Morex	Boot	Anthesis	Early Anthesis	Late Anthesis*	Anthesis*	Soft Dough
Robust	Early Boot	Boot	EarlyAnthesis	Anthesis*	Anthesis*	Soft Dough
Valier	Vegetative	Boot	Early Anthesis	Early Anthesis*	Anthesis*	Milk
Westford	Vegetative	Vegetative	Boot	Early Anthesis	Anthesis*	Anthesis*

* Indicate samples used for global ANOVA of all entries at the anthesis stage of maturity.

Trial 2 (2005A)

Trial 2 was conducted between 15 May and 27 June, 2005. Hays, Westford, Baronesse, Harrington, Conlon, Eslick, Metcalf, Valier, Haybet, Moravian 37, Robust, Morex, Tradition, and Haxby were tested.

Growing conditions, management practices, and irrigation schedules were the same as Trial 1, 2004.

Sample clippings were taken on two occasions when the majority of entries were in the boot and heading stages of maturity, 21 June, 2005 and 27 June, 2005 respectively. Late spring frost and erratic plant growth occurred. For this reason, the trial was terminated on 29 June, 2005. Data from this trial were not included in analyses. The soil was tilled and trial 3 was planted on 5 July, 2005.

Trial 3 (2005B)

Trial 3 was conducted between 6 July and 30 August, 2005. Hays, Westford, Baronesse, Harrington, Conlon, Eslick, Metcalf, Valier, Haybet, Moravian 37, Robust, Morex, Tradition, and Haxby were tested.

Sample clippings (15 cm per block) were taken on three occasions when the majority of entries were in the boot (17 August), heading (24 August), and milk (30 August) stages of maturity. Maturity at cutting date is presented in Table 3.

Table 3. Maturity stages of nine barley cultivars irrigated with well or CBM discharge water in Trials 3 (2005).

Cultivar	17, August		24, August		30, August	
	Well	CBM	Well	CBM	Well	CBM
Conlon	LateBoot	LateBoot	Anthesis*	Anthesis*	Late Anthesis	Milk
Haxby	LateBoot	LateBoot	Early Anthesis	Anthesis*	Late Anthesis*	Milk
Haybet	Boot	Boot	Early Anthesis	Anthesis*	Late Anthesis*	Milk
Hays	Early Boot	Boot	Late Boot	LateBoot	Late Anthesis*	Late Anthesis*
Moravian37	LateBoot	Boot	Late Boot	LateBoot	Anthesis*	Late Anthesis*
Morex	LateBoot	LateBoot	Anthesis*	Anthesis*	Milk	Milk
Robust	LateBoot	Boot	Anthesis*	Anthesis*	Milk	Milk
Valier	Boot	Early Boot	Late Boot	Anthesis*	Late Anthesis*	Late Anthesis
Westford	Boot	Early Boot	Late Boot	LateBoot	Late Anthesis*	Late Anthesis*

*Indicate samples used for ANOVA of all entries at the anthesis stage of maturity.

Ten cultivars common between 2004 and 2005 were analyzed in this trial. The cultivars which were common to both years include: Hays, Westford, Baronesse, Conlon, Valier, Haybet, Haxby, Morex, Moravian 37, and Robust. A large amount of data were missing for the cultivar Baronesse due to poor emergence in one trial. For this reason, only nine cultivars common to both Trial 1 (2004) and Trial 3 (2005B) were analyzed.

Validation Trial

A small additional trial was conducted in 2005. It was an attempt after Trial 1 (2004) to evaluate the greenhouse effect (one greenhouse received the same water treatment in all trials). Four 18.9 L containers were placed under each greenhouse, side by side. Containers were filled with soil from the same source which filled the greenhouses. Two of the containers received well water and two containers received the CBM water treatment. Assignment of treatment was randomized. The cultivar Hays was planted in all buckets. Treatment waters were synthesized to match the CBM and well water used in the main trials, well water: EC = 0.43 dS m^{-1}, SAR = 0.25 and CBM treatment water: EC = 1.6 dS m^{-1}, SAR = 35. Containers were managed in the same manner as the greenhouses. Fertilizer containing N, P, and K was added to both treatment water sources. Containers received individual treatment water (2.5 cm) once weekly. Barley was clipped at the anthesis stage of maturity and analyzed for forage quality in the same manner as samples from the main trials.

Sample Collection

Sample clippings were taken on three dates when the majority of entries were in the boot, heading, and milk stages of maturity. At the time of clipping, stage of maturity and crop height were recorded. Wet field weights (g) for each sample were taken and evaluated for dry matter composition and yield estimates. Samples were collected in paper bags and immediately transported to drying ovens. All samples were dried for 48 hours at 60˚C. They were then re-weighed (g) to determine dry matter composition.

Sample Analysis

Samples were ground to pass through a 1 mm screen. Ground samples were analyzed for concentrations of DM, N, NO_3-N (AOAC, 2000), NDF, and ADF (Van Soest et al., 1991).

Forage samples were analyzed to determine their concentrations of Ca, P, Mg, Na, S, Cu, Zn, K, Mo, Fe, and Mn. Samples were analyzed by Mid West Laboratories, Omaha, NE, www.midwestlabs.com, using the inductively coupled plasma-atomic emission spectrometry method (Welch et al., 1980). The remainder of the subdivided sample was incubated in the Daisy rumen simulator for 48 hours and *in vitro* dry matter digestibility (IVDMD) was calculated.

In Vitro Tests (Four Common Cultivars)

In vitro DMD trials were conducted in an Ankom Daisy incubator, www.ankom.com, on four common cultivars ,Hays, Westford, Valier, and Robust. After being ground through a 1mm screen, 0.5 g of sample was placed in F57 filter bags which have a pore size of 25 µm.

Rumen fluid was collected from two ruminally cannulated cows that were on a diet of low quality grass hay for four weeks prior to collection. The fluid was composited and strained through 8 layers of cheesecloth. The F57 bags were placed in digestion jars with 400 ml of innoculum (composited rumen fluid) and degassed McDougal buffer solution to simulate saliva (Tilley and Terry 1963). The samples were incubated for 48 hrs at 39.5°C. After samples were removed from the incubation chamber they were washed thoroughly with cold water. They were then placed in a dryer at 16° C for 48 h, then removed and weighed. Dry matter percent was calculated on the original samples by dry sample divided by wet sample *100. In vitro true digestibility (IVTD) was calculated by the equation:

$$100-\frac{\text{(final bag weight- (final bag weight - blank bag correction))}}{\text{initial sample weight}}\ *100$$

Mineral Analyses

Mineral analyses were conducted on four common entries, Hays, Westford, Valier, and Robust. Approximately 0.350 mg (actual weight recorded) of sample digested overnight in 8.5 ml of acid mixture comprised of nitric acid and perchloric acid (5:1). In the morning, the samples were placed on a hot plate. Once the temperature of the hot plate reached 266° C, they were baked at this temperature for 30 minutes. The temperature was then raised to 338° C and held at this point for 30 minutes, while yellow fumes are emitted. Then, over a 45 minute period, the temperature was increased to 410° C. Once the solution was clear, the digestion was considered finished and the samples were allowed to cool. They were then filtered through Whatman 1 Qualitative filter paper and diluted to 50 ml using a 2% nitric acid solution. After being thoroughly mixed, they were transferred to a 30 ml scintillation vial (AOAC, 2000). Mineral analysis was conducted in the same manner on residue of IVDMD samples.

Samples were sent to Mid West Labs, Omaha NE, www.midwestlabs.com, for the final reading of mineral concentrations. Mineral concentrations were reported on a ppm basis with a 1 ppm accuracy rate. The inductively coupled plasma-atomic emission spectrometry method was used (Welch et al., 1980).

Statistical Analyses

Forage yield and quality were recorded for each cultivar by year, repetition, water source, and stage of maturity. A series of ANOVA were computed for all data in each year and across both years. For each greenhouse, or respective water treatment, ANOVA for cultivars was analyzed as a randomized complete block design, with each repetition considered as block. From global GLM ANOVA (SAS Inst., Inc., Cary, NC) F Tests for years and water sources were tested as the ratios over the MS rep (year x water). This is analogous to split plot and provides conservative F tests (Table 4). Means within trials were separated using protected LSD at the 10% level.

Table 4. Analysis of variance model with sources and degrees of freedom.

Source	Degrees of Freedom
Year (2004 vs. 2005)	1
Water (CBM vs. Well)	1
Water x year	1
Rep (water x year) Error A	6
Cultivar	8
Cultivar x year	8
Cultivar x water	8
Cultivar x water x year	8
Error MS	46

The null hypotheses tested were that: 1) there was no difference in barley performance (yield and quality) when irrigated with CBM discharge water vs. well water 2) there was no difference among barley cultivars (in yield and quality) when irrigated with CBM discharge water vs well water. Differences were considered significant at P<0.10.

CHAPTER 4

RESULTS AND DISCUSSION

Forage agronomic and quality parameters were tested for 18 barley cultivars under simulated field conditions irrigated with well water or CBM discharge water in three trials conducted between 2004 and 2005 (Trial 2005A discontinued). Each greenhouse (well or CBM) had three replications of 14 cultivars (Table 1) in a randomized complete block design.

A series of ANOVA were computed for all data in each year and across both years. A global set of data for nine common entries in 2004 and 2005 was developed due to the experimental design (greenhouse) confounding with water source effects. The main effects of water sources and years were tested as in a split plot ANOVA (ratio of MS water/ MS rep (year x water)). This design creates limitations due to the level of F required to detect significance in a two year period. This did not alter the objectives of the study to evaluate and determine barley cultivars with high performance under irrigation of CBM discharge water.

Since barley cultivars vary in maturation rates under normal growing conditions it is necessary to evaluate yield and forage quality at an equal stage of maturity. Barley irrigated with CBM discharge water matured at a faster rate than barley irrigated with well water (Tables 2 and 3). For these reasons, the global subset of data for all cultivars at the anthesis stage of maturity was extracted to make comparisons at an equivalent maturity stage. The ANOVA from this subset of data is presented in Table 5.

Table 5. ANOVA results (F values) of nine barley cultivars irrigated with well or CBM discharge water evaluated for yield and forage quality at the anthesis stage of maturity.

Source	df	Maturity Zadoks	Height cm	Air DM, mg g^{-1}	DM yield, kg ha^{-1}	ADF mg g^{-1}	NDF mg g^{-1}	CP mg g^{-1}	NO_3-N mg g^{-1}
Year (2004 vs 2005)	1	4.52*	877.68***	27.6***	1.09	25.76***	33.96***	6.92**	0.09
Water (CBM vs. Well)	1	3.13	199.49***	0.01	11.62**	0.10	2.75	3.50	4.76*
Year x Water	1	3.21	55.07***	1.24	0.49	0.76	0.03	0.53	1.12
Rep x (Water x Year) error A	6								
Cultivar	8	4.92***	76.55***	1.58	2.12*	3.98***	3.91***	4.20***	4.68***
Cultivar x Year	8	6.06***	70.08***	1.93*	1.84*	2.98***	3.07***	3.87**	2.46**
Cultivar x Water	8	4.11***	20.20***	4.66***	1.08	1.00	1.91*	3.74***	0.38
Cultivar x Year x Water	8	1.83*	6.89***	3.46***	0.64	1.06	0.66	0.84	1.05
		MS	MS	MS	MS	MS	MS	MS	MS
Error	46	25.51	11.48	1637.1	1759643.5	631.2	829.04	367.5	0.835
CV%		8.3	7.4	16.8	21.9	7.5	4.9	12.9	44.2

Water treatment had a significant effect ($P<0.10$) on barley forage yield, height, and NO_3-N concentration (Table 5). Years were significantly different for all parameters measured except for yield and NO_3-N, and the year x water interaction was only significant for height (Table 5). The significant year effect for several of the parameters estimated is likely due to the different growing conditions at harvest (July 2004 vs. August 2005).

Maturity

For the data subset of all treatments at anthesis, no significant differences were seen between maturity scores for barley forages when irrigated with well water or CBM discharge water ($P>0.10$, Table 6). The cultivar x year x water, cultivar x water, and cultivar x year were all significant ($P<0.10$). In Trial 1 (2004), when irrigated with well water, Westford did not mature ahead of most other cultivars but when irrigated with CBM water, Westford was the fastest maturing ($P<0.10$). In Trial 3 (2005B), when irrigated with well water, Hays did not mature ahead of the other cultivars but when irrigated with CBM discharge water Hays had the highest anthesis maturity score ($P<0.10$). Despite a difference between years, this data reinforces the validity that most maturity effects of this global subset of data were removed.

Table 6. Forage maturity score (Zadok's scale) of nine barley cultivars irrigated with well or CBM discharge water in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Conlon	61	59	60	59	55	57	60	57	58
Haxby	65	62	63	80	55	67	72	58	65
Haybet	69	62	65	65	51	58	67	56	61
Hays	65	65	65	67	55	70	66	69	67
Moravian 37	51	59	55	65	57	61	58	58	58
Morex	61	63	62	59	59	59	60	61	60
Robust	63	62	62	55	51	53	59	56	57
Valier	69	61	65	57	54	51	63	53	58
Westford	61	71	66	53	51	52	57	61	59
Mean $_{\text{water}}$	62^a	62^a		62^a	55^a		62^a	59^a	
Mean $_{\text{year}}$			62^a			58^b			
LSD$_{\text{cultivar}}$	2	5	8	NS	NS	NS	12	11	9

^{a,b} Means within a row denoted with different superscripts are significantly different (P<0.10), however all interactions were significant.

Height

Barley height was significantly reduced by 26% when irrigated with CBM discharge water (P<0.10, Table 7). The cultivar x year x water interaction and all two way interactions were significant (P<0.001, Table 5).

Cultivars were significantly different within trials. In Trial 1 (2004), plant heights of Haxby, Haybet, Robust, Morex, and Valier were reduced by one third to one half when irrigated with CBM discharge water (P<0.10, Table 7). In Trial 3 (2005B), Morex and Valier were 39 and 45% shorter when irrigated with CBM discharge water.

These findings are consistent with Steppuhn and Wall (1996b) who found that plant height in wheat declined linearly with increasing salinity. This response was seen in all cultivars at EC of 2 dS m^{-1}or greater.

Table 7. Forage height (cm) of nine barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Conlon	39	35	37	26	26	26	32	30	31
Haxby	74	37	55	34	22	28	54	29	41
Haybet	73	38	55	30	25	27	52	31	41
Hays	85	77	81	32	28	30	58	52	55
Moravian 37	31	28	29	30	30	30	30	29	29
Morex	72	48	60	44	27	35	58	37	47
Robust	72	45	58	27	26	27	50	35	42
Valier	71	33	52	32	18	25	51	25	38
Westford	92	84	88	29	27	28	60	55	58
Mean $_{water}$	67^a	47^b		31^a	25^a		49^a	36^b	
Mean $_{year}$			57^a			28^b			
$\text{LSD}_{cultivar}$	26	26	24	7	5	11	25	25	13

^{a,b} means within a row denoted with different superscripts are significantly different ($P<0.10$), however there were significant interactions.

Not all cultivars were negatively affected. In Trial 1 (2004), Westford was the tallest cultivar ($P<0.10$) when irrigated with both well water and CBM water. Hays followed this pattern maintaining normal plant height when irrigated with CBM discharge water. Conlon and Moravian 37 were unaffected ($P<0.10$).

In Trial 3 (2005B), Westford, Hays, Conlon, Moravian 37, Haybet, and Robust were again unaffected by water treatment. Two forage cultivars (Westford and Hays) and two malt cultivars (Conlon and Moravian 37) were unaffected by CBM water with regards to height. This provides producers with options when considering CBM water as an irrigation source. Stunted plant growth is one of the main plant responses to salinity (Maas, 1993). Barley may have a 50% reduction in height and still maintain normal grain yields (Bernstein, 1964). Hays and Westford, which were unaffected in both trials, are becoming increasingly popular forage barley cultivars in Montana. Hays has been proven to have superior feeding characteristics (Todd et al., 2003). Its performance in this trial will have significant impact on its potential use under CBM irrigation.

Dry Matter Concentration

Barley forage DM concentration at harvest is generally related to plant maturity (Khorasani et al., 1997). Few significant effects were detected for dry matter concentration (Table 5) supporting the Zadok's maturity scores. No difference was seen between barley forage dry matter when irrigated with CBM discharge water or well water (Table 8, P>0.10). There were significant cultivar x year x water and cultivar x water interactions.

In Trial 1 (2004), there was a consistent, although not significant, higher DM content for barley irrigated with CBM discharge water. In Trial 3 (2005B), the reverse was true with six of the nine cultivars evaluated having higher DM content under well water irrigation.

Table 8. Forage DM concentration (mg g^{-1}) of nine barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trial		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Conlon	153	210	174	342	166	254	247	188	218
Haxby	197	176	187	159	338	249	178	257	218
Haybet	187	213	200	260	317	288	223	265	244
Hays	170	232	201	302	358	330	236	295	266
Moravian 37	148	183	166	430	269	350	289	226	258
Morex	167	188	178	354	313	334	260	251	256
Robust	160	195	178	423	272	348	292	234	263
Valier	179	188	183	359	265	312	269	227	248
Westford	150	223	187	348	183	266	249	203	226
Mean$_{water}$	168^{a}	201^{a}		331^{a}	276^{a}		249^{a}	238^{a}	
Mean$_{year}$			184^{b}			303^{a}			
LSD$_{cultivar}$	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] means within a row denoted with different superscripts are significantly different (P<0.10), however there were significant interactions.

ForageYield

Barley forage dry matter yield was significantly reduced by 24% when irrigated with CBM water (P<0.10, Table 9). In Trial 1 (2004), barley forages irrigated with well water yielded 26% higher than barley forages irrigated with CBM discharge water, 7167 vs. 5300 kg ha^{-1} respectively (P<0.10). Haxby, Haybet, Moravian 37, Morex, and Robust all had higher yields when irrigated with well water than when irrigated with CBM water (P<0.10). Although reduced under CBM irrigation, Haxby and Haybet still had yields higher than the average of forages irrigated with well water in Trial 3 (2005B).

Table 9. Forage yield (kg ha $^{-1}$) of nine barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Conlon	5633	4233	4933	7666*	2786	5226	6649*	3509	5080
Haxby	8733*	5866	7300	2653	3318	2986	5693	4592	5143
Haybet	9000*	6066	7533	5675	5173	5424	7337*	5620	6478
Hays	7033	6600	6817	6865	6833	6849	6949	6717	6833
Moravian 37	6600*	3500	5050	4165	5525	4845	5382	4513	4947
Morex	7433*	5400	6417	7309	5566	6437	7371*	5483	6427
Robust	7300*	5166	6233	6457	5365	5911	6878*	5266	6072
Valier	6700	5200	5950	5516	3546	4531	6108*	4373	5241
Westford	6067	5667	5867	6185	3072	4628	6125*	4369	5247
Mean $_{\text{water}}$	7167^{a}	5300^{b}		5832^{a}	4575^{b}		6499^{a}	4937^{b}	
Mean $_{\text{year}}$			6233^{a}			5204^{a}			
LSD$_{\text{cultivar}}$	NS	NS	1662	NS	NS	3155	NS	2470	1308

^{a,b} Means within a row denoted with different superscripts are significantly different (P<0.10).
* Cultivar means within a year or across trials denoted by an asterisk had significant difference between well and CBM water (P<0.10), however the cultivar x year interaction was significant.

In Trial 3 (2005B), barley forages irrigated with well water yielded 22% higher than those irrigated with CBM water (P<0.10). Conlon exhibited higher yields when irrigated with well water, 7666 vs. 2786 kg ha $^{-1}$ (P<0.10). Across trials, Conlon, Haybet, Morex, Robust, Valier, and Westford all yielded higher when irrigated with well water (P<0.10), however the cultivar x year interaction was significant.

These findings are consistent with Maas and Hoffman (1977) who found that as salt levels increased above threshold levels, the growth rate and size of the plant decreased. Specifically, a 7.1 unit decrease in barley forage for every unit increase above the salinity threshold. This also concurs with Majerus, (1996) who stated that productivity of barley grain will decline at salt levels of 7 dS m $^{-1}$. The synthesized CBM water in these trials was targeted at 1.2 dS m $^{-1}$ and SAR of 35. These trials indicate that

EC threshold levels are much lower for forage yield of barley than for barley grain, and also that elevated SAR has an impact on forage yield.

In both trials, use of CBM water as an irrigation source did not significantly reduce ($P<0.10$) the yield of Hays, Westford, Haxby, or Haybet. Hays was the highest yielding cultivar across both water treatments and trials. Morex and Robust both performed better under well water than the average of all cultivars under well irrigation and their yields under CBM water were not drastically reduced. This gives producers the option of using CBM water with malt barley for forage. Even though barley grain tolerates higher EC levels than forage, the forage cultivars generally had higher forage yields than the malt cultivars under CBM irrigation.

Fiber

Acid Detergent Fiber

Barley forages were not different in ADF concentrations when irrigated with CBM or well water (Table 5, $P>0.10$). There was no cultivar x year x water interaction but there was a cultivar effect and cultivar x year interaction and some significant cultivar differences within trials did occur. In Trial 1 (2004), Conlon, Haxby, Hays, Moravian 37, and Morex all had ADF concentrations which were not significantly different from each other when irrigated with well water (Table 10, $P<0.10$). When irrigated with CBM water in the same trial, all of the cultivars had similar ADF concentrations ($P<0.10$). Water treatment had no effect on ADF concentration of Conlon, Haxby, Hays, Moravian 37, or Morex in this trial. In Trial 3 (2005B), all cultivars under well irrigation had similar ADF concentrations. The same was true for all cultivars under CBM irrigation (P<0.10). Hays, Morex, and Robust are three cultivars that maintained stable ADF concentrations throughout both trials under both treatments.

Table 10. Forage ADF (mg g $^{-1}$) of nine barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Conlon	359.3	351.2	355.2	324.3	283.6	304.0	341.8	317.4	329.6
Haxby	354.9	326.3	340.6	266.9	279.7	273.3	310.9	303.0	307.0
Haybet	377.1	364.9	371.0	300.0	323.8	311.9	338.6	344.4	341.5
Hays	341.6	329.5	335.6	308.0	288.0	298.0	324.8	308.8	316.8
Moravian 37	323.0	320.4	321.7	275.7	340.5	308.2	299.4	330.5	314.9
Morex	357.1	357.3	357.2	309.3	302.1	305.7	333.2	329.7	331.4
Robust	377.1	368.7	372.9	329.3	323.3	326.3	353.2	346.0	349.6
Valier	378.3	374.6	376.5	306.8	278.1	292.5	342.6	326.4	334.5
Westford	379.7	340.6	360.2	260.9	258.2	259.6	320.3	299.4	309.9
$\text{Mean}_{\text{water}}$	359.1^{a}	349.5^{a}		297.9^{a}	297.5^{a}		329.4^{a}	322.8^{a}	
$\text{Mean}_{\text{year}}$			354.5^{a}			297.7^{b}			
$\text{LSD}_{\text{cultivar}}$	20.4	NS	21.0	NS	NS	NS	NS	NS	37.8

[a,b] Means within a row denoted with different superscripts are significantly different (P<0.10), however the cultivar x year interaction was significant.

Neutral Detergent Fiber

No significant effect was detected in NDF concentrations between barley forages when irrigated with CBM or well water (Table 5, P>0.10). There was no cultivar x year x water interaction, but there were cultivar x water and cultivar x year interactions as well as some significant cultivar differences within trials. In Trial 1 (2004), Moravian 37 had the lowest NDF concentration of all nine cultivars when irrigated with well water but no difference was seen in its NDF concentration when irrigated with CBM water in comparison to the other cultivars (Table 11, P<0.10). Hays and Westford were among the highest in NDF concentration under well irrigation when compared to the other cultivars but when irrigated with CBM water, no difference was detected among any of the nine cultivars and Westford and Hays were among the lowest (P<0.10). No adverse reaction was detected in NDF concentration in this trial with the exception of Moravian 37 which was significantly lower than the other cultivars under well irrigation but not different under CBM irrigation. In Trial 3 (2005B), no difference was detected in NDF concentration among any of the nine cultivars under well irrigation (P<0.10). When under CBM irrigation, Westford was had the lowest NDF concentration in comparison with the other cultivars. No difference was detected in NDF concentration for six of the nine cultivars evaluated in this trial (P<0.10).

Use of CBM water as an irrigation source had no significant negative impact on the NDF concentration of Hays, Haybet, or Westford in either trial. Robust maintained stable NDF concentrations under both treatments in Trial 3 (2005B).

Table 11. Forage NDF (mg g $^{-1}$) of nine barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Conlon	605.7	643.0	624.3	556.4	523.1	539.7	581.0	583.0	582.0
Haxby	608.2	626.9	617.5	488.6	565.3	526.9	548.4	596.1	572.2
Haybet	622.3	621.7	622.0	560.7	577.3	569.0	591.5	599.5	595.5
Hays	599.1	589.7	594.4	568.4	559.8	564.1	583.8	574.7	579.2
Moravian 37	558.4	620.4	589.4	509.7	580.4	545.0	534.0	600.4	567.2
Morex	616.4	655.8	636.1	532.6	574.0	553.3	574.5	614.9	594.7
Robust	627.0	670.7	648.8	568.5	576.0	572.3	597.8	623.3	610.5
Valier	624.1	656.0	640.0	553.6	516.7	535.2	588.9	586.3	587.6
Westford	625.6	607.6	616.6	481.7	511.9	496.8	553.6	559.8	556.7
$\text{Mean}_{\text{water}}$	609.6^{a}	632.4^{a}		535.6^{a}	553.8^{a}		572.6^{a}	593.2^{a}	
$\text{Mean}_{\text{year}}$			621.0^{a}			544.7^{b}			
$\text{LSD}_{\text{cultivar}}$	36.1	NS		NS	50.2		NS	NS	42

^{a,b} Means within a row denoted with different superscripts are significantly different ($P<0\ .10$), however there were significant interactions.

Helm and Salmon (2002) reported average barley forage quality values at ten days post anthesis. They reported ADF concentrations of 346 mg g $^{-1}$ In Trial 1 2004, ADF concentrations of barley forages irrigated with both CBM and well water were very close to this level at the anthesis stage of maturity. In Trial 3 (2005B), barley forages irrigated with both CBM discharge water and well water had ADF concentrations lower than the average reported by Helm and Salmon (2002).

Helm and Salmon (2002) reported average barley forage quality values at ten days post anthesis, NDF concentrations of 590 mg g $^{-1}$. In Trial 1 (2004), NDF concentrations did not differ between barley forage irrigated with well water and barley forages irrigated with CBM discharge water. Both were very close to the average reported by Helm and Salmon (2002). In Trial 3 (2005B), NDF concentrations again did not differ between barley forages under either treatment but they were lower than those reported by Helm and Salmon (2002).

Fiber concentrations, both ADF and NDF followed a trend throughout both trials with use of CBM irrigation water having no effect on fiber concentrations of most barley cultivars.

Crude Protein

Use of CBM discharge water as an irrigation source consistently reduced the CP concentrations for the majority of the cultivars evaluated, however these differences were not significant (Table 5, P>0.10). In Trial 1 (2004), Conlon, Hays, Moravian 37, and Westford all had high CP concentrations in comparison with other cultivars (Table 12) when irrigated with well water but when under CBM irrigation, their CP concentrations were not significantly different from the other cultivars (P<0.10). They did outperform other cultivars under well irrigation but use of CBM irrigation reduced their performance relative to the average CP in this trial.

In Trial 3 (2005B), no difference was detected in CP concentration among cultivars under well irrigation water (P>0.10). Conlon, Valier, and Westford all had higher CP concentrations under CBM irrigation than the other cultivars (P<0.10). Haxby, Haybet, Hays, Moravian 37, Morex, and Robust all had reduced CP concentrations under CBM irrigation.

Use of CBM discharge water as an irrigation source had little effect on some cultivars. In Trial 3 (2005B), Westford remained fairly stable having the highest CP concentrations under both irrigation treatments ($P<0.10$).

The majority of the cultivars evaluated in both trials had consistently lower CP concentration when irrigated with CBM water than when irrigated with well water. However, due to the limitations of the experimental design and split plot ANOVA, no significant differences were detected.

Table 12. Forage CP (mg g $^{-1}$) of nine barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Conlon	171.7	85.3	128.5	189.8	218.9	204.3	180.8	152.1	166.4
Haxby	120.3	101.2	110.8	200.2	142.8	171.5	160.3	122.0	141.1
Haybet	138.6	92.7	115.6	196.9	186.5	191.7	167.7	94.6	131.2
Hays	178.6	101.8	140.2	175.8	159.0	167.4	177.2	130.3	153.8
Moravian 37	206.7	108.7	157.7	233.5	145.7	189.6	220.1	127.2	173.7
Morex	131.8	91.5	111.7	191.0	175.7	183.3	161.4	133.6	147.5
Robust	137.8	88.4	113.6	173.7	167.7	170.7	155.7	126.1	140.9
Valier	138.0	97.1	117.5	203.9	203.5	203.7	171.0	150.3	160.6
Westford	158.4	83.8	121.1	255.3	222.1	238.7	206.9	152.9	179.8
Mean $_{water}$	153.5^{a}	94.5^{a}		202.4^{a}	180.2^{a}		177.9^{a}	130.2^{a}	
Mean $_{year}$			124^{b}			191^{a}			
LSD$_{cultivar}$	22	NS	NS	NS	32	55	51	59	39

^{a,b} means within a row denoted with different superscripts are significantly different ($P<0.10$), however there were significant interactions.

Forage quality data for barley is particularly limited at the anthesis stage of maturity. Khorasani et al. (1997) found CP concentrations to decrease from approximately 250 mg g^{-1} at the boot stage to 120 mg g^{-1} at soft dough.

When specifically examining CP concentrations at the anthesis stage of maturity, barley irrigated with CBM discharge water averaged across trials had CP concentrations of 130 mg g^{-1}. This is what is typical of CP concentrations at the soft dough stage of maturity (Khorasani et al., 1997). Since quality is known to decline with increasing stage of maturity, barley irrigated with CBM discharge water at the soft dough stage will likely have below average CP concentrations compared with averages reported by Khorasani et al. (1997).

Helm and Salmon (2002) reported average CP concentrations of 132 mg g^{-1} at ten days post anthesis. In Trial 1 (2004), barley forages irrigated with well water had CP concentrations higher than this (153.5 mg g^{-1}) while barley forages irrigated with CBM discharge water had CP concentrations much lower, 94.5 mg g^{-1}. In Trial 3 (2005B), the same pattern emerged with barley irrigated with well water being higher than the average of 202 mg g^{-1} reported by Helm and Salmon (2002). Barley irrigated with CBM discharge water had CP concentrations of 180.2 mg g^{-1} which were lower than barley forages under the well treatment but higher than the average132 mg g^{-1} reported by Helm and Salmon (2002). When averaged across trials, barley forages irrigated with CBM discharge water had CP concentrations equal to those reported by Helm and Salmon (2002).

Nitrate-N

Water source had a significant effect on NO_3-N concentrations ($P<0.10$, Table 5). Across trials, barley cultivars irrigated with CBM discharge water had 80% lower NO_3-N concentrations than when irrigated with well water ($P<0.10$, Table 13). In Trial 1 (2004), barley forages irrigated with CBM water had lower NO_3-N concentrations than barley forages irrigated with well water, 0.33 vs 4.16 mg g^{-1}, respectively ($P<0.10$). All nine cultivars had higher NO_3-N concentrations in 2004 when irrigated with well water than when irrigated with CBM water ($P<0.10$).

In Trial 3 (2005B), barley forages irrigated with CBM water again had lower NO_3-N concentrations than barley forges irrigated with well water, 0.99 vs 2.44 mg g^{-1}, respectively ($P<0.10$). All of the nine cultivars evaluated, Haybet, Hays, Moravian, Valier, and Westford, had higher NO_3-N concentrations in 2005 when irrigated with well water as opposed to CBM water($P<0.10$). When averaged across treatments, Westford had higher NO_3-N concentrations than the rest of the cultivars. This is consistent with past reports which have found Westford to be higher than other barley cultivars in NO_3-N concentration (Surber et al., 2001). No cultivar remained stable between water treatments in either trial.

Table 13. Forage NO_3-N (mg g $^{-1}$) of nine barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Conlon	3.17*	0.27	1.73	2.01	1.16	1.59	2.59*	0.72	1.59
Haxby	3.87*	0.25	2.06	1.60	0.57	1.09	2.70*	0.41	1.09
Haybet	2.96*	0.36	1.66	2.04*	0.51	1.27	2.49*	0.44	1.09
Hays	4.50*	0.40	2.53	2.56*	1.14	1.85	3.53*	0.77	1.85
Moravian 37	4.26*	0.29	2.28	2.17*	0.16	1.16	3.22*	0.22	1.16
Morex	5.20*	0.10	2.67	2.50	1.75	2.12	3.84*	0.93	2.12
Robust	4.93*	0.39	2.66	1.45	0.68	1.06	3.19*	0.54	1.06
Valier	3.42*	0.42	1.92	2.79*	1.21	2.00	3.10*	0.82	2.00
Westford	5.10*	0.49	2.80	4.94*	1.73*	3.33	5.02*	1.11	3.07
$Mean_{water}$	4.16^a	0.33^b		2.44^a	0.99^b		3.30^a	0.66^b	
$Mean_{year}$			2.26^a			1.72^a			
$LSD_{cultivar}$:	1.38	0.15	1.42	NS	NS	1.28	1.69	NS	0.98

^{a,b} Means within a row denoted with different superscripts are significantly different ($P<0.10$).
*Cultivar means within a year denoted by an asterisk had significant difference between well and CBM water ($P<0.10$).

In both trials of this study, nitrate levels were higher in barley irrigated with well water than barley irrigated with CBM discharge water ($P<0.10$). In a study Surber et al. conducted (2003b), barley cultivars were found to have an average NO_3-N level of 1.9 mg g^{-1} at the anthesis stage of maturity. Forages irrigated with CBM water are slightly higher than this reported average at the anthesis stage and barley irrigated with well water are more than 15 times higher than this reported average.

Murphy and Smith (1967) found that forage NO_3-N concentrations decrease as plants mature. Gul and Kolp (1960) reported that oat in the 25% flower stage had nitrate levels of approximately 28 mg g^{-1}. This level dropped to 10 mg g^{-1} in the hard dough stage. Other sites showed similar results with nitrate levels of 60 mg g^{-1} at the 25% flower stage and then dropping to 3 mg g^{-1} in the hard dough stage. Cash et al. (2002)

also states that immature plants (vegetative to boot stage) usually have higher nitrate concentrations than more mature plants. This is supported by Surber et al. (2003b) who found that NO_3 -N levels were lower at the boot and anthesis stage of maturity (avg. 24.4 mg g^{-1}) than at harvest stage of maturity (16.8 mg g^{-1}).

Considering the consistent (although non significant) decline in CP and NO_3-N concentrations of barley forages irrigated with CBM discharge water, it appears that when barley cultivars are irrigated with CBM discharge water, the N uptake or metabolism is altered in some fashion. No literature is available to explain this effect. If use of CBM discharge water as an irrigation source is responsible for reduced NO_3-N concentrations and does not cause CP concentrations to decline below livestock requirement levels, it could be a beneficial factor in regulating forage quality as far as NO_3-N levels are concerned.

Validation Trial

A small additional trial was conducted in 2005 to investigate the confounding effects of the single greenhouses used in Trials 1, 2, and 3. Four 18 L containers were placed under each greenhouse, side by side, filled with the same soil as used in the main trials. Two of the containers (reps) received well water and two received CBM water. The cultivar Hays was planted in all buckets, clipped at the anthesis stage of maturity and analyzed for forage quality. The ANOVA for the bucket trial are presented in Table 14. In this validation trial, greenhouse and the water x greenhouse interaction were not significant (P>0.10). The results suggest that growing conditions under both greenhouses were similar for the production of Hays barley in 2005.

Table 14. ANOVA results of Hays irrigated with well or CBM discharge water at the anthesis stage of maturity in 2005.

Source	df	Yield kg ha^{-1} P>F	ADF mg g^{-1} P>F	NDF mg g^{-1} P>F	CP mg g^{-1} P>F	NO_3N mg g^{-1} P>F
Water	1	0.157	2.533	0.455	0.137	0.007
Greenhouse	1	0.836	1.000	0.959	0.855	0.637
Water x Greenhouse	1	0.493	0.881	0.797	0.842	0.191
Error	4					
Total	7					
CV%		8.4	4.7	3.7	13.1	19.0

Results from this trial support the findings of Trial 1 (2004) and Trial 3 (2005). Yield was slightly higher in Hays barley irrigated with well water than when irrigated with CBM discharge water, however no significant difference was detected (P>0.10, Table 15). The yield data for the bucket trial and main trials are similar in that Hays did not display dramatically reduced yields when under the CBM treatment.

Concentrations of both ADF and NDF, mg g $^{-1}$, were similar across treatments with no significant difference detected (P>0.10, Table 15). Hays did not display a difference in either ADF or NDF concentration in either the container trial or the greenhouses between water sources.

The trend for Hays barley irrigated with well water having CP concentrations higher than barley forages irrigated with CBM discharge water carried through in the validation trial, however significant differences were not detected (P>0.10, Table 15).

Nitrate levels were again significantly ($P<0.10$) higher in barley forages irrigated with well water than in barley forages irrigated with CBM discharge water. This is consistent with the Trials 1 and 3 where Hays had much higher NO_3-N concentrations when irrigated with well water as opposed to CBM water, 3.53 vs. 0.77 mg $\cdot g^{-1}$ respectively ($P<0.10$).

Table15. Forage yield and quality of Hays irrigated with well or CBM discharge water at the anthesis stage of maturity in 2005.

Greenhouse	Treatment	Yield, kg ha^{-1}	ADF,mg g^{-1}	NDF,mg g^{-1}	CP,mg g^{-1}	NO_3-N,mg g^{-1}
Central	Well	4881.0	291.8	524.6	190.8	2.55^{a}
Central	CBM	4215.0	278.0	509.5	157.5	1.55^{b}
South	Well	4620.5	290.5	520.0	184.1	3.10^{a}
South	CBM	4357.5	279.5	512.5	157.9	1.20^{b}

^{a,b} Means within a row denoted with different superscripts are significantly different ($P<0.10$).

Results from the validation trial imply that under both greenhouses, the growing conditions and barley performance were similar. The existing greenhouse design is useful for growing multiple cultivars under simulated field conditions however due to the confounding factor of only having one greenhouse per water treatment created limitations on the appropriate statistical analysis. If trials were repeated in more years some of the trends which were apparent in Trials 1 and 3 would likely have been detected at a significant level. Another option would be replicated container trials with both water sources under each greenhouse in a factorial design.

IVDMD

Four cultivars common in 2004 and 2005 and at the anthesis stage of maturity were evaluated for IVDMD. The cultivars were Hays and Westford (two-row) and Valier and Robust (six-row) and were chosen based on end use (Table 1). The ANOVA for IVDMD is presented in Table 16. No difference in IVDMD was seen between water sources (P>0.10, Table 17). In Trial 1 (2004), Hays and Westford had higher DMD when irrigated with CBM water and Valier and Robust had higher DMD when irrigated with well water. In Trial 3 (2005B) Robust remained stable under both treatments with low digestibility in both.

Table 16. ANOVA of forage IVDMD (mg g $^{-1}$) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

Source	df	F Value
Year (2004 vs.2005)	1	5.379*
Water(CBM vs. well)	1	1.833
Year x water	1	0.376
Rep (Water x year) error A	4	
Cultivar	3	17.94***
Cultivar x Year	3	1.88
Cultivar x Water	3	14.08***
Cultivar x Year x Water	3	17.43***
Error MS	12	77.89
CV%		5.0

* and *** denote significance at the P< 0.1 and 0.01 levels respectively.

Table 17. Forage IVDMD (mg g $^{-1}$) concentration of nine barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	418.1	569.2	493.6	570.1	578.9	574.5	494.1	574.0	534.1
Westford	425.1	580.4	502.7	568.5	559.9	564.2	496.8	570.2	533.5
Valier	504.0	464.8	484.4	468.3	573.2	520.8	486.1	519.0	502.6
Robust	466.6	393.2	429.9	485.9	446.2	466.0	476.2	419.7	448.0
Mean $_w$	453.4^a	501.9^a		523.2^a	539.5^a		488.3^a	520.7^a	
Mean $_y$			477.7^b			531.4^a			
LSD$_{cultivar}$	NS	NS	NS	NS	NS	NS	NS	NS	39

^{a,b} means within a row denoted with different superscripts are significantly different (P<0.10).

Minerals

Forage samples were analyzed for Ca, Mg, P, K, Na, S, Cu, Fe, Mn, and Zn. ANOVA and F test results for gross mineral content are presented in Table 18. Few differences were detected between water treatments with regards to mineral concentrations (Table 18). All minerals evaluated accumulated in the soil between the beginning and end of Trial 1 (2004) (Table 19) and mineral concentrations in forages increased between 2004 and 2005 for all minerals evaluated (Table 19). The soil mineral content was adequate to meet the critical grass forage level for all minerals evaluated (Table 19, Mayland, 2002).

Table 18. ANOVA results of forage mineral concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

		K	Ca	Mg	P	Na	S	Cu	Fe	Mn	Zn
Source	df										
year (04 vs 05)	1	7.06**	10.62**	5.14*	5.82*	2.43	18.6***	4.1*	4.9*	2.32	0.38
water (CBM vs. Well)	1	8.59**	6.75**	1.46	0.35	0.36	2.80	1.73	1.03	1.04	8.82**
year x water	1	0.31	0.00	0.02	2.21	0.02	0.00	0.34	0.80	1.01	0.28
Rep x (Water x year) error A	4										
cultivar	3	11.73***	5.73**	0.13	1.20	1.11	1.23	1.47	0.85	1.02	1.59
cultivar x year	3	7.30***	0.34	1.55	1.92	0.42	2.59	4.08**	1.36	1.02	0.77
cultivar x water	3	2.56	0.58	1.15	1.51	1.17	0.14	2.26	2.77*	1.82	1.29
cultivar x year x water	3	3.88**	1.66	2.33	1.57	0.41	1.65	2.56	2.01	1.81	0.57
		MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
Error	12	16337954	606947	111212	663854.1	1934296	195517	12.65	994.6	202998	6942.6
CV%		13.1	12.5	19.6	26.1	31.7	20.3	36.7	34.9	193.5	117.8

*, **, and *** denote significance at the P<0.10, 0.05, and 0.01 levels respectively

Table 19. Mineral concentrations (ppm) of soil and barley, critical levels of forage grass and livestock mineral requirements.

	Soil Concentration			Barley Forage Concentration				Critical Grass Forage level	Livestock Requirement		
	Apr-04	Oct-04		2004		2005			Gestating Cow	Lactating Cow	Maximum Limit
		Well	CBM	Well	CBM	Well	CBM				
Mineral											
Ca	6885	7362	7361	5973	3939	8517	6490	<2000	0-12	14-20	-
Mg	610.0	650.7	663.3	1533	1026	2327	1929	1000	1200.0	2000.0	4000.0
P	2.5	4.0	2.3	2529	2960	4359	3359	2000 to 3000	0-5	11.0	-
K	464	543	512	30467	22594	44169	29555	20000 to 30000	6000.0	7000.0	30000.0
S	15	13	26	1790	1137	3471	2791	1000 to 3000	1500.0	1500.0	4000.0
Na	218	255	214	27430	3810	6184	5827	<1000 to 3000	600-800	1000.0	-
Fe	13.0	9.7	9.7	69	67	132	93	<50000	50.0	50.0	1000.0
Mn	5.3	1.3	1.4	42	38	683	169	20000	40.0	40.0	1000.0
Cu	1.3	1.0	1.0	8	6	16	10	4000	10.0	10.0	100.0
Zn	0.4	0.4	0.4	26	102	51	104	10000 to 1000	30.0	30.0	500.0

Critical grass forage levels adapted from Mayland, 2002.
Mineral requirements for beef cattle adapted from NRC, 2000.

Barley irrigated with well water had higher K concentrations than barley irrigated with CBM water (P<0.10, Table 18). In Trial 1 (2004), barley irrigated with well water had 25% higher (P<0.10) K levels than those irrigated with CBM water (Table 20). In Trial 3 (2005B) barley irrigated with well water had higher K levels than when irrigated with CBM water, 41,169 vs 29,555 ppm respectively (P<0.10). All cultivars evaluated in 2005 had higher K levels when irrigated with well water (P<0.10). Forages irrigated with well water were at toxic levels with regards to livestock requirements (Table 19). Despite lower concentrations under CBM irrigation, all cultivars still had high K concentrations with regards to livestock requirements.

At the end of Trial 1 (2004), soil K levels were slightly higher in samples from both greenhouses, well at 543 ppm and CBM at 512 ppm. This may account for the higher K levels in the forages irrigated with well water. Also, K concentrations were significantly higher (P<0.10) in 2005 which may a result of accumulating K (at the beginning of the trial, soil samples had K concentrations of 464 ppm). Cultivars irrigated with well water almost always had higher K concentrations than when irrigated with CBM water.

Table 20. Forage K concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	30644*	15202	22923	34998*	25880	30439	32821	20541	26681
Westford	37349*	19615	28482	48468*	36410	42439	42909	28012	35461
Valier	26676	27724	27200	49029*	36206	42617	37852	31965	34908
Robust	27198	27835	27517	32181*	19723	25952	29689	23779	26734
Mean $_{w}$	30467^{a}	22594^{b}		41169^{a}	29555^{b}		35818^{a}	26074^{b}	
Mean $_{y}$			26530^{a}			35362^{b}			
LSD$_{cultivar}$	NS	6088	NS	NS	8674	2810	NS	NS	6435

[a,b] means within a row denoted with different superscripts are significantly different ($P<0.10$).

Barley forage cultivars irrigated with well water had nearly 30% more Ca than those irrigated with CBM water (Table 21, $P<0.10$). Across trials, all cultivars irrigated with well water had significantly higher levels of Ca than those irrigated with CBM ($P<0.10$).

Soil samples from the beginning of the trial from both greenhouses before and after Trial 1 (2004) contained similar concentrations of Ca, 6,885 and 7,362 ppm respectively. Despite similar Ca levels in both soils, forage Ca concentrations were different ($P<0.10$). Therefore, the difference in barley forage Ca concentrations appears to be due to water treatments and not due to differences in soil Ca levels. A difference was detected in Ca concentrations between years with barley forages having higher Ca concentrations in 2005 than 2004 ($P<0.10$). Barley forages irrigated under both treatments had higher Ca concentrations in 2005 than 2004 indicating that Ca may be accumulating in the soils and therefore more Ca is available for uptake by the plants.

Table 21. Forage Ca concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	7532*	4113	5823	8746*	7096	7921	8139*	5604	6872
Westford	5218*	3387	4303	7894*	6326	7110	6556*	4857	5706
Valier	4674	3823	4249	8239*	5740	6990	6456*	4782	5619
Robust	6467*	4434	5451	9188*	6796	7992	7828*	5615	6721
Mean_{w}	5972^{a}	3939^{b}		8516^{a}	6489^{b}		7244^{a}	5214^{b}	
Mean_{y}			4956^{b}			7503^{a}			
$\text{LSD}_{\text{cultivar}}$	1154	NS	NS	NS	603	NS	NS	NS	1240

^{a,b} Means within a row denoted with different superscripts are significantly different (P<0.10).
* Within trials or across trials denotes significant difference (P<0.10).

No significant difference was detected in Mg concentrations between water treatments (Table 18, P>0.10). In Trial 1 (2004), Hays and Westford had higher Ca concentrations in comparison with the other cultivars under well water irrigation (Table 22, P<0.10). Under CBM irrigation, Hays, Westford, and Valier had low Ca concentrations in comparison with Robust. Under well irrigation, Hays and Westford had high Ca concentrations but under CBM irrigation, their Ca concentrations were low. Robust had high Ca concentrations under CBM irrigation compared to other cultivars (P<0.10). In Trial 3 (2005B), no differences were detected in Mg concentrations among cultivars for either irrigation treatment (P>0.10).

Cultivars irrigated with well water almost always had numerically higher Mg concentrations than when irrigated with CBM water. However, no significant differences were detected.

Concentrations of Mg were similar in soil samples for both treatments at the beginning and end of 2004 (610 and 650 ppm, respectively), indicating that treatment did not affect soil Mg concentration. Any difference in plant Mg concentration is not apparently due to the soil Mg levels. A difference was detected in Mg concentrations between years with barley forages irrigated with both well and CBM water having higher Mg concentrations in 2005 than 2004 but the Mg concentration was higher at the end of 2004 than the beginning indicating that Mg may be accumulating in the soil.

Table 22. Forage Mg concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	1809	801	1305	2064	1989	2027	1937	1395	1666
Westford	1647	968	1307	2287	1890	2089	1967	1429	1698
Valier	1249	1003	1126	2930	1876	2403	2090	1439	1764
Robust	1426	1332	1379	2026	1958	1992	1726	1645	1686
Mean $_w$	1533^a	1026^a		2327^a	1928^a		1930^a	1477^a	
Mean $_y$			1279^b			2128a			
LSD$_{cultivar}$	3356	292	NS	NS	NS	NS	NS	NS	NS

^{a,b} Means within a row denoted with different superscripts are significantly different (P<0.10).

No difference was detected in P concentrations between barley irrigated with well water or CBM water (Table 18, P>0.10). In both Trial 1 (2004) and Trial 3 (2005B), as well as across trials, no differences were detected between cultivars in either the well or CBM irrigation treatment (Table 23, P>0.10).

At the end of Trial 1 (2004), P concentrations were higher in soils irrigated with well water than soils irrigated with CBM discharge water, 4.0 vs 2.3 ppm respectively.

This may be part of the reason why forages irrigated with well water in Trial 3 (2005B) had higher P concentrations than CBM. A difference was detected in P concentrations between years. Barley forages irrigated with both well and CBM water had higher ($P<0.10$) P content in 2005 than 2004 indicating that P may be accumulating, possibly due to fertilizer or the simulated water ingredients.

Table 23. Forage P concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	2264	2972	2618	2880	3177	3029	2572	3075	2823
Westford	1956	3394	2675	5099	3086	4093	3528	3240	3384
Valier	2701	2050	2376	5314	3561	4437	4008	2805	3407
Robust	2587	2711	2649	3240	2965	3103	2913	2838	2876
Mean $_{w}$	2377^{a}	2781^{a}		4133^{a}	3197^{a}		3255^{a}	2764^{a}	
Mean $_{y}$			2579^{b}			3665^{a}			
LSD$_{cultivar}$	NS	NS	NS	NS	NS	NS	NS	NS	NS

^{a,b} Means within a row denoted with different superscripts are significantly different ($P<0.10$).

No difference was detected in sodium concentration of barley forages irrigated with well water or CBM discharge water (Table 18, $P>0.10$). In Trial 1 (2004), Westford had high Na concentration with well water irrigation compared to other cultivars ($P<0.10$, Table 24). Under CBM irrigation, Westford and Robust had high Na concentrations compared to the other cultivars ($P<0.10$). Westford maintained high Na concentrations under both treatments. In Trial 3 (2005B), no difference was seen in Na concentrations between cultivars under either irrigation treatment ($P>0.10$).

At the end of Trial 1 (2004), Na concentrations were higher in soil samples from the well greenhouse than the CBM greenhouse, 255 vs 214 ppm respectively. Soil under the well treatment appears to be accumulating Na while soil under the CBM treatment is not. This is interesting since CBM water has high Na levels.

Table 24. Forage Na concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	2590	2319	2454	5766	4623	5195	4178	3471	3825
Westford	3826	4297	4062	4495	6387	5441	4161	5342	4751
Valier	1913	3573	2743	4999	5857.	5428	3456	4715	4085
Robust	2639	5050	3845	5476	6440	5958	4057	5745	4901
Mean $_w$	2742^a	3810^a		5184^a	5827^a		3963^a	4818^a	
Mean $_y$			3276			5505			
LSD$_{cultivar}$	NS	NS	NS	NS	NS	NS	NS	NS	NS

^{a,b} means within a row denoted with different superscripts are significantly different (P<0.10).

No difference was detected in S concentration of barley forages irrigated with either well or CBM discharge water (Table 18, P>0.10). In Trial 1 (2004), Hays and Westford had higher (P<0.10) S concentrations under well irrigation than other cultivars (Table 25). Under CBM irrigation, no difference was seen in S concentration between cultivars (P>0.10). Hays and Westford had higher (P<0.10) S concentrations under well irrigation but were non significant under CBM irrigation. In Trial 3 (2005B), no differences were detected in S concentrations among cultivars in either treatment (P>0.10). The well water treatment was designed to match the chemical composition of the water in the PRB which according to Clark et al. (2001) is higher in sulfates than CBM water. This could explain why Hays and Westford had higher sulfate levels under well irrigation and no difference under CBM irrigation in 2004. At the beginning of the trials, soils under both greenhouses had equal S concentrations (15 ppm) but at the end of

Trial 1 (2004), soil under the CBM treatment had higher S levels than soil under the well treatment (26 vs 13 ppm respectively). Cultivars irrigated with well water almost always had higher K concentrations than when irrigated with CBM water.

Table 25. Forage S concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	2003	913	1458	2630	2592	2611	2316	1752	2034
Westford	1772	890	1331	3468	2755	3111	2620	1822	2221
Valier	1430	1143	1287	3944	3094	3519	2687	2119	2403
Robust	1526	1319	1422	3118	2214	2666	2322	1766	2044
Mean $_{water}$	1683^{a}	1066^{a}		3290^{a}	2663^{a}		2486^{a}	1864^{a}	
Mean $_{year}$			1374^{b}			2976^{a}			
LSD$_{cultivar}$:	303.7	NS	NS	NS	NS	NS	NS	NS	NS

^{a,b} means within a row denoted with different superscripts are significantly different (P<0.10).

No difference was detected between copper concentrations of barley forage irrigated with well water or CBM discharge water (Table 18, P>0.10). In Trial 1 (2004), no difference was detected in Cu concentrations among cultivars under either irrigation treatment (Table 26, P>0.10). In Trial 3 (2005B), no difference was detected in Cu concentrations among cultivars under either irrigation treatment (P>0.10). Cultivars irrigated with well water almost always had higher Cu concentrations than when irrigated with CBM water. However, due to the split plot experimental design no significant differences were detected.

Soil Cu concentrations were equivalent at the beginning and at the end of Trial 1 in both greenhouses, 1.3 and 1.0 ppm, respectively. Any difference detected between treatments for Cu concentration is therefore not likely due to Cu levels in the soil.

Table 26. Forage Cu concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	12.71	4.94	4.67	10.11	9.57	9.84	11.41	7.26	9.33
Westford	7.88	4.95	4.68	23.93	10.08	17.00	15.90	7.51	11.71
Valier	4.63	5.64	5.26	18.71	11.19	14.95	11.67	8.42	10.04
Robust	5.97	8.54	7.95	9.28	8.72	9.00	7.62	8.63	8.13
Mean $_{water}$	8.3^a	6.0^a		16.4^a	10.4^a		12.3^a	8.2^a	
Mean $_{year}$			7.2^b			13.4^a			
LSD:	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] means within a row denoted with different superscripts are significantly different (P<0.10),however cultivar x year was significant.

No difference was detected in iron concentration of barley forages irrigated with well water or CBM discharge water (Table 18, P>0.10). In Trial 1 (2004), Hays and Westford had higher Fe concentrations when irrigated with well water in comparison to the other cultivars (Table 27, P<0.10). When irrigated with CBM water, Hays and Westford had Fe concentrations lower (P<0.10) than the other cultivars implying an adverse reaction to CBM water (P<0.10). In Trial 3 (2005B), no differences were seen in Fe concentrations between cultivars under either treatment (P>0.10).

Iron levels were equal in soil samples for soils under both treatments at the start of the trials and at the end of 2004, 13.0 and 9.7 ppm, respectively. Any difference in Fe concentrations between treatments is therefore not due to soil concentrations.

Table 27. Forage Fe concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	88.8	52.0	70.4	101.1	106.5	103.8	94.9	79.2	87.1
Westford	80.7	46.8	63.7	157.9	71.8	114.9	119.3	59.3	89.3
Valier	55.6	76.2	65.9	188.3	98.7	143.5	121.9	87.4	104.7
Robust	51.7	92.1	71.9	80.9	96.6	88.7	66.3	94.3	80.3
$\text{Mean}_{\text{water}}$	69.2^a	66.8^a		132.1^a	93.4^a		100.7^a	80.1^a	
$\text{Mean}_{\text{year}}$			68^b			112^a			
$\text{LSD}_{\text{cultivar}}$	15.7	18.4		NS	NS		NS	18.9	NS

[a,b] Means within a row denoted with different superscripts are significantly different (P<0.10), however there was a cultivar x water interaction.

No differences were detected in manganese concentrations of barley forages irrigated with either well or CBM water (Table 18, P>0.10). In Trial 1 (2004), there were no differences in Mn concentration among cultivars under either treatment (Table 28) (P>0.10). In Trial 3 (2005B) Westford and Valier had higher Mn concentrations when irrigated with well water than other cultivars although they are abnormally high concentrations and could more likely be due to analysis error than water treatment. No other differences were detected in Trial 3 (2005B).

Soil samples from both greenhouses indicated equal Mn concentrations at both the start and at the end of Trial 1, 5.3 and 1.3 ppm, respectively. The extremely high Mn concentrations of Valier and Westford are due to a factor other than soil Mn levels.

Table 28. Forage Mn concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	46.1	32.7	39.4	59.3	58.6	58.9	52.7	45.6	49.2
Westford	44.0	36.2	40.1	1183.0	67.8	625.4	613.5	52.0	332.7
Valier	40.4	38.1	39.2	1436.7	77.7	757.2	738.5	57.9	398.2
Robust	37.8	44.4	41.1	51.7	473.0	262.4	44.8	258.7	151.7
Mean $_{water}$	42.1^{a}	37.8^{a}		682.7^{a}	169.3^{a}		362.4^{a}	103.6^{a}	
Mean $_{year}$			39.9^{a}			426.0^{a}			
LSD$_{cultivar}$	NS	NS	NS	NS	NS	NS	NS	NS	NS

^{a,b} means within a row denoted with different superscripts are significantly different ($P<0.10$).

Barley forages irrigated with well water had lower zinc concentrations than those irrigated with CBM, 102.8 vs 38.7 ppm respectively ($P<0.05$, Table 18). In Trial 1 (2004) barley forages irrigated with well water had lower Zn concentrations than those irrigated with CBM water, 26.4 vs 101.9 ppm, respectively (Table 29, $P<0.10$). In Trial 3 (2005B), no differences were seen among cultivars under either treatment ($P>0.10$).

Concentrations of Zn were similar in soil samples from both greenhouses both at the start and at the end of Trial 1, 0.4 ppm. Higher Zn levels in forages irrigated with CBM water is therefore not due to soil concentrations.

Table 29. Forage Zn concentrations (ppm) of four barley cultivars irrigated with well or CBM discharge water at the anthesis stage of maturity in 2004 and 2005.

	Trial 1 (2004)			Trial 3 (2005B)			Across Trials		
Cultivar	Well	CBM	Mean	Well	CBM	Mean	Well	CBM	Mean
Hays	41.4	30.6	36.0	39.1	44.2	41.6	40.3	37.4	38.8
Westford	22.3	31.4	26.8	63.8	157.1	110.4	43.0	94.2	68.6
Valier	19.2*	223.5	121.3	70.8	180.2	125.5	45.0	201.9	123.4
Robust	22.5*	121.9	72.2	30.5	32.8	31.7	26.5	77.4	51.9
Mean $_{w}$	26.4^{a}	101.9^{b}		51.1^{a}	103.6^{a}		38.7^{a}	102.8^{b}	
Mean $_{y}$			64.1			77.4			
LSD$_{cultivar}$	NS	NS	NS	NS	NS	NS	NS	NS	NS

^{a,b} Means within a row denoted with different superscripts are significantly different ($P<0.10$).

Livestock Requirements

In order to compare the effects of irrigation treatment on forage quality, livestock requirements must be considered. For this discussion, requirements of a 550 kg beef cow in the gestation and lactation stages of production will be considered. The industry intake assumption for beef cattle is considered 2% of body weight (BW). Using this assumption, daily intake for energy, protein, and minerals were calculated.

Following the NO_3 toxicity guidelines given by Cash et al. (2002), in Trial 1 (2004) and Trial 3 (2005B) barley forages irrigated with well water were considered toxic for all classes of livestock and barley forages irrigated with CBM water were considered safe for non pregnant livestock if limit fed at 25 to 50% of the ration.

Considering that barley forages irrigated with well water are considered toxic, only forages irrigated with CBM water will be discussed from this point forward.

Concentrations of ADF are often used to predict TDN (the energy content of a forage). The calculation for TDN is: TDN, % = 88.9 – (0.779 x %ADF) (Rohweder et al., 1990). Forages irrigated with CBM water had ADF concentrations of 315 mg g^{-1}. Consider a 550 kg cow consuming 2% of cow body weight (BW), this values corresponds to 7.08 kg of TDN intake which would meet the requirements of mid-gestation, late gestation, and average lactation stages of production for a 550 kg cow (Table 29).

The NDF concentration of forages is often used as an estimator of intake, 120/ % NDF (Mertens, 1987). A general guideline is to aim for 2% of cow BW for daily intake recommendations. In Trial 1 (2004), only 2 of the cultivars irrigated with CBM water would meet this. However, Robust had the highest NDF concentration, which approximates a level of 1.8% intake. Depending on the protein and ADF levels, this may be acceptable. In Trial 3 (2005B), all nine of the cultivars evaluated had NDF concentrations below 60% providing intakes above 2% BW for beef cattle.

Although no significant difference was detected between water treatments, forages irrigated with well water had higher CP concentrations than those irrigated with CBM water, 173.3 vs 130.2 mg g^{-1}, respectively. Despite this, the 550 kg cow consuming 2% of her BW, or 11 kg would have CP intake 1.43 kg when consuming forages irrigated with CBM water. This meets the requirements of a 550kg cow at the mid-gestation, late gestation, lactation-average, and lactation-superior stages of requirements. The lowest CP concentration reported between both trials was Westford under CBM irrigation, 2004. Its CP concentrations of 83.8 mg g^{-1}, would translate to 0.9 kg CP intake which would meet the requirements of a 550 kg cow at the mid and late gestation stages of production.

Table 30.Nutrient Requirements of 550 kg beef cow.

Stage of Production	TDN Requirement, Kg	CP Requirement , Kg
Mid- gestation	4.6	0.66
Late gestation	5.4	0.79
Averge Lactation	5.9	1.00
Superior Lactation	7.1	1.29

Adapted from NRC, 1984.

Potassium concentrations of barley forages irrigated with both well and CBM water would meet livestock K requirements at all stages of production, although forages irrigated with well water are considered toxic and forages irrigated with CBM water are close to toxic concentrations (Table 19).

Livestock Ca requirements for gestating and lactating beef cows are not met by either the CBM or well water irrigated barley forages (Table 19). In addition to this, a factor to consider is the high K levels of these forages. A study which looked at lambs infused with K in their rumens found Ca absorption to be reduced in comparison with control lambs (Wylie et al., 1985).

Barley forages irrigated with well and CBM water were below livestock Mg, P, S, and Cu requirements for gestating and lactating stages of production (Table 19).

Forages under both water treatments met livestock Na, Fe, Mn, and Zn requirements for all stages of production (Table 19).

CHAPTER 5

CONCLUSIONS

The major issues regarding the use of CBM discharge water as an irrigation source are the elevated levels of salt and sodium that it contains as well as the long term impacts on soil and plant productivity.

In these experiments, the data indicate that most cultivars were impacted in similar ways by the use of CBM water as an irrigation source. Yield was reduced 27% and height was reduced 24% in forages irrigated with CBM discharge water. Nitrate concentrations were low in barley forage irrigated with CBM water but were highly toxic in all cultivars in all trials when irrigated with well water. No significant differences were detected in ADF, NDF, or CP concentrations between forages irrigated with CBM or well water. A strong trend did exist in CP concentrations, forages irrigated with well water consistently had higher CP concentrations than forages irrigated with CBM water. However, due to the experimental design and conservative split plot analysis, we were unable to detect a significant difference between water treatments. Maturity was considerably impacted by CBM water as cultivars under this irrigation treatment matured at a faster pace than those under well treatment.

Of ten forage mineral concentrations measured, only Ca and K were significantly impacted in these trials, with lower concentrations under CBM irrigation. Concentrations of Mg, S, Cu, and Mn were consistently lower in forages irrigated with CBM discharge water, however no significant differences were detected. Concentrations of Zn were significantly higher in barley forages irrigated with CBM water than when irrigated with well water.

Use of CBM discharge water as an irrigation source did impact the forage productivity of the barley cultivars evaluated. The forage quality in these two trials was not reduced drastically enough to consider it an unacceptable feed source. Reduced NO_3-N levels might be an advantage. More research is necessary to determine the long term impact of CBM discharge water on forage quality with respect to livestock requirements.

Barley has been proven to be adapted to saline conditions and tolerant of saline and sodium, and it could provide an alternative which would maintain an adequate level of forage quality for livestock operations. Hays, Westford, Morex, and Robust all withstood the elevated saline and sodium conditions of the CBM treatment water particularly well and could be considered potential sources of barley forage for use under CBM irrigation.

LITERATURE CITED

Acosta, Y.M., C.C. Stallings, C.E. Polan, and C.N. Miller. 1991. Evaluation of barley silage harvested at boot and soft dough stages. J. Dairy. Sci. 74:167-176.

Anderson, J.V., O.F. Bailey, and H.F. Oregne. 1972. Short term effects of irrigation with high sodium water. Soil Sci. 113:358-362.

Anderson, P.E., E.A. Oelke, and S.R. Simmons. 2002. Growth and development guide for spring barley. U. of M. Ext. Serv. Available at :
http://www.extension.unm.edu/distribution/cropsystems/DC2548.html
Accessed: June 20, 2005.

Ansotegui, Raymond. 2004. Personal Communication, Range Nutrition Specialist, 235A Linfield Hall, MSU, 994-5155, Oct.26, 2004.

AOAC, 2000. Official method of analysis of AOAC International (17th Ed.) AOAC International, Gaithersburg, MD.

Arthington, J. D., J. E. Rechcigl, G. P. Yost, L. R. McDowell, and M. D. Fanning. 2002. Effect of ammonium sulfate fertilization on bahigrass quality and copper metabolism in grazing beef cattle. J. Anim. Sci. 80:2507-2512.

Bauder, J. W., J.S. Jacobsen, and W.T. Lanier. 1992. Alfalfa emergence and survival response to irrigation water quality and soil series. Soil Sci. Soc. Am. J. 56:890-896.

Bauder, J.W. and Thomas Blake. 2001. Conversion of coalbed methane waste water to a beneficial water resource: Strengthening Montana's forage and livestock industry using phytoremediation.

Benjamin, R. W. , E. Oren, E. Katz, and K. Becker. 1992. The apparent digestibility of *Atriplex barclayana* and its effect on nitrogen balance in sheep. Anim. Prod. 54:259-267.

Bernstein, L. 1964. Salt tolerance of plants. Soil and Water Conservation Research Division, Agricultural Research Service. Washington, D.C.

Blunt, K R., 2001. Seasonal forage dry matter production and quality of 29 dryland grasses in Montana. M.S. Thesis. Montana State University. Bozeman, MT.

Boles, J.A., J.G. Bowman, L.M.M. Surber, and D.L. Boss. 2004. Effects of barley variety fed to steers on carcass characteristics and color of meat. J. Anim. Sci. 82(7):2087-2091.

Buxton, D. R. 1996. Quality-related characteristics of forages as influenced by plant environment and agronomic factors. Anim. Feed Sci. Technol. 59:37-49.

Cash, D., R. Funston, M. King, and D. Wichman. 2002. Nitrate toxicity of Montana forages. M. S. U. Ext. Serv.
Available at : www.animalrangeextension.montana.edu/articles/Forage/General/Nitrate-tox.htm. Accessed: December 1, 2005.

Cherney, J.H., and G. C. Marten. 1982. Small grain crop forage potential: I. Biochemical determinants of quality and yield. Crop Sci. 22:227-231.

Church, D. C . and W. G. Pond. 1975. Basic animal nutrition and feeding. O & B Books, Corvallis, OR.

Clark, M. L., K. A. Miller, and M.H. Brooks. 2001. U.S. Geological Survey Monitoring of Powder River Basin Stream-Water Quantity and Quality. Available at: http://water.usgs.gov/pubs/wri.wri014279/html.report.htm. Accessed October 22, 2004.

Curtin, D., H. Steppuhn, and F. Selles. 1993a. Structural stability of Chernozemic soils as affected by exchangeable sodium and electrolyte concentration. Can. J. Soil Sci. 74:157-164.

Curtin, D., H. Steppuhn, and F. Selles. 1993b. Division S-4-Soil fertility and plant nutrition. Soil Sci. Soc. Am J. 57:1304-1310.

Curtin, D., H. Steppuhn, A.R. Mermut and F. Selles. 1994a. Sodicity in irrigated soils in Saskatchewan: Chemistry and structural stability. Can. J. Soil Sci. 75:177-185.

Curtin, D., H. Steppuhn, and F. Selles. 1994b. Clay dispersion in relation to sodicity, electrolyte concentration, and mechanical effects. Soil Sci. Soc. Am. J. 58:955-962.

Curtin, D., H. Steppuhn, and F. Selles. 1994c. Division S-2-Soil chemistry. Soil Sci. Soc. Am. J. 58:730-737.

Dadshani, S.A.W., Annette Weidner, and Gerhard H. Buck-Sorlin. 2004. QTL analysis for salt tolerance in barley. Available at: www.tropentag.de/links/Asch_FGL65usg.pdf. Accessed: Oct. 17, 2004.

Dewey, D. R. 1962. Breeding crested wheatgrass for salt tolerance. Crop Sci. 2:403-407.

Ditsch, D. D. and M. J. Bitzer. 2005. Managing small grains for livestock forage. Dept. Agron., Univ. of Kent. Available at: http://www.ca.uky.edu/agc/pubs/agr/agr160/agr160.htm. Accessed: December 1, 2005.

Dodds, D and E. Vasey. 1985. Forages for salt affected soils. N. Dak. St. Univ. Coop. Ext. Serv. September 1985.

Emanuele, S.M. and C.R. Staples. 1989. Ruminal release of minerals from six forage species. J. Anim. Sci. 68:2052-2060.

Emanuele, S.M., C.R. Staples, and C.J. Wilcox. 1990. Extent and site of mineral release from six forage species incubated in mobile Dacron bags. J. Anim. Sci. 69:801-810.

Embry, L.B., M.A. Hoelscher, R.C. Wahlstrom, C.W. Carlson, L,M. Krista, W.E. Brosz, G.F. Gastler, and O.E. Olson. 1959. Salinity and livestock water quality. S. Dak. Agr. Exp. Sta. Bull. 481.

Flowers, T.J. 2003. Improving crop salt tolerance. J. of Exp. Bot. 55:307-319.

Franklin-McEvoy, J., D. Revell, B. Bellotti, D. Tivey, and N. Edwards. 2004. Improving the performance of sheep grazing on salt tolerant forages: animal responses to plant responses. Available at: www.ndsp.gov.au/downloads/pdfs/Purs12003_4_pp_Franklin-McEvoy_Jim.pdf. Accessed: January 4, 2006.

Franzen, D. 2003. Managing saline soils in North Dakota. N. Dak. St. Univ. Ext. Serv. Available at: www.ext.nodak.edu/extpubs/plantsci/soilfert/sf1087-1.htm. Accessed: January 4, 2006.

Gardner, W.K. 2004. Changes in soils irrigated with saline groundwater containing excess bicarbonate. Aust. J. of Soil Res. 42:825-831.

Gihad, E.A., and El Shaer, H.M. 1994. Utilization of halophytes by livestock on rangelands: problems and prospects. In: V.R, Squires and A.T., Ayoub (Editors), Halophytes as a Resource for Livestock and for Rehabilitation of Degraded Lands. Kluwer Academic, Dordrecht, pp. 77-96.

Glenn, B.P. and D.G., Ely. 1981. Sulfur, nitrate, and starch supplementation of tall fescue for the ovine. J. Anim. Sci. 53:1135.

Gratten, S, C. Grieve, J. Poss, P. Robinson, D. Suarez, and S. Benes. 2004. Evaluation of salt-tolerant forages for sequential water re-use systems: Implications for ruminant mineral nutrition. Ag. Water Manag. 70:137-150.

Greene, W.L., A.B. Johnson, J. Paterson, and R. Ansotegui. 1998. Role of trace minerals in cow-calf cycle examined. In: FEEDSTUFFS, Aug. 1998. pg 12-17.

Grooms, D. 2005. Beef cattle water quality. MSU Veterinary Extension Service. Available at: http://cvm.msu.edu/extension/docs/WATERQ.htm. Accessed November 16, 2005.

Gul, A. and B.J. Kolp. 1960. Accumulation of nitrate in several oat varieties at various stages of growth. Agron. J. 52:504-506.

Hardt, P. F., W. R. Ocumpaugh, and L. W. Greene. 1991. Forage mineral concentration, animal performance, and mineral status of heifers grazing cereal pastures fertilized with sulfur. J. Anim. Sci. 69:2310-2320.

Helm, J.H. and D. Salmon. 2002. Cereal silage options for Western Canada. Available at: http://www.wcds.afns.ualberta.ca/Proceedings/2002/Chapter%2019%20Helm.htm Accessed 13 March, 2006.

Hensleigh, Pat. 2006. Personal Communication, Research Assoc. Plant Sci. and Plant Path. Dept., 324A Leon Johnson Hall, Mont. St. Univ., 994-5059, Jan. 15, 2006.

Horpestad, A. 2001. Water quality analysis of the effects of CBM produced water on soils, crop yields, and aquatic life. Montana Department of Environmental Quality. Available at: www.deq.state.mt.us/CoalBedMethane/Criteria-sar-EC-h.htm. Accessed: June 24, 2004.

Johnson, R. C. 1991. Salinity resistance, water relations, and salt content of crested and tall wheatgrass accessions. Crop Sci. 31:730-734.

Khorasani, G.R., P.E. Jedel, J.H. Helm, and J.J. Kennelly. 1997. Influence of stage of maturity on yield components and chemical composition of cereal grain silages. Can. J. Anim. Sci. 77:259-267.

Kincheloe, J.J., J.G.P. Bowman, L.M.M. Surber, D.L. Boss, K.A. Anderson, and T.K. Blake. 2003. Effects of barley or corn on performance and digestibility in finishing diets. Proc., West. Sect., Am. Soc. of An. Sci. Vol. 54.

Kirkpatrick, A.D. 2004. Assessing constructed wetlands for beneficial use of saline-sodic water. MS Thesis. Dept. Land Resources and Environmental Sciences. Mont. St. Univ.

Lee, R.W., 1991. Effect of Zinpro zinc methionine or CuPLEX copper lysine on performance and health of wheat pasture cattle. TB C-9202-B. Zinpro. Corp.

Loneragan, G.H., J.J. Wagner, D. H. Gould, F. B. Garry, and M. A. Thoren. 2001. Effects of water sulfate concentration on performance, water intake, and carcass characteristics of feedlot steers. J. Anim. Sci. 79:2941-2948.

Maas, E.V. and G.J. Hoffman. 1977. Crop salt tolerance and current assessment. J. Irrig. Drain. Eng. 103:115-134.

Maas, E.V., J.A. Poss, and G.J. Hoffman. 1993. Salinity sensitivity of sorghum at three growth stages. Irrig. Sci. 7:1-11.

Machen, R. 2005. Minerals. Tex. Ag. Ext. Serv. ASWeb-080. SRS-5.

Majerus, M. 1996. Salt, electrical conductivity (EC, mmho/cm). Publications and information. Animal and Range Sciences, Extension Service. Montana State University. Available at: http://www.animalrange.montana.edu/faculty/faculty-cash.htm. Accessed: January 6, 2006.

Manske, L. 2002. Mineral requirements for beef cows grazing native rangeland. Dickinson Research Extension Service 2002 Annual Report. Available at: www.ag.ndsu.nodak.edu/dickinso/research/2001/range01h.htm. Accessed November 16, 2005.

Mayland, H. Plant nutrient content and animal health issues. USDA-ARS, 3793N 3600E.

Mertens, D.R. 1987. Predicting intake and digestibility using mathematical models of rumen function. J. Anim. Sci. 64:1548-1558.

Moir, R.J. 1970. Implications of the N:S ratio and differential recycling. In: O.H.Muth (ed) Symposium: Sulfur in Nutrition. AVI Publ. Co. Inc., Westport, CT. pp.167-177.

Montana Ag. Exp. Station. Western Triangle Ag Research Center. Barley Variety Notes and Comments. Available at: www.ag.montana.edu/wtarc/web2004/Agronomy/Bar/Barley%20variety%20Notes.pdf. Accessed: Jan. 18, 2006.

Montana Ag. Statistics Service. 2004. All Crops: Irrigated and Non-irrigated, Harvested Acres, Montana, USA. Available at: http://www.nass.usda.gov/mt/county/crops/04alcrop.htm. Accessed March, 31, 2005.

Mortimer, R.G., D. Dargatz, L. Corah. 1999.Forage analyses from cow/calf herds in 23 states. Available from USDA:APHISS:VS, Centers for epidemiology and animal health at 555 S. Howes, Ft. Collins, CO 80521.

Murphy, L.S. and G.E. Smith. 1967. Nitrate accumulation in forage crops. Agron. J. 59:171-174.

Norman, H., R. Dynes, and D. Masters. 2002. Saltland pastures can sustain sheep. In: Farming Ahead, Dec. 2002.

NRC. 1984. Nutrient Requirements of Breeding Cattle. In: Richard O. Kellems and D.C. Church (Ed.) Livestock Feeds and Feeding. p. 528-529.

NRC. 1996. Nutrient Requirements of Beef Cattle (6th Ed.). National Academy Press, Washington, DC.

NRC. 2000. Nutrient Requirements of Beef Cattle (7th Ed.). National Academy Press, Washington, DC.

Oster, J.D. 2001. Sustainable use of saline-sodic irrigation waters. 2001 California Plant and Soil Conference. Feb. 2001. Dept.of Environmental Sciences. UOC, Riverside, CA.

Patterson, H. H., P. S. Johnson, T. R. Patterson, D. B. Young, and R. Haigh. 2002. Effects of water quality on animal health and performance. Proc. West. Sec. Amer. Soc. Anim. Sci. 53:217-220.

Patterson, H.H., P. S. Johnson, and W. B. Epperson. 2003. Effect of total dissolved solids and sulfates in drinking water for growing steers. Proc. West. Sec. Amer. Soc. Anim. Sci. Vol. 54.

Phelps, S.D. 2003. Effects of irrigation water quality and water table position on plant biomass production, crude protein, and base cation removal. M.S. Thesis, Dept. Land Res. And Env.Sci., Mon. St. Univ.

Rasby, R., D. Brink, I. Rush, and D. Adams. 1998. Minerals and vitamins for beef cows. Nebraska Coop. Ext. Serv. EC97-277.

Rengasamy, R. and K.A. Olsson. 1993. Irrigation and sodicity. Aust. J. Soil Res. 31:821-837.

Robinson, K., J.W. Bauder, and K. E. Pearson. 2001. Soil behavior upon wetting with saline-sodic water. Background information. Available at: http://waterqualtiy.montana.edu/docs/methane/soilstructure_part1.sthml. Accessed: Oct. 22, 2004.

Rohweder, D.A, Barnes, K.F and Jorgensen, N. 1990. J Anim. Sci. 68:403. As cited in: Forage Analysis Procedures. Undersander, D., D.R. Mertens, and N. Thiex. July 1993.

Rumsey, T.S. 1978. Effects of dietary sulfur addition and Synovex-S ear implants on feedlot steers fed an all-concentrate finishing ration. J. Anim. Sci. 46:463-477.

SAS Institute. 2004. SAS Version 9.1. User's Guide. Carey, N.C: SAS Institute, Inc. 5136 p.

Smart, M. E., R. Cohen, D. A. Christensen, and C.M. Williams. 1986. The effect of sulphate removal from the drinking water on the plasma and liver copper and zinc concentrations of beef cows and their calves. Can. J. Anim. Sci. 66:669-680.

Smoliak, S, R.L Ditterline, J.D. Scheetz, L.K. Holzworth, J.R.Sims, L.E. Wiesner, D.E Beldridge, and G.L. Tibke. 2000. Plant Species. In: Publications and Information, Animal and Range Sciences, Extension Service. Montana State University. Available at: http://animalrangeextension.montana.edu/Articles/Forage/Species/Grasses.html. Accessed: Oct. 20, 2004.

Soder, K. J. and W. L. Stout. 2003. Effect of soil type and fertilization level on mineral concentration of pasture: Potential relationship to ruminant performance and health. J. Anim. Sci. 81:1603-1610.

Steppuhn, H., K. Wall, V. Rasiah, and Y.W. Jame. 1996a. Response functions for grain yield from spring-sown wheats grown in saline rooting media. Can. Ag. Eng. 38: 249-256.

Steppuhn, H.K. and K. G. Wall. 1996b. Grain yields from spring-sown Canadian wheats grown in saline rooting media. Can. J. Plant Sci. 77:63-68.

Steppuhn, H.K., H. Wang, and Y. Gan. 1998. Evaluating Russian wild ryegrass emergence from saline seedbeds using the Gompertz function. Can. Ag. Eng. 40:241-247.

Surber, L.M.M, M.T Stowe, J.G.P Bowman, S.D. Cash, P.F.Hensleigh, and T.K. Blake. Vol. 52, 2001. Variation in forage quality characteristics of barley. Proc.West. Sec., Am. Soc. An. Sci.

Surber, L.M.M, S.D. Cash, J.G.P. Bowman, and K.M. Rolfe. 2003a. Vol. 54, 2003. Stage of maturity, time of sampling, and method of drying effects on forage quality of Haybet barley. Proc.West. Sec., Am. Soc. An. Sci.

Surber, L.M.M, S.D. Cash, J.G.P. Bowman, and M.C. Meuchel. 2003b. Vol. 54, 2003. Nitrate concentration of cereal forage species at three stages of maturity. Proc.West. Sec., Am. Soc. An. Sci.

Suttle, N.F. 1991. The interactions between copper, molybdenum, and sulfur in ruminant nutrition. Annu. Rev. Nutr. II:12 1

Swenson, C.K., R. P. Ansotegui, J. A. Paterson, and B.W. Hess. 2000. Trace mineral supplementation of the beef cow and reproductive performance. In: Strategic supplementation of beef cattle consuming low quality roughages in the western United States. Ore. St. Ag. Exp. Sta. SB 683. November 2000.

Swift, C.E. 2003. Sodium Adsorption Ratio (SAR). Colorado State University Cooperative Extension. Available at: www.colostate.edu/Depts/CoopExt/TRA/PLANTS/sar.html. Accessed: 10/27/2004.

Swingle, R.S., E.P. Glenn, and V. Squires. 1996. Growth performance of lambs fed mixed diets containing halophyte ingredients. An. Feed Sci. Tech. 63:137-148.

Tilley, J. M. A. and R. A. Terry. 1963. A two stage technique for in vitro digestion of forage crops. Journal of British Grassland Society. 18:104-111

Todd, A.L., J.G.P. Bowman, L.M.M. Surber, M.A. Thompson, J.J. Kincheloe, M. F. McDonnell, and P.F. Hensleigh. 2003. Effect of barley varieties harvested for forage on backgrounding steer performance and diet digestibility. Proc., West. Sec., Am. Soc. An. Sci. Vol. 54, 2003.

U.S. Grain Council. 2004. An Importers Guide to U.S. Barley. Available at: http://www.grains.org/galleries/technical_publications/Barley_Book.pdf. Accessed: February 7, 2006.

Van Soest, P.J., J.B. Robertson, and B.A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74: 3583-3597.

Weeth, H. J. and J. E. Hunter. 1971. Drinking of sulfate-water by cattle. J. Anim. Sci. 32(2):277-81.

Welch, C. D., C. Gray, D. Pennington and M. Young. 1980. Soil Testing Procedures. Tex. Ag. Ext. Service, Texas A & M Univ., College Station.

Whanger, P.D., and G. Matrone. 1970. Effects of sulfur deficiency on metabolism in sheep. In: O. H. Mulh, and J. F. Oldfield (ed.) Sulfur in Nutrition. The AVI publishing Co. Westport, CT.

Woodbury, B.L. 1993. Hydraulic property modification of saline-sodic soils by addition of calcium chloride. M.S. Thesis, Dept. Plant and Soil Sciences, Mont. St. Univ.

Wright, M.J. and K. L. Davison. 1964. Nitrate accumulation in crops and nitrate poisoning in animals. Adv. in Agr. Vol. 16. pp. 197-247.

Wylie, M. J., J.P. Fontenot and L.W. Green. 1985. Absorption of magnesium and other macro-minerals in sheep infused with potassium in different parts of the digestive tract. J. Anim. Sci. 61:1219.

Wyoming Oil and Gas Conservation Commission (WOGCC). 2006. Available at: http://wogcc.state.wy.us/. Accessed: March 31, 2006.

Zinn, R. A., E. Alvarez, M. Mendez, M. Montano, E. Ramirez, and Y. Shen. 1997. Influence of dietary sulfur level on growth performance and digestive function in feedlot cattle. J. Anim. Sci. 75:1723-1728.