INFLUENCE OF HERBICIDE APPLICATIONS AND COMMON PASTURE WEEDS ON TOTAL FORAGE YIELD AND NUTRITIVE VALUES IN TALL FESCUE PASTURES AND HAYFIELDS IN MISSOURI

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled:

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INFLUENCE OF HERBICIDE APPLICATIONS AND COMMON PASTURE WEEDS ON TOTAL FORAGE YIELD AND NUTRITIVE VALUES IN TALL FESCUE PASTURES AND HAYFIELDS IN MISSOURI

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ABSTRACT

Currently, little research is available on the effects of common pasture weeds on forage yield or nutritive values in tall fescue pastures and hayfields in Missouri. This, coupled with the recent influx of new pasture herbicides onto the marketplace has led many growers to question their options for weed management in a grass pasture or hayfield. Therefore, the objectives of these experiments were to: 1) evaluate the effect of various herbicides on the control of tall goldenrod (*Solidago canadensis* subsp. *altissima* (L.)), common ragweed (*Ambrosia artemisiifolia* L.), and tall ironweed (*Vernonia gigantea* (Walt.) Trel), 2) evaluate the effect of herbicides on total forage biomass yield and nutritive values, and 3) evaluate the effects of increasing densities of common ragweed and common cocklebur (*Xanthium strumarium* L.) on total forage yield and nutritive values. Experiments were conducted in tall fescue pastures from 2006 to 2009 in several locations in central and southwest Missouri. Results from these experiments indicate that a variety of herbicide treatments will provide good control of these weed species in a typical pasture or hayfield environment. However, across all experiments, total forage biomass was usually greater and total forage nutritive values were usually improved in untreated forage compared to forage treated with a herbicide. The increase observed in the untreated forage is due to higher densities of weed and legume species. Examinations of the nutritive values of pure weed species revealed that tall goldenrod, tall ironweed, and common ragweed provide greater values than pure tall fescue for June forage harvest. Collectively, the results from these experiments indicate that weed infestations may not necessarily reduce the nutritive values or yield of total biomass harvested from tall fescue pastures and hayfields, but additional research is necessary to determine why these species continue to be problems in Missouri tall fescue pastures and hayfields.

Chapter 1

Literature Review

Research Justification

Grazing lands occupy 237 million hectares, or approximately 26 percent of the total land area of the United States (Lubowski et al., 2006). Tall fescue forage is used on 12 to 14 million ha of these grazing lands (Moyer and Kelley, 1995) and is also the predominant grass forage utilized in Missouri. Of the 6.9 million hectares of forages in Missouri, one third is tall fescue (Gerrish and Roberts, 1999). However, most pastures in Missouri tend to consist of mixed grass-legumes forages. This mixture allows for higher quality forages in comparison to the grass species alone (Gerrish and Roberts, 1999).

A major threat to the yield, and/or quality of tall fescue forages is invasion by weeds. Losses from weed and brush infestations on grazing lands in the United States have been estimated conservatively at $2 billion per year (Bovey, 1987). Herbicides are sometimes necessary for the selective control of broadleaf weed infestations in tall fescue pastures. However, the decision to use herbicides in a pasture setting is dependent upon a variety of factors, such as stage and severity of weed growth, time of year, presence of desirable legume species, sensitivity to nearby crops, waiting period after treatment to graze or hay the forage, and cost of the treatment (Green and Martin, 1998). Although all of these factors are important considerations, there is currently little to no information regarding the density of specific weed species that justify removal in a pasture setting. Many producers will choose to eliminate weeds with broadcast herbicide applications once their pasture reaches some predetermined infestation level. However, this undesirable infestation level is based upon the producer’s own decision to apply herbicides at certain times or target specific weeds and not on valid weed density or weed threshold research.

In Missouri, tall ironweed (*Vernonia altissima*), common ragweed (*Ambrosia artemisiifolia*), and common cocklebur *(Xanthium strumarium*) are some of the most common weeds encountered in pasture environments (Kevin Bradley, personal communication). While it is generally recognized that weeds will effectively compete with forages for moisture, fertility and light, the contribution of weed species to overall forage productivity and quality is not well known (Hoveland et al., 1986). Not all weedy plants are detrimental to pastures or hayfields. In fact, some weedy plants provide nutritional value to grazing animals. However, few studies have shown how common pasture weeds actually affect forage yield or quality, and how varying densities of specific weeds impact the overall yield or quality of the forage stand.

This research will be conducted in order to understand the impact of specific weed densities on the overall forage yield and quality of tall fescue pastures. Ultimately, we hope to be able to predict specific “threshold” densities of common ragweed and common cocklebur that justify removal in a pasture environment. Additionally, experiments will be conducted to evaluate the utility of several prepackaged herbicide combinations recently made available for use in tall fescue pastures in Missouri.

Introduction

Forage Quality

Quality forage is the extent to which forage has the potential to produce a desired animal response (Ball et al., 2001). The value of a given forage is influenced by palatability, intake, digestibility and nutrient content. Maturity, crop species, environment, soil fertility, and cultivars play key roles in impacting forage yield and quality. Maturity is the most important factor determining forage quality. As the plant reaches full maturity the stems will become more fibrous and digestibility or intake will decrease. As is true of grass and legumes forage species, the quality of weeds is better during their vegetative stages and will decrease in quality as the plant flowers and matures (Curran and Lingenfelter, 2001).

There are several measured values that are used to define the overall forage quality of a given sample. Crude protein (CP) is calculated from the nitrogen content of the forage. Crude protein levels of 16 to 18 percent or more are adequate for growing animals, whereas crude protein levels of 12 to 14 percent are needed for lactating cows and sheep (Ball et al., 2001). When there is more protein generated from the actual forage that is consumed by grazing animals, fewer supplements need to be incorporated into the diet. Neutral detergent fiber (NDF) consists of the slowly digested fibrous portions of the plant: hemicelluloses, cellulose, and lignin. NDF is a chemical analysis associated with space occupying, or fill effect, of the ruminant diet (Mertens, 1987). Most ruminants can hold 1 to 1.5 percent or more of their body weight as NDF (Belyea et al., 1993). Acid detergent fiber (ADF) represents the portion of the forage that does not dissolve in an acid detergent solution: cellulose and lignin. ADF content has an inverse relationship to the energy content of a forage, the absence of ADF essentially equals higher energy content (Belyea et al., 1993). Another important value used in the measurement of forage quality is relative feed value (RFV). RFV is an index that estimates digestible dry matter of the forage from ADF, and calculates the dry matter intake potential from NDF (Jeranyama and Garcia, 2004). However, the term used currently to determine forage quality is relative forage quality (RFQ). RFQ is a newer approach to improve forage quality indices while having the same concept and format to calculate forage quality as RFV. The main difference between RFQ and RFV is through analyses and equations used to solve for the respective index. RFQ uses an updated version to analyze and equate forage quality, implementing total digestible nutrients and dry matter intake while RFV consist of dry matter intake and digestible dry matter. The key to using either RFQ or RFV is the utilization of many more components feeding into their respective indices rather than dependence upon only NDF and ADF values. RFQ is the preferred index to be used because of the opportunity to improve forage quality indices using a newer analysis and equation (Undersander, 2007). Digestibility is one of the best indicators of forage quality. Digestibility values of 60 percent or higher are considered good and should be satisfactory for growing cattle, while values of 50 percent or less are unsatisfactory (Marten et al., 1987).

The specific knowledge of weed forage quality and the impact of weeds on the overall quality of a forage is essential for producers to make sound management decisions regarding weed control. Information about forage quality is lacking for many important annual and perennial weed invaders of pastures and hay fields (Marten et al., 1987). Bosworth et al. (1980) found that many warm-season weed species, such as prickly sida (*Sida spinosa* L.), redroot pigweed (*Amaranthus retroflexus* L.), jimsonweed (*Datura stramonium* L.), fall panicum (*Panicum dichotomiflorum* Michx.) and crabgrass (*Digitaria sanguinalis* (L.) Scop), if consumed at the vegetative stage of growth, can offer a nutrient concentration comparable to that of cultivated warm-season forage grasses. However, these studies were conducted with pure samples of the weeds in question, and not in a mixed stands of tall fescue and weeds as would normally occur in a pasture setting. Other authors have found that some weeds, such as common pokeweed (*Phytolacca americana* L.), common ragweed (*Ambrosia artemisiifolia* L.), goldenrod (*Solidago* spp.), prickly sida, and horsenettle (*Solanum carolinense* L.) have definite yield and palatability limitations (Hoveland et al., 1986). A better understanding of the impacts of specific weed species and densities on the overall forage quality and quantity of a given forage stand would allow for the establishment of economic weed removal thresholds in a pasture setting. Although common in row crop agricultural settings, economic thresholds have only been rarely utilized or considered in grass pastures or hay fields.

Invasion of Weeds in Tall Fescue Pastures

One of the most common causes of weed invasion in pastures is overgrazing. Overgrazing pressures will almost always favor weed growth over the desirable forage grasses. Weeds in a pasture are able to grow much faster and will out-compete the preferred forage grasses once there is not a grazer present. Additionally, when pastures have improper soil pH or low fertility levels, emergence, propagation, and growth of weeds are favored (Green and Marten, 1998).

One of the primary methods for the control of weed infestations in pastures or hayfields is the application of selective herbicides. Herbicides are often applied to pastures and hayfields to decrease the amount of weeds present and increase the longevity of the desirable forage stand. Weeds can react differently to each of the herbicides and/or herbicide combinations applied, therefore producers must decide which herbicide(s) provides the best control for their weed spectrum without damaging the forage stand.

Common Ragweed

Common ragweed (*Ambrosia artemisiifolia* L.) is a summer annual, wind-pollinated herb that is native to North America and found throughout the United States. It is most commonly found in disturbed sites in the temperate regions worldwide (McKone and Tonkyn, 1986). Evidence has been found from late-glacial time periods that unvegetated land provided suitable habitats for the northern migration and spread of ragweed (Mitich, 2007b). Common ragweed, also known as Roman wormwood or hogweed, has become more abundant within the past 200 years (Mitich, 2007b). As this weed invades tall fescue pastures, common ragweed is often consumed by cattle when other desirable forages become scarce due to overgrazing or drought. As the plants mature they become less palatable, however, and cattle tend to avoid grazing common ragweed when possible.

Common ragweed is easily identified by its uniquely divided leaves and growth habit. It can be found along disturbed sites, cultivated fields, and roadsides. In the seedling stage, common ragweed has stems that are green with purple spots and two spatulate-shaped cotyledons. Common ragweed has much variation in design, having plants of differing size, leaf shape, inflorescence form, and degree of hairiness (Mitich, 2007b). Mature plants have divided leaves that range from 4- to 10-cm in length, are egg-shaped in outline, and have slightly pointed lobes. Leaves are hairy on the upper surface and margin, and densely appressed on lower surfaces. Ragweed flowers and flower heads are unisexual (Payne, 1963; Mckone and Tonkyn, 1986). Ragweeds possess floral heads of two kinds; staminate heads which bear only pollen-producing florets and pistillate heads which bear one or a few seed-producing florets. Staminate heads are arranged in clusters at the tips of stems and branches. Pistillate heads occur in clusters in leaf axils below the staminate spikes (Payne, 1963). Plants range in height from 0.2 to 2.5 meters tall.

Common ragweed is well known in agriculture because of its prevalence in most agronomic crops in the eastern and central parts of the United States (Dickerson and Sweet, 1971). Common ragweed is fast-growing and commonly invades weak and overgrazed pastures, reducing productivity. Common ragweed is distributed by seed which can remain viable in the soil from 10 to 35 years (Brandes and Nitzshe, 2006). Small common ragweed plants average about 3,000 seeds per plant, while larger plants can produce up to 62,000 seeds (Dickerson and Sweet, 1971).

Influence of Common Ragweed on Grass Pastures

Although few studies have been conducted to investigate the effects of common ragweed on total forage quality and yield in a tall fescue pasture, Marten and Anderson (1975) found that pure samples of common ragweed harvested at early stages of growth were comparable to alfalfa forage in *in vitro* digestible dry matter (IVDDM), ADF, acid detergent lignin (ADL), and CP content. However, in subsequent feeding experiments the majority of grazing sheep refused to consume mature common ragweed plants, illustrating that palatability is expected for plants to be consumed is based on a plant and an animal function (Marten and Anderson, 1975). The grazer's preference to utilize a specific species is determined by the expression of innate and learned behaviors of the animal interacting with the vegetation (Walker et al., 1992; Provenza, 1995). The Walker et al. (1992) study exposed different maturities of sheep to leafy spurge (*Euphorbia esula* L.). The sheep that had exposure to leafy spurge at birth consumed about 70% of spurge regardless of phenophase. Those lambs with experience consuming spurge spent more time grazing in comparison to more mature sheep without previous exposure to leafy spurge that consumed minimal amounts of vegetative leafy spurge plants. Herbage disappearance per lamb was 28% greater in pastures grazed by experienced versus naïve lambs (Walker et al., 1992).

Control of Common Ragweed

A variety of herbicides are labeled for the selective control of common ragweed in tall fescue pastures. These include herbicides such as 2,4-D, dicamba, and aminopyralid, as well as prepackaged herbicide mixtures such as 2,4-D and picloram, 2,4-D plus triclopyr, metsulfuron-methyl plus dicamba plus 2,4-D, triclopyr plus fluroxypyr, picloram plus fluroxypyr, and 2,4-D plus dicamba. Many university extension publications list these herbicides as providing excellent control of common ragweed (Bradley and Kendig, 2004; Rhodes et al., 2005; Green et al., 2006). One of the few herbicides that may provide less than acceptable control of common ragweed is metsulfuron-methyl. Heavy common ragweed infestations can also be minimized by maintaining adequate soil pH and fertility and implementing other management practices that optimize the desirable forage canopy.

Tall Ironweed

Tall ironweed (*Vernonia gigantea* (Walt.) Trel.), a member of the *Asteraceae* family, is a herbaceous, perennial weed that is also a common weed of pastures throughout Missouri. Ironweed is most easily identified by its showy purple flowers and grows to as much as 3 meters in height (Mann et al., 1983). The leaves which alternate along the stem are thin, tapering from a rounded base towards the apex, 15 to 25 cm long by 3 to 7 cm wide, finely serrated, and have hairs only on the bottom side of the leaf (Mann et al., 1983). There are 13 to 29 flower heads on each plant, which bloom from July to October. Mann et al. (1983) found that an average tall ironweed plant can produce between 5,000 and 7,000 seeds, but viability is lost within the first 7 months if the seeds are buried in the soil. Ironweeds are so named for the toughness of the stem and the ability of stems to persist throughout the winter.

Influence of Tall Ironweed on Grass Pastures

The nutritional value and profitability of a grass pasture can be adversely affected by tall ironweed (Marshall et al., 2006). Green and Marten (1998) indicated that weeds such as ironweed can become more prominent in the field over time in a grazed pasture because they are less palatable to the animal than most other species. Bradley and Kallenbach (2005) also investigated the impact of tall ironweed on total forage yield and quality in tall fescue pastures and found ADF, NDF, and crude protein content of ironweed were not different from untreated plots that contained dense infestations of tall ironweed compared to herbicide-treated plots without tall ironweed.

Control of Tall Ironweed

Several studies have shown that triclopyr is one of the most effective herbicides for the selective control of tall ironweed in grass pastures (Mann et al., 1983; Marshall et al., 2006). For example, Mann et al. (1983) and Marshall et al. (2006) have both observed greater than 90% tall ironweed control with triclopyr-containing treatments at least 8 months after treatment. In these studies, many other herbicide treatments like 2,4-D ester, dicamba, and metsulfuron, provided excellent tall ironweed control during the first season after treatment but offer little control one year or longer after treatment (Bradley and Kallenbach, 2005; Mann et al., 1983; Marshall et al., 2006). Bradley and Kallenbach (2005) also showed that 2,4-D plus picloram provides good long-term control of tall ironweed compared to many other herbicide treatments.

Common Cocklebur

Common cocklebur (*Xanthium strumarium* L.), another member of the *Asteraceae* family, is a widespread weed of economic importance. Common cocklebur is a summer annual that is perhaps most known for its prickly cocklebur seedpod. Originating from Central or South America, common cocklebur has spread throughout most of North America and into Europe, Australia, and Africa. Common cocklebur is a self-pollinated, out-crossing species. Common cocklebur inflorescences are highly modified composite heads with separate male and female flowers occurring on the same plant (Mitich, 2007a). Male flowers are small, inconspicuous, and rayless, and are grouped in axillary racemes. The female flowers are in axillary clusters found below the male flowers and are surrounded by many branched, elongated involucres (Mitich, 2007a). This entire structure of the cocklebur plant becomes the fruit. The involucral bracts turn outward and form hooked woody spines (Mitich, 2007a). These hooked spines help disperse the seed by attaching to animal fur or clothing. The seed can also be dispersed long distances by water (Tranel and Wassom, 2001). Each "bur" contains two seeds which germinate in consecutive seasons making it very difficult to eradicate this weed.

The cotyledons of common cocklebur are easy to identify by their waxy and smooth appearance and linear to oblong outline. The cotyledons are approximately 2 to 4.5 cm long and no more than 1.2 cm wide. The first true leaves are opposite followed by leaves that are arranged alternately along the stem. Common cocklebur ranges in height from 1 to 60 cm in most settings. Common cocklebur can grow in a wide range of soils and in a wide variety of moisture conditions.

Influence of Common Cocklebur on Grass Pastures

Little to no research has been conducted on the impacts of common cocklebur on either forage quality or yield. However, common cocklebur is toxic during the seedling stage of growth and therefore one weed that can impact forage quality considerably. The poison, hydroquinone, is found primarily in the seeds but can also be found in the cotyledons of seedlings, which may be significant as this is a stage when the plant is most palatable to livestock. As the true leaves develop, hydroquinone concentration decreases in seedlings but never completely leaves the plant (Mitich, 2007a).

In research conducted by Marten and Anderson (1975), pure common cocklebur was never consumed by sheep even when harvested in the vegetative stage of growth, suggesting that common cocklebur is unpalatable by at least some ruminant animals. Marten and Anderson

(1975) also reported that ADF and CP content of common cocklebur was 28 and 24%, respectively, across three years of research. This and other research led them to conclude that some annual weeds like common cocklebur that commonly occur in perennial forages do not decrease the nutritive value of hay or pasture if utilized at relatively early stages of maturation. However, as mentioned previously, common cocklebur was never found to be palatable in other experiments.

Control of Common Cocklebur

Many of the herbicides labeled for selective control of annual weeds in grass forages will provide good control of common cocklebur. For example, 2,4-D plus dicamba, 2,4-D plus triclopyr, 2,4-D plus picloram, picloram, and metsulfuron-methyl plus dicamba plus 2,4-D have all been listed as providing good to excellent control of common cocklebur in several extension publications (Bradley and Kendig, 2004; Rhodes et al., 2005; Green et al., 2006). As with common ragweed, metsulfuron-methyl is one of the few pasture herbicides that may provide fair or poor control of common cocklebur in a pasture setting (Bradley and Kendig, 2004; Rhodes et al., 2005; Green et al., 2006).

Conclusion

In most cases, overgrazing, drought, low fertility or nutrient deficiencies are the reasons that weeds invade a pasture setting. Weed infestations can or will negatively impact pasture quality, productivity and profitability. Forage yield and forage quality have been studied with pure stands of weeds; however few studies have researched overall forage quality of a stand with mixed densities of grass forage plus weeds as would typically occur in a grass pasture or hay field. Currently, the density of a specific weed species like common ragweed or common cocklebur that would justify removal in a grass pasture setting is unknown. It seems appropriate that weed removal thresholds established in pasture settings should be based on the effects of the weeds in question on both forage yield and quality. Therefore, this research will be conducted as a first step in establishing a weed threshold that will justify removal in a grass pasture setting.

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CHAPTER II

Influence of Selected Herbicide Treatments on Tall Goldenrod Control, Total Biomass Yield and Biomass Nutritive Value in Tall Fescue Hayfields

Kristin K. Payne and Kevin W. Bradley

ABSTRACT

Field experiments were conducted in 2006 and 2007 to evaluate the effect of various herbicides on tall goldenrod (*Solidago canadensis* subsp. *altissima* (L.)) control, total biomass nutritive value and total biomass yield in mixed tall fescue (*Lolium arundinacea* (Schreb.) S.J. Darbyshire) and legume hayfields in Missouri. Aminopyralid, aminopyralid plus 2,4-D, aminopyralid plus metsulfuron, aminopyralid plus metsulfuron plus 2,4-D, metsulfuron, metsulfuron plus dicamba plus 2,4-D, and 2,4-D plus picloram were applied at various rates to tall goldenrod ranging from 26 to 28 cm in height in the spring of 2006 and 2007. Aminopyralid and aminopyralid plus 2,4-D provided the lowest tall goldenrod visual control one month after treatment (1MAT); all herbicides other than aminopyralid and aminopyralid plus 2,4-D resulted in 58 to 88% control of tall goldenrod 1MAT in 2006, and 80 to 88% control in 2007. Aminopyralid and aminopyralid plus 2,4-D provided the lowest tall goldenrod visual control and highest tall goldenrod density one year after treatment (YAT) compared to all treatments evaluated. All treatments except aminopyralid resulted in a 76 to 99% reduction in tall goldenrod stem density compared to the untreated control 1YAT. There were no biomass yield or nutritive value differences between herbicide treatments, therefore all biomass yield and nutritive value data were combined across herbicide treatments and compared to the untreated control. Total biomass yield was lower in herbicide-treated compared to untreated plots 1MAT and 1YAT, likely because of fewer tall goldenrod and legume plants remaining in untreated compared to herbicide-treated biomass. Herbicide-treated biomass yields decreased by as much as 33% 1YAT compared to the untreated control. There were no nutritive value differences between herbicide treatments and the untreated control 1MAT. One YAT, crude protein (CP) content increased by 2.5% and acid detergent fiber (ADF) and neutral detergent fiber (NDF) content decreased by 2.4 and 6.4%, respectively, in biomass harvested from untreated compared to herbicide-treated plots. Pure samples of tall goldenrod collected at the time of each harvest were lower in CP, ADF and NDF content than pure samples of tall fescue collected at the same harvests. Results from this study indicate that a variety of herbicide treatments will provide good control of tall goldenrod, but tall goldenrod infestations will not likely decrease the overall yield or nutritive values of the total biomass harvested in mixed tall fescue and legume hayfields. However, other factors such as tall goldenrod palatability and digestibility should be considered.

INTRODUCTION

Tall goldenrod is an erect perennial in the *Asteraceae* family that emerges from creeping rhizomes. It is often found in poorly managed pastures and hayfields, unmanaged roadsides, and prairies throughout the continental United States and adjacent regions of Canada and portions of Mexico (Scoggan, 1979; Walck et al., 1999; Weber, 2000; Werner et al., 1980). Tall goldenrod is a native of North America but is also present in Europe and China and was introduced for ornamental purposes (Egli and Schmid, 2000; Walck et al., 1999; Weber, 2000; Werner et al., 1980). Tall goldenrod is often an indicator of clay and nutrient-rich soils, but the species can occur over a wide range of soil fertility and texture conditions (Weber, 2000). According to Banta et al. (2008), tall goldenrod has a greater ability to attenuate light than many other plant species.

Tall goldenrod seedling germination occurs from March through October, peaking in April and May (Huang and Guo, 2005). Once seedlings have established, rhizomes and shoots develop an extensive root and shoot system (Weber, 2000). Clonal growth occurs by means of vegetative growth and asexual reproduction during the summer season with rhizomes growing outward from a central area (Weber, 2000). Roots and rhizomes of tall goldenrod can reach a depth of at least 20 cm (Weber, 2000). Lanceolate leaves are produced along the stem, with the largest leaf in the middle or above the middle of the stem while leaves above this point become progressively smaller towards the inflorescence. Inflorescences form broad pyramidal panicles and individual flower heads are small and numerous (Weber, 2000). One plant may produce as many as 20,000 seeds, however seed germination is usually less than 30% even under suitable conditions (Huang and Guo, 2005). Although water, human, and livestock activities may contribute to the spread of the seed of tall goldenrod (Huang and Guo, 2005), the seeds are most aptly suited for long-distance dispersal by wind (Guo et al., 2008).

Goldenrod is one of many weeds that can develop into a thick monoculture if left uncontrolled. Goldenrod is known to grow as fast as the desired forage species and can out-compete the forage grass once there is not a grazer present (Walck et al., 1999). The competitive ability of *Solidago* species was investigated by Walck et al. (1999) in one study utilizing three species: *Solidago altissima* (tall goldenrod), *Lolium arundinaceum* (tall fescue), and *Solidago shortii* (Short's goldenrod). In this study, the competitive ability of the three species was found to be directly proportional to individual plant size; the smaller-sized Short’s goldenrod did not compete with the taller and more aggressive tall fescue and tall goldenrod.

Many management strategies have been investigated for reducing tall goldenrod infestations in a grass pasture or hayfield setting. Mowing or a combination of mowing, sowing of other species after mowing and slight cultivation to allow disturbance of the soil can result in decreased rhizome and shoot growth and reduce seed production (Egli and Schmid, 2000; Meyer and Schmid, 1999). Tillage, with or without the sowing of a grass or forb has been shown to decrease shoot density, stem diameter, and percent ground cover of tall goldenrod (Weber, 2000). Hartmann et al. (1995) found that cultivation with sowing decreased shoot density by 96% and goldenrod ground cover by 94% whereas cultivation without sowing decreased shoot density by 42% and goldenrod ground cover by 40%. Hartmann et al. (1995) also found that mowing goldenrod at least two times a year can decrease shoot density by 7 to 8%, stem diameter by 14 to 25% and ground cover by 50 to 60% when compared to one mowing or unmowed tall goldenrod.

An additional method of reducing tall goldenrod infestations and increasing the longevity of the desired forage species in a grass pasture or hayfield setting is the application of selective herbicides. However, few studies have been conducted to evaluate the selective removal of tall goldenrod from grass pastures and hayfields with herbicides. Tunnell et al. (2006) found that 2.1 kg 2,4-D ester/ha, 2,4-D plus picloram at 0.2 plus 0.84 kg/ha, and triclopyr at 2.2 kg/ha provided from 79 to 88% reduction in Missouri goldenrod ground cover while ground cover was reduced by 94% with 0.56 kg picloram/ha two growing seasons after the herbicide treatments (Tunnell et al., 2006). Since this research was conducted, a variety of new pasture herbicides have come onto the marketplace that are labeled for the control of various pasture weeds such as tall goldenrod. One of the newest is sold under the trade name Chaparral^{TM} and is an extruded granule product that contains 85% aminopyralid and 15% metsulfuron.

The decision to use herbicides in a pasture or hayfield setting depends on a variety of factors, such as stage of weed growth and severity of infestation, time of year, presence of desirable legume species, sensitivity to nearby crops, waiting period after treatment to graze or hay the forage, and cost of the treatment (Green and Martin, 1998). Another consideration should be the effects of herbicidal control on the total biomass yield and nutritive value of the biomass harvested. Generally, the total annual biomass yield for herbicide-treated biomass will be less than that of untreated biomass, as herbicide treatments generally remove a certain percentage of weeds from the total yield (Payne et al., 2008). Additionally, dense infestation of pasture weeds at the vegetative stage of growth in the spring season may offer a nutrient concentration similar to or greater than forage grasses such as tall fescue (Bosworth et al., 1980; Payne et al., 2008). Little is known about the effects of tall goldenrod on biomass yield or biomass nutritive value in tall fescue hayfields. Therefore the objectives of this research were to evaluate the effect of various herbicides and herbicide combinations on 1) tall goldenrod control, 2) total biomass yield, 3) and total biomass nutritive value in tall fescue hayfields in Missouri.

MATERIALS AND METHODS

Field experiments were conducted in 2006 and 2007 in separate areas at the University of Missouri Turkey Research Farm near Columbia, Missouri. The research areas were selected based on the presence of dense infestations of tall goldenrod (26 to 32 plants/ m^2) that occurred in tall fescue hayfields that contained sparse amounts (3 to 8% ground cover) of red clover (*Trifolium pretense* L.). In both years, the soil type at each location was a Leonard silt loam (fine, smectitic, mesic Vertic Epiaqualfs) with 2.6% organic matter and pH of 5.2. Individual plots were 3 x 9 m and arranged in a randomized complete block design with four replications.

The herbicide treatments evaluated in both experiments are listed in Table 2.1. All herbicide applications were applied on May 4th in 2006 and May 11th in 2007. In both years, tall goldenrod ranged from 25 to 30 cm in height at the time of the herbicide application while tall fescue ranged from 10 to 15 cm in height. Each herbicide was applied with a nonionic surfactant at 0.25 % v/v. All applications were made with a CO_2 backpack sprayer set to deliver 140 liters per hectare through XR8002[1] flat fan nozzles.

Visual tall goldenrod control and fescue injury were evaluated at one and 12 months after treatment. Visual ratings were taken on a scale of 0 to 100 percent with zero being equivalent to the ground cover and vigor observed in the untreated control plots, and 100 equivalent to complete weed control and tall fescue death. Just prior to harvest at 1 year after treatment (YAT), tall goldenrod densities were determined by counting all plants within each 3 x 9 m plot.

Total biomass yield was determined by harvesting two, 1 x 8 m strips within each plot using a Carter forage harvester[2] at 1MAT and 1YAT as tall fescue reached 20 to 26 cm height. One initial harvest was conducted approximately four to five weeks after the spring herbicide treatment and another harvest was conducted one YAT. At each harvest, two 300-g subsamples of the total harvested biomass were taken from each plot for analysis of forage nutritive value. One representative sample of pure tall goldenrod and pure tall fescue was also hand-harvested from the trial area and analyzed for forage nutritive values at the time of each biomass harvest. All samples were placed in a forced-air oven for 48 hours at 37°C in order to determine dry matter content. Subsamples from each plot were finely ground with an Udy-mill[3] to pass through a 1-mm screen. Neutral and acid detergent fiber were analyzed using an ANKOM 200 Fiber Analyzer (ANKOM Technology, Fairport, NY). Acid detergent fiber and NDF for calibration samples were determined using the methods described by VanSoest and Robertson (1980). Crude protein (CP) concentration was measured by thermal conductivity of nitrogenous

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[1] Teejet Spraying Systems Co, P.O. Box 7900, Wheaton, IL 60189
[2] Carter MFG CO., INC. 896 E. Carter Court, Brookston, IN 47923
[3] UDY Corporation, 201 Rome Court, Fort Collins, Co 80524

gases with a Leco Nitrogen (N) analyzer (Leco Corp., St. Paul, MN). Crude protein for calibration samples was determined by measuring total N content using the micro-Kjeldahl technique (Wall and Gerke, 1975) and then multiplying N values by 6.25.

Visual tall goldenrod control and tall goldenrod density ratings were subjected to analysis of variance (ANOVA) using the PROC GLM procedure in SAS[4] and tested for appropriate interactions. When present, non-significant terms were dropped from the model. Means were separated with a LSD at the 5% level. There were no significant differences between herbicide treatments for the biomass yield data, therefore total biomass yields for the 2006 and 2007 month and year after treatment harvests were combined across herbicide programs rather than listed separately as illustrated in Table 2.2. In addition, no significant differences between herbicides were found for biomass nutritive value in 2006 and 2007 month and year after treatment; herbicide programs were combined rather than listed separately as illustrated in Table 2.3. Biomass nutritive value data were subjected to PROC MIXED while biomass yield values were subjected to PROC MIXED and PROC GLM in SAS. PROC MIXED was used for orthogonal contrast analysis of biomass yield and nutritive value data. Considerations of orthogonal differences were made due to differing number of samples in the herbicide programs compared to the untreated control. All data were pooled when interactions between experimental years did not occur.

RESULTS AND DISCUSSION

Tall Goldenrod Control. One month after treatment (MAT), herbicide treatments provided 30 to 88% visual control of tall goldenrod (Table 2.1). Herbicide treatments also provided complete control of the sparse stands of red clover present in these locations in comparison to the untreated

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[4] SAS Institute, Inc., SAS Campus Drive, Cary, NC 27513.

control (data not shown). Research suggests that if tall goldenrod is left unattended its competitive ability is sufficient to overcome the forage grass (Walck et al. 1999). Aminopyralid provided lower tall goldenrod control 1MAT than all other herbicide treatments in 2006, and lower tall goldenrod control 1MAT than all treatments except aminopyralid plus 2,4-D in 2007. All herbicides other than aminopyralid and aminopyralid plus 2,4-D resulted in 58 to 88% control of tall goldenrod 1MAT in 2006, and 80 to 88% control in 2007. The differences in activity between years may be due to higher levels of precipitation in 2006 compared to 2007. Rainfall totals in 2006 after herbicide application until biomass harvest were 78 cm while those in 2007 were 31 cm.

Tall goldenrod density counts at 1YAT generally corresponded with 1MAT visual control ratings. Aminopyralid resulted in greater tall goldenrod stem densities 1YAT than all other herbicide treatments evaluated in this research and had similar tall goldenrod density as the untreated control plots (Table 2.1). The addition of 2,4-D to the aminopyralid treatment reduced tall goldenrod density 74% more than aminopyralid alone but still had tall goldenrod densities that were numerically higher than all other herbicide treatments evaluated in this research. Although no treatment completely eradicated tall goldenrod, all of the remaining herbicide treatments reduced tall goldenrod density by 94 to 99% 1YAT (Table 2.1). Similar to the results of Tunnell et al. (2006), picloram plus 2,4-D provided good control (90% or greater) of tall goldenrod 1YAT, as did any metsulfuron-containing treatment.

Total Biomass Yields. There was no significant treatment by year interaction for either the 1MAT or 1YAT biomass yield data, therefore all biomass yield results were combined across years and are presented in Table 2.2. Since there were no significant differences among herbicide treatments, yields were also pooled across herbicide treatments and compared to yields of the untreated control (Table 2.2). At the 1MAT harvest, total harvested yields were approximately 1,300 kg/ha higher in the untreated control compared to the herbicide-treated plots. Although botanical composition of the harvested biomass was not a variable measured in this research, this yield reduction is likely due to the removal of tall goldenrod and red clover with the herbicide treatments (Table 2.1). The removal of tall goldenrod plays a vital role in hayfield management considering goldenrod species are not a preferred species for forage grazing.

At the 1YAT harvest, total harvested yields were decreased by as much as 33% when compared to untreated control plots (Table 2.2). Few trends in total biomass yield were observed 1YAT, but the most effective treatments (greater than 90%) for tall goldenrod control tended to provide the highest yields 1YAT. Aminopyralid applied alone resulted in the poorest biomass yield 1YAT, suggesting that tall goldenrod can effectively compete with tall fescue (Table 2.2). As mentioned previously, red clover was only present in untreated control plots 1YAT and was completely eliminated from all herbicide-treated plots. The untreated control plots resulted in the overall highest yields 1YAT due to no herbicide treatment and no red clover disturbance.

Biomass Nutritive Value. There was no significant treatment by year interaction for either the 1MAT or 1YAT biomass nutritive value data, therefore results were combined across years and are presented in Table 2.3. There were also no differences between herbicide treatments in either year, therefore values were pooled across herbicide treatments and compared to the biomass nutritive value of the untreated control.

There were no differences in CP, ADF and NDF of the total harvested biomass between herbicide-treated and untreated plots 1MAT (Table 2.3), despite the removal of tall goldenrod with the herbicide treatments (Table 2.1). Pure tall goldenrod samples collected at the time of the 1MAT harvest were much lower in ADF and NDF than pure samples of tall fescue collected at the same time (Table 2.3). However, tall fescue was slightly higher in CP than tall goldenrod. The herbicides did not completely eliminate tall goldenrod 1MAT, therefore at least some portion of tall goldenrod or dying carcasses of tall goldenrod present in the herbicide-treated plots 1MAT likely contributed to the lack of difference in nutritive value between herbicide-treated and untreated biomass.

Spring herbicide-treated biomass was also higher in ADF and NDF and lower in CP (i.e. poorer nutritive value) than untreated biomass 1YAT (Table 2.3). One YAT, crude protein (CP) content increased by 2.5% and acid detergent fiber (ADF) and neutral detergent fiber (NDF) content decreased by 2.4 and 6.4%, respectively, in biomass harvested from untreated compared to herbicide-treated plots. As with the 1MAT harvest, pure samples of tall goldenrod were much lower in ADF (8 to 10%) and NDF (21 to 24%) and slightly lower in CP (0.2 to 0.3%) than pure samples of tall fescue harvested at the same time (Table 2.3). This response may be at least partially explained by the higher nutritive values found in pure samples of tall goldenrod compared to tall fescue, and the removal of tall goldenrod with herbicide treatments 1YAT (Table 2.1). Additionally, all herbicides eliminated red clover which likely contributed to the higher nutritive value of the untreated control compared to the herbicide-treated biomass.

CONCLUSIONS

Our results indicate that metsulfuron, metsulfuron plus 2,4-D plus dicamba, aminopyralid plus metsulfuron, aminopyralid plus metsulfuron plus 2,4-D, and picloram plus 2,4-D will provide good control (90% or higher) of tall goldenrod 1YAT, but aminopyralid applied alone provides essentially no control of tall goldenrod 1YAT. The addition of metsulfuron to aminopyralid treatments increased tall goldenrod control more than the addition of 2,4-D. The results from these experiments also indicate that herbicide treatments will likely reduce total biomass yields even up to 1YAT where severe tall goldenrod infestations exist due to the selective removal of tall goldenrod from the desirable grass forage. In addition, the removal of tall goldenrod with herbicide(s) may consequently decrease the nutritive value of the harvested biomass as a result of the elimination of legumes and tall goldenrod and herbicide activity at 1MAT and 1YAT. Therefore our results support those of (Bosworth et al., 1985) who suggested that the removal of cool-season weed species at the vegetative stage of maturity is not likely to increase the overall quality of harvested biomass, even 1YAT. Additional research is necessary to determine if biomass yield and/or nutritive value could be increased following tall goldenrod removal with cultural practices such as fertilization, liming, and inter-seeding of legumes. Additionally, further research should be conducted to determine what impacts tall goldenrod has on the palatability and digestibility of the total biomass as fed to ruminant animals such as cattle.

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Table 2.1 Tall goldenrod control with various herbicides one month after treatment (MAT) and one year after treatment (YAT).

		Tall Goldenrod Control[a]		
		Visual Control 1MAT		Density
Treatment[b]	Rate	2006	2007	1YAT[c]
	---kg/ha---	-----------%-----------		----plants/27m^2----
Picloram 2,4-D	0.15 0.56	62 c	86 a	2.0 b
Picloram 2,4-D	0.21 0.84	84 ab	85 a	0.6 b
Metsulfuron	0.01	88 a	88 a	1.0 b
Metsulfuron 2,4-D Dicamba	0.01 0.40 0.14	58 c	84 a	0.3 b
Aminopyralid	0.06	30 d	68 b	46.0 a
Aminopyralid 2,4-D	0.07 0.56	55 c	78 ab	12.0 b
Aminopyralid Metsulfuron	0.07 0.008	81 ab	80 a	3.0 b
Aminopyralid Metsulfuron	0.07 0.01	80 ab	82 a	1.0 b
Aminopyralid Metsulfuron 2,4-D	0.07 0.01 0.53	77 b	80 a	0.6 b
Untreated	---------	0 e	0 c	50.0 a

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

[b] All treatments applied with a non-ionic surfactant at 0.25% v/v.

[c] There was not a significant effect of location on tall goldenrod density 1YAT, therefore results were combined across locations for the 1YAT density data.

Table 2.2 Total biomass yields one month after treatment (MAT) and one year after treatment (YAT) with various herbicides.

		Harvest Timing[a,b]	
Treatment	**Rate**	**1MAT**	**1YAT**
	---kg/ha---	----------- kg/ha -----------	
Picloram	0.15	2815 b	2285 ab
2,4-D	0.56		
Picloram	0.21	2939 b	1819 cd
2,4-D	0.84		
Metsulfuron	0.01	2672 b	1876 cd
Metsulfuron	0.01	2747 b	2027 bcd
2,4-D	0.40		
Dicamba	0.14		
Aminopyralid	0.06	2599 b	1682 d
Aminopyralid	0.07	2832 b	1950 bcd
2,4-D	0.56		
Aminopyralid	0.07	2550 b	1873 cd
Metsulfuron	0.008		
Aminopyralid	0.07	2628 b	2145 abc
Metsulfuron	0.01		
Aminopyralid	0.07	2565 b	2188 abc
Metsulfuron	0.01		
2,4-D	0.53		
Untreated	---------	4031 a	2503 a
Pooled Herbicide Treatments		***1MAT***	***1YAT***
Herbicide-treated[c]		*2705 b*	*1983 b*
Untreated		*4031 a*	*2503 a*

[a] There was not a significant effect on location on total biomass yields, therefore results were combined across locations.

[b] Means within a column fb the same letter are not significantly different ($P \leq 0.05$).

[c] There were no differences between herbicide treatments, therefore yields were combined across herbicides for comparison to the untreated.

Table 2.3 Influence of herbicide treatments on total biomass quality at the time of each harvest.

Treatment	Harvest Timing	Total Nutritive Values [a,b] CP	ADF	NDF
		------------------------%	------------------------	
Herbicide-treated[c]	1MAT	7.5 a	39.8 a	55.8 a
Untreated[d]	1MAT	7.7 a	38.9 a	54.0 a
Herbicide-treated[c]	1YAT	5.5 b	40.8 b	61.9 b
Untreated[e]	1YAT	8.0 a	38.4 a	55.5 a

[a] There was not a significant effect of location on biomass nutritive value at any harvest, therefore results were combined across locations.

[b] Means within a column followed by the same letter are not significantly different ($P \leq 0.05$).

[c] No differences were found between herbicide treatments, therefore nutritive values were combined across herbicides treatments and compared to the untreated control.

[d] 1MAT pure sample nutritive values: *tall goldenrod* 6.3% CP, 27.4% ADF and 32.7% NDF and *tall fescue* 6.6% CP, 38.3% ADF and 57.0% NDF.

[e] 1YAT pure sample nutritive values: *tall goldenrod* 6.6% CP, 29.6% ADF and 36.9% NDF and *tall fescue* 6.8% CP, 38.4% ADF and 58.4% NDF.

Chapter III

Influence of Spring and Summer Herbicide Applications on Weed Control, Total Biomass Yield and Total Biomass Nutritive Value in Tall Fescue (*Lolium arundinacea* (Schreb.) Darbysh.) Pastures and Hayfields in Missouri

Kristin K. Payne, Byron B. Sleugh, and Kevin W. Bradley

ABSTRACT

Field experiments were conducted in the spring of 2007 through the spring of 2009 at four locations in Boone, Moniteau and Polk County, Missouri to evaluate the effect of various herbicides and herbicide combinations on weed control, total biomass and total biomass nutritive values. All sites consisted of tall fescue [*Lolium arundinacea* (Schreb.) Darbysh.] pastures that contained natural infestations of common ragweed (*Ambrosia artemisiifolia* L.) and tall ironweed (*Vernonia gigantea* (Walt.) Trel). At both locations, 2,4-D, metsulfuron, aminopyralid, 2,4-D plus dicamba, 2,4-D plus picloram, aminopyralid plus 2,4-D, and 2,4-D plus dicamba plus metsulfuron were applied at a spring and summer application timing. Spring-applied metsulfuron alone and 2,4-D plus dicamba plus metsulfuron resulted in 13 to 22% tall fescue injury; all other herbicide treatments caused less than 5% injury. All summer-applied herbicides resulted in less than 4% tall fescue injury. With the exception of 2,4-D one month after treatment (1MAT), all herbicide treatments resulted in 85 to 100% white clover injury for all visual evaluations. All herbicide treatments provided greater than 82% control of common ragweed 1MAT except metsulfuron-containing herbicides which provided 49 to 76% control. Summer-applied treatments resulted in higher residual control of common ragweed than spring-applied treatments when evaluated the following spring. Visual control evaluations of tall ironweed in response to herbicide treatments ranged from 61 to 81% control. Tall ironweed density the year following herbicide treatment resulted in few differences between application timing as metsulfuron-containing treatments provided from 6.6 to 7.1 plants m^{-2} and 2,4-D plus picloram provided from 0 to 1.9 plants m^{-2}. Both application timings provided biomass yields at June harvests highest in the untreated control and lowest in the metsulfuron plus 2,4-D plus dicamba. October harvest resulted in highest yields in the aminopyralid treatment for both application timings by as much as 636 kg ha^{-1}. Crude protein (CP) content and relative feed value (RFV) was greater in untreated compared to herbicide-treated biomass. Pure samples of common ragweed, tall ironweed, and white clover were higher in nutritive values than pure samples of tall fescue in the June harvest. Overall, the poorer nutritive values in herbicide-treated compared to untreated biomass may be at least partially explained by the removal of common ragweed, tall ironweed and legumes with herbicide treatments. Results from these experiments indicate that the removal of common ragweed and tall ironweed with herbicides will only marginally impact the total biomass and nutritive values of herbicide-treated pastures.

INTRODUCTION

Pasture and rangelands occupy about 192 million hectares, or 51% of the total farm land area of the United States (USDA, 2007). In Missouri alone, tall fescue is one of the most abundant forages utilized for beef production (Gerrish and Roberts, 1999). This cool season grass is found within Missouri's approximate 4.2 million hectares of pastures (USDA, 2007).

Common ragweed (*Ambrosia artemisiifolia* L.) and tall ironweed (*Vernonia gigantea* (Walt.) Trel) are weed species native to North America and are found abundantly in tall fescue pastures and hayfields throughout the Midwestern United States (Barbour and Meade, 1982; Mann et al., 1983; Marshall et al., 2006; Mitich, 2007). Common ragweed, the most common species in the ragweed family, is widespread in overgrazed pastures and hayfields throughout the

U.S. (Mitich, 2007). In a pasture or hayfield environment, common ragweed has been recognized as a source of nourishment when other forages are non-existent and offers ruminant animals, such as cattle, nutritive values similar to some pasture grasses or legumes (Marten and Anderson, 1975; Temme et al., 1979).

Tall ironweed is considered hard to manage in a pasture or hayfield due to the perennial nature of this weed species. The invasion of perennials like tall ironweed represents a significant threat to livestock producers as most perennials re-emerge from underground rootstocks unless long-term control strategies are implemented (Anonymous, 2007). Tall ironweed can become abundant in pastures and hayfields because of the decreased palatability of this species for ruminant animals when compared to many other weeds (Green and Martin, 1998).

Adequate knowledge of the effects of common ragweed or tall ironweed infestations on forage nutritive values is necessary in order for producers to make sound management decisions in a tall fescue pasture or hayfield. The forage nutritive values most commonly used to explain a given forage's quality consist of neutral detergent fiber (NDF), which estimates the amount of forage the animal can consume and measures cellulose, hemicelluloses and lignin, crude protein (CP) which determines the nitrogen concentration in the forage sample and indicates the amount of plant protein, and acid detergent fiber (ADF) which estimates the energy content of the forage sample and measures cellulose and lignin (Undersander, 2007). Another important value used in the measurement of forage quality is relative feed value (RFV). The RFV is an index that estimates digestible dry matter of the forage from ADF, and calculates the dry matter intake potential from NDF (Jeranyama and Garcia, 2004).

Pasture weeds such as common ragweed or tall ironweed can reduce pasture production directly by interfering with grazing or indirectly by lowering the yield and/or nutritive values of the forage. Other researchers have found that certain weeds can have more favorable nutritive values than the preferred forage species (Carlisle et al., 1980; Jones et al., 1971; Marten and Anderson, 1975; Temme et al, 1979). Jones et al. (1971) reported red sorrel (*Rumex acetosella*) and common lambsquarters (*Chenopodium album*) digestibility was much greater than Australia native grasses. Temme et al. (1979) showed that CP content of many common pasture weeds like common ragweed and common lambsquarters exceeds that of grasses or alfalfa. Carlisle et al. (1980) studied the nutritive values of 11 pasture weeds and found that five of the 11 contained sufficient CP for ruminant animals while six of the 11 were more than 50 percent digestible. Lastly, Marten and Anderson (1975) found that common annual weeds such as common ragweed, redroot pigweed, and common lambsquarters did not decrease the nutritive value of the total biomass if utilized at relatively early stages of maturity. Until full plant maturation, many common pasture weeds can supply adequate digestible energy and nitrogen for livestock. However, digestibility and CP concentrations generally decline as plants mature past the vegetative stage of growth (Bosworth et al., 1985; Bosworth et al., 1980; Green and Martin, 1998). Conversely, some pasture weed species may be unpalatable throughout their life cycle (Hoveland et al., 1986; Jones et al., 1971).

Pastures, whether grazed or hayed, require management to maintain the desired vegetation (Bovey, 1987). Effective weed management can seldom be achieved by a single method or action and the use of herbicides is one of the most effective means to suppress or eliminate weed infestations. However, all selective herbicides used in grass pastures and hayfields will not usually control the entire spectrum of weeds present to the same degree. For example, metsulfuron can provide good control of common weeds like curly dock (*Rumex crispus*) or tall goldenrod (*Solidago altissima* L), but generally provides poorer control of common ragweed and tall ironweed (Anonymous, 2007; Bradley and Kendig, 2004; Green and Martin, 1998; Payne et al., 2008). Conversely, 2,4-D, dicamba, picloram, aminopyralid, and various prepackaged combinations of these herbicides have been shown to provide good control of common ragweed (Bradley and Kendig, 2004; Marshall et al., 2006; Rhodes et al., 2005).

The timing of herbicide application is likely to affect the degree of weed control as well (DiTomaso, 2000). Summer annual weeds, such as common ragweed, are most easily controlled with spring or early summer herbicide applications when these weeds are young and actively growing (Bradley and Kendig, 2004; Green and Martin, 1998). Perennials, such as tall ironweed, should be sprayed in the bud-to-bloom growth stage (Bradley and Kendig, 2004; Green and Martin, 1998). Perennial weed species are most susceptible to herbicides at the bud-to-bloom or reproductive stage of growth because translocated herbicides can move downward with food reserves to the roots, thus killing the entire plant (Bradley and Kendig, 2004). Determining the most suitable herbicide application timing for common pasture weeds is difficult, especially when multiple weed species are present within a given pasture or hayfield.

Currently, little to no research has been conducted to examine the effects of spring versus summer herbicide applications on weed control within the season of treatment as well as the spring following treatment. Similarly, information is lacking on the effects of weeds and weed control on total biomass nutritive values and/or yields. Therefore, the objectives of this research were to determine the effects of herbicides and application timings on weed control, forage injury, total biomass yield and total biomass nutritive values in tall fescue pastures in Missouri.

MATERIALS AND METHODS

Field experiments were established at four locations in Missouri with a total of 4 site-years from the spring of 2007 through the spring of 2009. The spring 2007 established trials were duplicated in time and space for 2008. Two sites were located in Boone County in central Missouri, one site was located in Moniteau County in south central Missouri, and another site was located in Polk County in southern Missouri. The three research areas were selected based on the presence of dense infestations of common ragweed (20 to 100 plant m^{-2}) and tall ironweed (2 to 10 plants m^{-2}) that occurred in tall fescue pastures. In all experiments, the experimental design consisted of a randomized complete block with a factorial arrangement of eight treatments and two application timings. All plots were 3 x 9 meters and replicated three or four times (dependent upon site).

The herbicide treatments evaluated in these experiments are listed in Table 3.1. Each herbicide treatment was combined with a nonionic surfactant at 0.25% v/v. All applications were made with a CO_2 backpack sprayer set to deliver 140 liters per hectare with XR8002[5] flat fan nozzles. Spring herbicide applications were made in mid-to-late-May. At the time of the spring herbicide applications, tall ironweed plants ranged from 15 to 25 cm in height and were in the vegetative stage of growth while common ragweed seedlings ranged from 3 to 9 cm in height. Summer herbicide applications were made in late-August after the initial June biomass harvest had been conducted and all weeds and tall fescue exhibited ample regrowth, tall fescue ranging from 9 to 12 cm in height. These two herbicide application timings represent the most common windows that producers utilize for broadleaf weed control in tall fescue pastures and hayfields in Missouri (K. Bradley, personal communication). At the time of the summer herbicide applications, tall ironweed plants were 35 to 37 cm in height and were in the pre-bloom stage of growth while common ragweed were flowering and 20 to 24 cm in height. For both herbicide application timings, tall fescue ranged from 9 to 12 cm in height. All treatments were visually rated for tall fescue and white clover injury and common ragweed and tall ironweed

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[1] Teejet Spraying Systems Co, P.O. Box 7900, Wheaton, IL 60189

control. Visual ratings were taken on a scale of 0 to 100 percent with zero being equivalent to the ground cover and vigor in the untreated control, and 100 equivalent to complete tall fescue or white clover death and complete weed control. Just prior to harvest at 1YAT, tall ironweed and common ragweed densities were determined by counting all plants within 2, 1/3 m^2 areas in each plot.

Total biomass yield was determined by harvesting 2, 1 x 8 m strips within each plot using a Carter forage harvester[6] as soon as tall fescue reached 20 to 26 cm height (approximately 4 to 5 weeks after each treatment application). At each harvest, two 300-g subsamples of the total harvested biomass were taken in each plot for analysis of forage nutritive values. One representative sample of pure tall fescue, pure common ragweed and pure tall ironweed was also hand-harvested from the trial area and analyzed for forage nutritive values at the time of each biomass harvest. All samples were placed in a forced-air oven for 48 hours at 37^oC in order to determine dry matter content. Subsamples from each plot were ground with an Udy-mill[7] to pass through a 1-mm screen.

Neutral and acid detergent fiber were analyzed using an ANKOM 200 Fiber Analyzer[8]. The ADF and NDF for calibration samples were determined using the methods described by VanSoest and Robertson (1980). Crude protein concentration was measured by thermal conductivity of nitrogenous gases with a Leco Nitrogen (N) Analyzer[9]. Crude protein for calibration samples was determined by measuring total N content using the micro-Kjeldahl technique (Wall and Gerke, 1975) and then multiplying N values by 6.25. To stimulate fall

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[6] Carter MFG CO., INC. 896 E. Carter Court, Brookston, IN 47923

[7] UDY Corporation, 201 Rome Court, Fort Collins, CO 80524

[8] ANKOM Technology, Fairport, NY

[9] Leco Corp., 3000 Lakeview Avenue, St. Paul, MN

growth, all treatments received a broadcast application of 56 kg ha^{-1} of nitrogen in mid August at all sites.

Tall ironweed and common ragweed density, total biomass yield and nutritive values, and tall fescue and white clover injury were analyzed using the Mixed procedure in SAS[10] and tested for appropriate interactions. Biomass yield and CP concentration were tested for harvest by treatment by application timing interactions. Crop injury, RFV and weed densities were combined across all harvest and tested for interactions between herbicide treatment and application timing. As suggested by Carmer et al. (1989), each site-year was considered an environment sampled at random. Random effects were replication by location and replication by treatment, timing, and location. The linear statistical model contained location, treatment, and time as fixed effects. Means were separated with an LSD at the 0.05% level. The ADF and NDF results were used to compute RFV values using the following equations (Jeranyama and Garcia 2004):

$$\text{DDM} = \text{Digestibile Dry Matter} = 88.9 - (0.779 * \%\text{ADF})$$

$$\text{DMI} = \text{Dry Matter Intake (\% of BW)} = 120 / (\%\text{NDF})$$

$$\text{RFV} = (\text{DDM} * \text{DMI}) / 1.29$$

RESULTS AND DISCUSSION

Tall Fescue Injury. Tall fescue injury was evaluated one month after the spring-applied herbicide treatments. Spring-applied metsulfuron provided the highest visual injury to tall fescue resulting in 22% injury one month after treatment (MAT) (Table 3.1). Other authors have also observed significant injury to tall fescue injury following applications of metsulfuron (Bradley and Kendig, 2004; James et al. 1999; Moyer and Kelley, 1995). The addition of 2,4-D

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[10] SAS Institute, Inc., SAS Campus Drive, Cary, NC 27513

and dicamba to metsulfuron decreased tall fescue injury in June by 9% (Table 3.1). This decrease in tall fescue injury is common with the addition of 2,4-D which essentially provides a safening effect on the forage grass. This safening effect is supported by the metsulfuron herbicide label which suggests the addition of 2,4-D to minimize tall fescue injury symptoms (Anonymous, 2009). Tall fescue injury for all other spring-applied herbicides ranged from 2 to 5% (Table 3.1).

Less than 5% visual injury was observed across all summer-applied herbicide treatments (Table 3.1). These results are similar to other authors who have reported little to no signs of visual tall fescue injury following applications of these herbicides (James et al., 1999; Moyer and Kelley, 1995). This decrease in tall fescue injury for all summer-applied treatments is likely associated with the stage of tall fescue at the time of the summer compared to spring herbicide applications. At the time of the summer herbicide applications, tall fescue, a cool-season grass species, is semi-dormant during that time of the year and not as actively growing as during the spring application timing, so we observe less injury (Cherney and Johnson, 1993).

White Clover Injury. All herbicide treatments almost completely eliminated native populations of white clover. Across all site-years and application timings, the herbicides evaluated in these trials resulted in 85 to 98% visual control of white clover the season following treatment (Table 3.2). The spring application of 2,4-D was the only herbicide that did not eliminate all legumes within the treated area in June (Table 3.2).

Common Ragweed Control with Spring and Summer Herbicide Applications. Herbicide treatments provided 49 to 99% visual control of common ragweed 1 MAT, regardless of the spring or summer application timing (Table 3.3). Applying metsulfuron provided lower common ragweed control 1MAT than all other herbicide treatments across application timings, locations and years. Other authors have also reported poor control of common ragweed with metsulfuron (Anonymous, 2007; Bradley and Kendig, 2004; Green and Martin, 1998; Payne et al., 2008).

Spring-applied herbicide treatments did not influence common ragweed density 1YAT (Table 3.3). Common ragweed density ranged from 27 to 44 plants m^{-2} in response to the spring herbicide applications evaluated in these experiments. Applications of these same herbicides made at the summer timing did influence common ragweed density the following June. (Table 3.3). Summer applications of 2,4-D, 2,4-D plus picloram, aminopyralid, aminopyralid plus 2,4-D, and metsulfuron plus 2,4-D plus dicamba decreased common ragweed densities compared to the untreated control. Metsulfuron and 2,4-D plus dicamba resulted in common ragweed densities similar to the untreated control. The difference in common ragweed density between the spring and summer application timing is likely a direct reflection of the length of the residual activity of these herbicides applied in the spring compared to late summer. These results indicate that spring-applied herbicides will likely dissipate within a year’s timeframe and not be available for uptake on emerging annual weed seedlings the following season. However, a late summer application of these same herbicides may provide residual control of emerging seedlings the following spring.

Tall Ironweed Control with Spring and Summer Herbicide Applications. One MAT, the herbicide treatments and timings evaluated in these experiments provided from 61 to 81% visual control of tall ironweed (Table 3.4). Applying metsulfuron or 2,4-D provided lower tall ironweed control 1MAT than all other herbicide treatments across application timings, locations and years.

Spring herbicide applications resulted in tall ironweed densities of 0 to 7 plants m^{-2} 1YAT (Table 3.4). Metsulfuron and metsulfuron plus 2,4-D plus dicamba resulted in tall ironweed densities similar to the untreated control 1YAT. All other spring herbicide treatments reduced tall ironweed density compared to the untreated control 1YAT. Picloram plus 2,4-D completely eliminated tall ironweed 1YAT, while 2,4-D, 2,4-D plus dicamba, aminopyralid, and aminopyralid plus 2,4-D resulted in 3.3 or less stems m^{-2}. Applications of picloram plus 2,4-D, 2,4-D, 2,4-D plus dicamba, aminopyralid, and aminopyralid plus 2,4-D in the summer provided similar, but less favorable results (Table 3.4). Using summer application timing, 2,4-D plus picloram and aminopyralid provided the greatest reductions in tall ironweed density by the following June when compared to the untreated control. As with the spring application timing, metsulfuron and metsulfuron plus 2,4-D plus dicamba provided no reductions in tall ironweed density when applied at the summer application timing. These results indicate a spring application of 2,4-D plus picloram provides the greatest control (0 stems m^{-2}) of tall ironweed 1YAT in tall fescue pastures and hayfields. Other treatments providing greater than 70% control of tall ironweed included 2,4-D and aminopyralid. Metsulfuron and metsulfuron plus 2,4-D plus dicamba did not provide greater than 30% tall ironweed control for either the spring or summer application timings, and therefore should not be selected to control tall ironweed in grass pastures or hayfields.

Total Biomass Yields. At the initial June harvest, few differences in total harvested yields were observed between treatments (Table 3.5). Only metsulfuron plus 2,4-D plus dicamba or 2,4-D plus dicamba resulted in yields that were significantly lower than the untreated control but total biomass yields from all herbicide treatments were generally lower than the untreated control, presumably due to the removal of weeds and forage legumes with the herbicide treatments. Across all herbicide treatments, the total harvested biomass yields averaged 1905 kg ha^{-1}, which was 313 kg ha^{-1}lower than the untreated control. There were no differences in total harvested biomass between any of the herbicide treatments, which ranged from 1779 to 2037 kg ha^{-1} (Table 3.5).

By the time of the October biomass harvest, all herbicide treatments except 2,4-D resulted in greater total biomass yields than the untreated control in response to the spring herbicide treatments (Table 3.5). Spring herbicide application increased biomass yields by 381 to 636 kg ha^{-1} compared to untreated plots (Table 3.5). As with the initial June harvest, no differences were found across herbicide treatments at the October harvest. The October harvest provided higher biomass yields than June harvests.

By 1 year after treatment (YAT), few differences in total harvested yields between spring-applied herbicide treatments and the untreated control were observed (Table 3.5). The 1YAT harvest results were similar to the initial June harvest in that all herbicides except metsulfuron plus 2,4-D plus dicamba provided yields similar to the untreated control and there were no differences between herbicide treatments. As previously mentioned, white clover and other legumes were only present in the untreated control and essentially completely eliminated from all herbicide treatments (Table 3.2). This likely contributed to the similarity in total biomass yields between the spring herbicide-treated plots and the untreated control. Additionally, there were no differences between herbicide-treated and untreated plots in common ragweed density at the 1YAT harvest, and few differences in tall ironweed density 1YAT. Therefore, the lack of differences in weed density likely resulted in similar biomass yields 1YAT, regardless of spring herbicide applications the previous year.

Herbicide treatments over a one year timeframe resulted in total annual forage yields ranging from 7019 kg ha^{-1}in the metsulfuron plus 2,4-D plus dicamba treatment to 7645 kg ha^{-1}in the aminopyralid treatment. All spring-applied treatments resulted in total annual yield reductions no less than 8% lower than the aminopyralid treatment.

In response to the summer herbicide application timing, all herbicides except 2,4-D plus picloram resulted in total biomass yields that were not different from the untreated control at the October harvest (Table 3.5). At the October biomass harvest, summer-applied herbicides resulted in total biomass yields that ranged from 2996 to 3435 kg ha^{-1} while the untreated control resulted in total biomass yields of 3384 kg ha^{-1}. By the time of the subsequent June harvest, all summer herbicide treatments except metsulfuron plus 2,4-D plus dicamba provided similar yields as the untreated control (Table 3.5).

Crude Protein. At the time of the initial June harvest, CP concentrations of the total harvested biomass in response to the spring herbicide applications were similar for all herbicide treatments (Table 3.6). Only aminopyralid plus 2,4-D resulted in a CP concentration that was significantly lower than the untreated control (Table 3.6). CP concentration of the harvested biomass was highest with the metsulfuron treatment, which is likely due to the poor control of common ragweed and tall ironweed (Tables 3.3 and 3.4). Jones et al. (1971) and Marten and Anderson (1975) have also shown that common ragweed or tall ironweed harvested at the vegetative stage of growth can provide CP concentrations higher in quality than many forages. These results are not different from our research findings (Table 3.8).

By the October harvest, CP concentrations of the total harvested biomass ranged from 9.2 to 10.3%, but there were still few differences between spring-applied herbicide treatments and the untreated control (Table 3.6). The highest CP concentrations were in the 2,4-D, 2,4-D plus picloram, and aminopyralid plus 2,4-D herbicide treatments. The metsulfuron plus 2,4-D plus dicamba treatment provided the lowest CP concentration. Tall fescue provided greater CP concentrations than weed species in October (Table 3.8). The lower CP values in the total biomass are likely due to the lower levels of common ragweed and tall ironweed control. As common ragweed and tall ironweed reach full maturity, the CP concentration of these weed species declines in nutritive value (Bosworth et al., 1985; Bosworth et al., 1980; Green and Martin, 1998; Payne et al. 2008). Therefore the herbicide treatments with poor control of common ragweed or tall ironweed will provide lower CP values in October.

One YAT, few differences in CP concentration of the total harvested biomass were detected between untreated and plots treated with spring herbicide applications (Table 3.6). In addition, no differences were observed between herbicide treatments (Table 3.6). The only herbicide treatment different from the untreated control was aminopyralid plus 2,4-D.

At the time of the October harvest, there were no differences in CP content of the harvested biomass for herbicide treatments applied in the summer timing (Table 3.6). Common ragweed control was greater and very few differences in tall ironweed were observed at the October harvest. Additionally, tall fescue at this harvest provided higher CP values than the weed species. Therefore a combination of weed control and pure sample CP values likely contributed to the similarity in total biomass CP concentrations observed in these experiments.

By the subsequent June harvest, the highest CP concentration occurred in the untreated control (Table 3.6). Only 2,4-D plus dicamba, aminopryalid, aminopyralid plus 2,4-D, and metsulfuron plus 2,4-D plus dicamba provided total biomass CP concentrations that were lower than the untreated control. A common trend at most harvest timings was that the untreated control biomass was highest in CP concentration. This is likely due to the presence of clover or other legumes and weed species within the untreated plot area. Therefore a combination of weed and/or legumes in the untreated control is likely responsible for the higher CP concentrations recorded in the total biomass. During June, pure samples of common ragweed and tall ironweed provided higher CP values than tall fescue (Table 3.8). For all treatments in this research, CP values of the total harvested biomass were not sufficient for lactating cows and sheep according to data provided by Ball et al. (2001). The range of CP concentration in our trials was from 7.42 to 10.64% (Table 3.6).

Relative Feed Value. The RFV value estimates the digestible dry matter from ADF and calculates the dry matter intake potential from NDF. The RFV values in this research are relative to a standard used to compute RFV, which is full bloom alfalfa with an RFV index number set at 100 (Jeranyama and Garcia, 2004). In these experiments, RFV values ranged from 92 to 99 (Table 3.7). At either the spring or summer herbicide application timing, the highest RFV values occurred in the untreated control. All herbicide treatments except 2,4-D were lower in RFV values in response to spring-applied herbicide treatments (Table 3.7) This difference is likely due to the clover remaining in the 2,4-D treatment 1 MAT (Table 3.2). In response to the summer application timing, 2,4-D plus dicamba, aminopyralid, aminopyralid plus 2,4-D and metsulfuron plus 2,4-D plus dicamba provided lower RFV values than the untreated control (Table 3.7).

Greater RFV values in the untreated control may be at least partially explained by the elimination of white clover and other legumes from the herbicide-treated biomass. In addition, the amount of fiber for individual forage samples is a portion of the RFV calculation and can be different for each plant species. The variation in quality can be attributed to grass and legumes naturally differing in digestibility (Jeranyama and Garcia, 2004). In addition, the increased density of common ragweed (Table 3.3) or tall ironweed (Table 3.4) within the herbicide treatments associated with individual plant RFV values (Table 3.8) may have contributed to the greater total biomass RFV values. Pure samples of common ragweed and tall ironweed had higher RFV values than pure tall fescue at the majority of the harvest timings (Table 3.4). Therefore, the combination of high weed density, legume presence, and pure plant species RFV values all contributed to the higher total biomass RFV concentrations observed in the untreated controls. Similar to the results of the total biomass CP concentrations, the range of RFV values are quite comparable for all herbicides and are not greatly influenced by one particular herbicide treatment.

CONCLUSIONS

Results from these experiments indicate that with the exception of metsulfuron-containing herbicides, all herbicide treatments evaluated in the research will provide greater than 82% control of common ragweed 1MAT regardless of the application timing, and also that summer-applied treatments will provide higher residual control of common ragweed the following spring. Metsulfuron-containing herbicides provided the highest tall fescue injury in these experiments and all herbicide treatments evaluated in this research eliminated white clover 1YAT. Metsulfuron-containing herbicides or 2,4-D also provided poorer control of tall ironweed 1 MAT and 1YAT, while spring applications of 2,4-D plus picloram was one of the better treatments for the control of tall ironweed.

Across application timings, there were few differences in total harvested biomass between herbicide treatments. Total annual yield reductions in spring-applied herbicide treatments were no less than 8% lower than the highest yielding herbicide treatment. The results from these experiments also indicate that herbicide treatments will only marginally reduce total biomass yields the following spring where severe common ragweed or tall ironweed infestations existed due to the selective removal of these species from the desirable grass forage. In addition, the removal of common ragweed or tall ironweed with herbicide treatments may consequently decrease the CP and RFV values of the harvested biomass as a result of the elimination of any legumes, and in some cases weeds, that may be present at the time of application.

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Table 3.1. Influence of herbicides and application timings on visual injury of tall fescue one month after treatment (MAT) over four site-years in Missouri.

		Spring Application	Summer Application
Treatments[a]	Rate	June	October
	---- kg/ha ----	---------------------------- % visual injury[b]	----------------------------------
2,4-D	1.01	4 c	1 ab
2,4-D + dicamba	1.07 + 0.56	5 c	1 ab
2,4-D + picloram	0.57 + 0.15	4 c	2 a
Aminopyralid	0.07	3 cd	1 ab
Aminopyralid + 2,4-D	0.75 + 0.10	5 c	1 ab
Metsulfuron	0.01	22 a	1 ab
Metsulfuron + 2,4-D + dicamba	0.01 + 0.71 + 0.14	13 b	1 ab
Untreated	-------------	0 d	0 b

[a] All treatments applied with a non-ionic surfactant at 0.25% v/v.

[b] Means within a column followed by the same letter are not different, $p \leq 0.05$.

Table 3.2. Influence of herbicides and application timings on visual injury of white clover evaluated before each harvest over four site-years in Missouri.

		Spring Application			Summer Application	
Treatments[a]	Rate	June	October	YAT	October	June Year 2
	---- kg/ha ----	% visual injury[b]				
2,4-D	1.01	35 c	100 a	85 b	100 a	94 c
2,4-D + dicamba	1.07 + 0.56	100 a	100 a	91 ab	100 a	98 a
2,4-D + picloram	0.57 + 0.15	89 b	100 a	92 a	100 a	98 a
Aminopyralid	0.07	100 a	100 a	88 ab	100 a	97 ab
Aminopyralid + 2,4-D	0.75 + 0.10	99 a	100 a	93 a	100 a	98 a
Metsulfuron	0.01	100 a	100 a	85 b	100 a	97 ab
Metsulfuron + 2,4-D + dicamba	0.01 + 0.71 + 0.14	97 a	100 a	89 ab	100 a	95 bc
Untreated	--------------	0 d	0 b	0 c	0 b	0 d

[a] All treatments applied with a non-ionic surfactant at 0.25% v/v.
[b] Means within a column followed by the same letter are not different, $p \leq 0.05$.

Table 3.3. Influence of herbicides and application timings on common ragweed control one month after treatment (MAT) and density one year after treatment (YAT) over four site-years in Missouri.

		Spring Application		Summer Application	
Treatments[a]	Rate	1MAT	1YAT	1MAT	June Year 2
	---- kg/ha ----	----%visual control ----	---plants m^{-2}---	---%visual control ---	---plants m^{-2}---
2,4-D	1.01	98 a	27 a	85 b	18 d
2,4-D + dicamba	1.07 + 0.56	99 a	43 a	86 b	33 abc
2,4-D + picloram	0.57 + 0.15	99 a	42 a	87 ab	27 bcd
Aminopyralid	0.07	98 a	44 a	82 bc	23 cd
Aminopyralid + 2,4-D	0.75 + 0.10	99 a	37 a	93 a	15 d
Metsulfuron	0.01	49 b	44 a	62 d	36 ab
Metsulfuron + 2,4-D + dicamba	0.01 + 0.71 + 0.14	99 a	36 a	76 c	21 cd
Untreated	-------------	0 c	34 a	0 e	41 a

[a] All treatments applied with a non-ionic surfactant at 0.25% v/v.

[b] Means within a column followed by the same letter are not different, $p \leq 0.05$.

Table 3.4. Influence of herbicides and application timings on tall ironweed control one month after treatment (MAT) and density one year after treatment (YAT) over four site-years in Missouri.

		Spring Application		Summer Application	
Treatments[a]	Rate	1MAT	1YAT	1MAT	June Year 2
	---- kg/ha ----	----%visual control ----	---plants m^{-2}---	---%visual control ---	---plants m^{-2}---
2,4-D	1.01	61 d	2.1 b	63 c	1.6 c
2,4-D + dicamba	1.07 + 0.56	69 bc	2.9 b	69 b	3.5 b
2,4-D + picloram	0.57 + 0.15	81 a	0.0 c	78 a	1.9 c
Aminopyralid	0.07	80 a	2.0 b	70 b	2.3 c
Aminopyralid + 2,4-D	0.75 + 0.10	72 b	3.3 b	81 a	3.6 bc
Metsulfuron	0.01	62 d	6.9 a	62 c	6.6 ab
Metsulfuron + 2,4-D + dicamba	0.01 + 0.71 + 0.14	64 cd	7.1 a	69 b	6.9 ab
Untreated	--------------	0 e	7.3 a	0 d	9.3 a

[a] All treatments applied with a non-ionic surfactant at 0.25% v/v.

[b] Means within a column followed by the same letter are not different, p≤0.05.

Table 3.5. Influence of herbicides and application timings on total biomass yields over four site-years in Missouri.

		Spring Application			Summer Application	
Treatments[a]	Rate	June	October	YAT	October	June Year 2
	---- kg/ha ----	---------------------------------- kg/ha[b] ----------------------------------				
2,4-D	1.01	2037 ab	3177 ab	2266 a	3043 bc	2282 ab
2,4-D + dicamba	1.07 + 0.56	1816 b	3247 a	1984 ab	3208 abc	2193 ab
2,4-D + picloram	0.57 + 0.15	1931 ab	3271 a	2133 ab	2996 c	2287 ab
Aminopyralid	0.07	1934 ab	3432 a	2279 a	3435 a	2242 ab
Aminopyralid + 2,4-D	0.75 + 0.10	1944 a	3268 a	2028 ab	3170 abc	2182 ab
Metsulfuron	0.01	1891 ab	3234 a	1940 ab	3178 abc	2168 ab
Metsulfuron + 2,4-D + dicamba	0.01 + 0.71 + 0.14	1779 b	3423 a	1817 b	3090 abc	2109 b
Untreated	-------------	2218 a	2796 b	2310 a	3384 ab	2508 a

[a] All treatments applied with a non-ionic surfactant at 0.25% v/v.

[b] Means within a column followed by the same letter are not different, $p \leq 0.05$.

Table 3.6. Influence of herbicides and application timings on total biomass crude protein (CP) concentration over four-site years in Missouri.

		Spring Application			Summer Application	
Treatments[a]	Rate	June	October	YAT	October	June Year 2
	---- kg/ha ----	---------- %CP[b] ----------				
2,4-D	1.01	8.8 ab	10.3 a	8.0 ab	10.6 a	8.5 ab
2,4-D + dicamba	1.07 + 0.56	8.5 ab	9.8 abc	7.7 ab	10.4 a	7.7 c
2,4-D + picloram	0.57 + 0.15	8.5 ab	10.2 a	8.1 ab	10.6 a	8.2 abc
Aminopyralid	0.07	8.7 ab	9.8 abc	7.9 ab	10.3 a	7.6 c
Aminopyralid + 2,4-D	0.75 + 0.10	8.0 b	10.3 a	7.4 b	10.6 a	7.6 c
Metsulfuron	0.01	9.1 a	9.4 bc	8.1 ab	9.9 a	8.3 abc
Metsulfuron + 2,4-D + dicamba	0.01 + 0.71 + 0.14	8.7 ab	9.2 c	8.3 ab	9.8 a	7.8 bc
Untreated	-------------	9.0 a	10.1 ab	8.3 a	9.9 a	8.6 a

[a] All treatments applied with a non-ionic surfactant at 0.25% v/v.

[b] Means within a column followed by the same letter are not different, $p \leq 0.05$.

Table 3.7. Influence of herbicides and application timings on total biomass relative feed value (RFV) over four site-years in Missouri.

		Spring Application	Summer Application
Treatments[a]	Rate	All Harvest	All Harvest
	---- kg/ha ----	-------------------- RFV[b]	--------------------
2,4-D	1.01	97.7 ab	97.7 ab
2,4-D + dicamba	1.07 + 0.56	93.1 c	96.0 b
2,4-D + picloram	0.57 + 0.15	95.6 b	99.2 a
Aminopyralid	0.07	93.9 bc	95.7 b
Aminopyralid + 2,4-D	0.75 + 0.10	92.4 c	96.3 b
Metsulfuron	0.01	95.7 b	99.0 a
Metsulfuron + 2,4-D + dicamba	0.01 + 0.71 + 0.14	95.6 b	95.6 b
Untreated	-------------	99.3 a	99.2 a

[a] All treatments applied with a non-ionic surfactant at 0.25% v/v.
[b] Means within a column followed by the same letter are not different, $p \leq 0.05$.

Table 3.8. Influence of herbicides and application timings on forage nutritive values of pure samples of tall fescue, common ragweed, tall ironweed, and white clover over four site-years in Missouri.

	Crude Protein			Relative Feed Value		
Species	June	October	June Year 2	June	October	June Year 2
	--------------CP%[a] --------------			--------------RFV[a] --------------		
Tall Fescue	7.6	16.9	7.8	87.2	140.7	97.9
White Clover	14.6	N/A[b]	14.6	168.2	N/A[b]	147.4
Common Ragweed	15.2	13.0	19.6	214.2	144.2	220.8
Tall Ironweed	10.5	7.1	12.5	149.8	139.2	165.4

[a] Data combined across locations for each harvest.
[b] White Clover was not present during October harvest.

Chapter IV

Influence of Increasing Common Ragweed (*Ambrosia artemisiifolia* L.) and Common Cocklebur (*Xanthium strumarium* L.) Densities on Forage Nutritive Value and Yield in Tall Fescue (*Lolium arundinacea* (Schreb.) Darbysh.) Pastures and Hayfields.

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Abstract

Separate field trials were conducted in 2007 and 2008 to investigate the effects of increasing common ragweed or common cocklebur densities on total yield and forage nutritive values in tall fescue [*Lolium arundinacea* (Schreb.) Darbysh.] pastures. Common ragweed densities ranged from 0 to 188 plants m^{-2} and common cocklebur densities ranged from 0 to 134 plants m^{-2}. Total plant biomass yields (weeds + tall fescue) were determined in response to each weed density and species; pure samples of tall fescue, common ragweed or common cocklebur were also hand collected from each plot at the time of the total biomass harvest. NIR spectroscopy was used to predict crude protein (CP) and in vitro true digestibility (IVTD) of the total harvested biomass, pure tall fescue, and pure weed species in each plot. Results indicate that biomass yield is likely to increase from 1 to 6 kg ha^{-1} as common ragweed or common cocklebur density increase within a tall fescue stand. Additionally, CP of the total harvested biomass, pure weed species, and tall fescue decreased by as much as 0.4 g kg^{-1}as common cocklebur or common ragweed density increased. Pure tall fescue IVTD increased minimally (0.01%) as weed densities increased, regardless of the weed species. Overall, results from these experiments indicate that plant biomass yield and nutritive values of total harvested biomass are only marginally influenced by increasing in weed densities. Additional research is necessary to

understand why these species are not consumed by cattle and continue to be significant weed problems in many Missouri pastures and hayfields.

INTRODUCTION

Currently, pasturelands occupy about 4.3 million ha, or 24% of the total land area in the state of Missouri (USDA, 2007). Tall fescue is one of the most predominant forage utilized within the 753 thousand ha used only for pasture or grazing in Missouri (USDA, 2007). In Missouri or pasture systems, the invasion of weeds represents a significant threat to livestock producers and the environment. Losses from weed and brush infestations on grazing lands throughout the U.S. have been estimated, conservatively, at $2 billion per year (Bovey 1987).

The invasion of weeds in grass pastures or hayfields depends on a variety of factors, most notably plant competition, soil properties and pasture management practices. Many pasture weeds are able to grow much faster and compete with forage grasses, especially when there is no grazing animal present. When pastures have improper soil pH, low nutrient levels, inadequate temperatures or moisture conditions, weed competition is greater, as these conditions favor the emergence, propagation, and growth of weeds (Green and Martin, 1998). Weed infestations can reduce yield and nutritive value of pastures and hayfields (Grekul and Bork, 2004; Gylling and Arnold, 1983). Not only do weeds compete for water and mineral nutrients, they also form a canopy interfering with light interception (Toler et al., 1996).

Common ragweed and common cocklebur are both highly variable annual weed species that can grow in a wide range of soils and moisture conditions (Mitich, 2007a; Mitich, 2007b). Common ragweed is well known in agriculture because of its prevalence in most agronomic crops in the eastern and central parts of the United States (Dickerson and Sweet, 1971). Common cocklebur is a summer annual that is perhaps most known for its prickly cocklebur seedpod.

Both weed species commonly invade tall fescue pastures and hayfields in Missouri and many other parts of the U.S (K. Bradley, personal communication). Common ragweed and common cocklebur can range from highly digestible to unpalatable for ruminant animals, such as cattle. Common ragweed is often consumed by cattle when other desirable forages become scarce, while common cocklebur is likely unpalatable to most ruminant animals (Marten and Anderson, 1975). Common ragweed and common cocklebur become less palatable as they mature to a majority of ruminant animals (Marten and Anderson, 1975) .

Research on how weeds impact forage yields and forage nutritive values has been limited and often conflicting, and the results usually depend on the weed species investigated. Forage nutritive values of pure common ragweed and common cocklebur have been reported to be similar to those of some forage crops (Bosworth et al., 1980; Hoveland et al., 1986; Marten and Anderson, 1975); however, many weed species, including common cocklebur, exhibit yield and palatability limitations; other examples include prickly sida, jimsonweed, horsenettle, field sandbur, giant ragweed, giant foxtail and common cocklebur (Bosworth et al., 1980; Hoveland et al., 1986; Marten and Anderson, 1975).

Although research has been conducted to determine the biomass yield, nutritive value and palatability of common pasture weeds (Bosworth et al. 1980; Bosworth et al. 1985; Fairbairn and Thomas 1959; Marten and Andersen 1975; Marten et al. 1987; Nashiki et al. 2005), much of the published research has been based on pure samples of weed species rather than in mixed stands of tall fescue and weeds as would occur in a typical pasture setting. Marten and Anderson (1975) found the nutritional values for pure samples of common ragweed and common cocklebur harvested at early stages of growth were comparable to alfalfa forage when analyzed for in vitro digestible dry matter (IVDDM), acid detergent fiber (ADF), acid detergent lignin (ADL) and crude protein (CP) content. However, in palatability grazing experiments, the majority of grazing sheep refused to consume common ragweed or common cocklebur plants (Marten and Anderson, 1975). Marten and Anderson (1975) therefore concluded the lack of palatability of common cocklebur and common ragweed must be exclusively associated with some unknown chemical or physical feature.

Shelley et al. (2000) found that biomass yields increased as herbicide treatments were applied to reduce spotted knapweed. Whereas, Lym and Messersmith (1985) found that biomass yields did not increase in response to herbicide treatments that provided good control of leafy spurge. In addition, Moyer (1984) reported biomass yields did not increase as herbicide treatments were applied to reduce dandelion populations and Bergen et al. (1990) found dandelion was highly palatable and utilized as readily as orchardgrass, brome grass and Kentucky bluegrass forages to grazing cattle. Conversely, Seefeldt et al. (2005) found that musk and bull thistle infestations in pastures reduced the amount of forage utilized by 42 and 72%, respectively. Canada thistle density and biomass will predict herbage yield loss (Grekul and Bork, 2004).

A better understanding of the impacts of specific weed species and densities on the overall biomass yield and nutritive values of a forage stand will assist in establishing and understanding the concept of weed removal thresholds in a pasture or hayfield environment. Although common in row crop agricultural settings, density thresholds have rarely been utilized or considered in grass pastures or hayfields. Many research trials have evaluated the impacts of increasing densities of row crop weed species. For example, in soybeans, high densities (one plant per m of row) of common cocklebur reduced soybean yield by 25 to 42% (Tranel et al., 2003). Similarly, Coble et al., (1981) found that four common ragweed plants per 10 m of row decreased soybean yield by 8%. The impacts of specific weed species and densities simply have not been determined in a grass pasture or hayfield.

The objectives of this research were to determine the effects of increasing densities of common ragweed and common cocklebur on total harvested biomass yield and nutritive value in a tall fescue pasture. Additionally, this research was conducted to evaluate the effects of increasing densities of common ragweed and common cocklebur on the nutritive value of pure samples of these respective weed species, as well as tall fescue itself, which to our knowledge has not been investigated in previous research.

MATERIALS AND METHODS

Three experiments were conducted at the University of Missouri Turkey Research Farm near Columbia, Missouri during 2007 and 2008. Experimental plots were established in predominately tall fescue pastures with minimal weed presence. In late-March, 0.21 kg paraquat ha^{-1} (approximately half-rate) was applied to the entire experimental area to slow the growth of tall fescue and allow for the establishment of common ragweed and common cocklebur seedlings. One week after paraquat application (early April), common cocklebur and common ragweed seed were spread evenly in each 3 m by 12 m plot with a 1 m alley separating adjacent plots. Increasing densities of common ragweed seed were spread using a drop spreader while common cocklebur seed were hand-sown. Prior to and after seeding, the entire area was rotary hoed to allow seeds to establish soil contact for germination. In all experiments, weed densities were arranged in a randomized complete block design with five replications. In both years, all plots were maintained free of weeds other than common ragweed or common cocklebur by hand removal or by hand sponging high volume glyphosate or 2,4-D concentrations on unwanted species.

Prior to spring harvest in each trial, actual common ragweed or common cocklebur densities were determined by counting all plants in two random ½ m^2 quadrats in each plot. Expected and actual densities of common ragweed or common cocklebur are listed in Tables 4.1 and 4.2, respectively.

Following total biomass harvest approximately 100 grams of pure tall fescue and common ragweed or common cocklebur (depending on the trial) were collected from each individual plot for subsequent forage nutritive value analysis. Total biomass harvests were conducted by harvesting two, 1 by 12 m strips from the center of each plot with a Carter forage harvester[1]. One biomass harvest occurred in mid-to late-July for each trial when tall fescue reached approximately 30 to 40 cm tall. The common ragweed trials were harvested on July 2, July 10, and August 5 for the 2007, 2008a, and 2008b experiments, respectively. The common cocklebur trials were harvested on July 13, July 11, and July 17 for the 2007, 2008a and 2008b experiments, respectively. Four subsamples from the total biomass harvest were taken from each plot; two subsamples were placed in a forced-air oven for 48 hours at 37°C to determine dry matter content of the total harvested biomass. The remaining subsamples as well as pure samples of tall fescue, common ragweed or common cocklebur were placed in a freeze dryer for 14 days at -10 °C and then ground through a cyclone mill[2] to pass a 1-mm screen. In vitro true digestibility (IVTD) was determined using a Daisy^{II} Incubator and ANKOM 200 Fiber Analyzer[3]. IVTD was determined by running a 48-h in vitro digestion in the Daisy^{II} Incubator followed by washing with a NDF solution in the fiber analyzer (Spanghero et al., 2003). Ruminal fluid was collected from a cannulated cow offered a forage-based diet. A Leco True Spec N

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[1] Carter Forage Harvester, 896 East Carter Court, Brookston, IN 47923
[2] Udy Corporation, 201 Rome Court, Ft. Collins, CO 80524
[3] ANKOM Technology, 2052 O'Neil Road, Macedon, NY 14502

analyzer[4] was used to determine the total amount of nitrogen in each sample; the total N concentration was then multiplied by 6.25 to determine the total CP for each sample.

All ground samples were analyzed by NIR spectroscopy using the methods described by Westerhaus et al. (2004). Optimum calibration equations (Table 4.3) were based on high coefficients of determination and low standard errors calculated during regression and cross-validation. Validated equations were used to predict CP and IVTD of the total harvested biomass, pure tall fescue, and pure weed species in each plot.

Data were subjected to analysis of variance (ANOVA) and regression analysis (PROC REG) using SAS[5] statistical software. Main effects and interactions were considered significant when $P < 0.05$. When the F-test was significant ($P < 0.05$), means were separated using Fisher's protected LSD. The regression equations developed were used to plot the influence of increasing common ragweed or common cocklebur densities on total biomass yield and nutritive values.

RESULTS AND DISCUSSION

Yield

Total biomass yield increased in the 2007 common ragweed density trial but not in any of the 2008 common ragweed trials (Table 4.4). The yield response in 2007 resulted in a quadratic relationship. Total biomass yields increased initially as common ragweed densities increased (Figure 4.1A), and the response remained linear until common ragweed densities reached 65 plants per m^2. Over the linear phase, each increase in common ragweed per m^2 resulting in a 6 kg ha^{-1} increase in total biomass yield. Total biomass yield did not increase for common ragweed densities above 65 plants. Biomass yield decreased by 4 kg ha^{-1} for common ragweed densities above 65 plants per m^2.

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[4] Leco Corp., 3000 Lakeview Avenue, St. Joseph, MI 49085

[5] SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513

In all other density trials, total biomass yield was not affected by density of common ragweed or common cocklebur (Table 4.4 and Figure 4.1A,B). This is not to say a long-term negative effect could not eventually occur in areas heavily infested with common ragweed or common cocklebur.

Nutritive Value

Total Biomass with Common Ragweed. In the 2008b trial, total harvested biomass CP increased with increasing ragweed density (Table 4.4; Figure 4.2A). In all other trials, CP was not affected by common ragweed density (Table 4.4; Figure 4.2A).

In all common ragweed trials, the CP value of common ragweed ranged from 75 to 109 g kg^{-1} and was lower than those reported by Marten and Anderson (1975), who reported CP values of 250 to 260 g kg^{-1}. These CP value differences may be due to the mixture of plant species, which included both tall fescue and common ragweed, the data reported by Marten and Anderson (1975) were from pure common ragweed samples only. Also, CP values could be influenced by the common ragweed stage of plant growth (Marten and Anderson 1975). The common ragweed analyzed by Marten and Anderson (1975) was harvested in the early vegetative stage of growth (early July). Therefore increased CP concentration of the total harvested biomass may be attributed to harvesting common ragweed at relatively high nutritive stages of growth. For all harvest tall fescue height and stage of growth were similar therefore tall fescue maturity is likely not significantly influencing the total biomass CP concentration.

Total biomass IVTD was affected by common ragweed density for the 2008b trial (Figure 4.3A). A quadratic relationship best described this response (Table 4.4). In this trial, the IVTD value was greatest with common ragweed densities of 100 plants per m^2. The IVTD of the total harvested biomass decreased (0.01 to 0.03%) for common ragweed densities above and below 100 plants per m^2.

In all other common ragweed trials, IVTD of the total biomass was not affected by common ragweed density (Table 4.4). All three trials, however, provided IVTD values adequate for maintenance of ruminant animals and were similar to results illustrated by Marten et al. (1987).

Total Biomass with Common Cocklebur. The CP of total biomass was not affected by common cocklebur densities, regardless of the trial (Table 4.4). The total biomass harvested in this research consisted of common cocklebur densities ranging from 0 to 134 plants per m^2. The CP values within this range of common cocklebur densities resulted in a slight change in CP concentration (less than 0.2 g kg^{-1}) for a one plant per m^2 density increase.

Regardless of the trial, IVTD of the total harvested biomass was not affected by common cocklebur density (Table 4.4 and Figure 4.3B). Digestibility values of 60% or higher are considered good and should be satisfactory for growing cattle, while values of 50% or less are unsatisfactory (Marten et al., 1987). In this research, IVTD values from all trials exceeded 60% (Figure 4.3A,B). Therefore, according to Marten et al. (1987), the weed species and range of plant densities in this research meets requirements for adequate forage digestibility in most ruminant animals.

Pure samples. The CP of pure tall fescue was not affected by common ragweed density (Table 4.5, Figure 4.4A) in any of the trials. However, CP concentration of pure common ragweed decreased (0.1 to 0.2 g kg^{-1}) as common ragweed density increased in the 2007 and 2008b trials (Table 4.6A). In both trials, the response was linear (Table 4.5).

Unlike CP concentration of the total biomass harvest, pure common ragweed nutritive value and other plant processes are likely impacted by photosynthetic activity. Additionally, tall fescue and the weed species are likely competing for available N in the soil. Insufficient N available to the plants may result in lower CP concentrations.

In 2007, tall fescue IVTD decreased as common ragweed density increased (Figure 4.5A). In the 2008a trial, tall fescue IVTD increased with increasing common ragweed density (Figure 4.5A). The reason for the inverse response is unclear. The 2008b trial tall fescue IVTD was not affected by increasing common ragweed density (Table 4.5).

In all trials, IVTD of pure common ragweed was not affected by common ragweed density (Table 4.5). Although there was a trend towards slight reductions for IVTD in pure samples of common ragweed as density increased.

The CP of pure tall fescue decreased as common cocklebur density increased in the 2007 and 2008a common cocklebur trials by 0.4 and 0.2 g kg^{-1}, respectively (Table 4.4B). In both trials a negative linear relationship was observed (Table 4.5).

The response of tall fescue to increasing densities of common cocklebur may be due to shading effects and the inability of tall fescue to attenuate light. In addition, shading may restrict N plant uptake from internal substrates such as plant roots and the competitive ability for nutrients can become limited (Hodgson and Blackman 1957). These results indicate that tall fescue becomes restricted as common cocklebur densities increase due to the competitive ability of the weed species, especially in this case the larger-leafed common cocklebur. The overall decrease in tall fescue plant production is likely caused by common cocklebur's ability to capture more energy from light. Therefore the CP and IVTD of the tall fescue grass can decrease as weed densities increase.

The CP concentration of pure common cocklebur was not significantly affected by common cocklebur density (Table 4.5, Figure 4.6B). However, overall trends were similar to the response observed to pure common ragweed CP; as common cocklebur density increased a minimal (0.2%) decrease in pure common cocklebur CP was observed. In addition, IVTD of tall fescue or common cocklebur were not affected by common cocklebur density (Table 4.5). Although IVTD for pure samples of common ragweed and common cocklebur were not significantly affected, a general trend towards reductions in pure sample IVTD as weed densities increased was observed (Figure 4.7A,B).

CONCLUSIONS

Total biomass yield is likely to increase as weed densities increase or a greater total plant presence (weed and grass combined) is established. However, in this research only in the 2007 common ragweed trial was yield affected as common ragweed density increased. The CP and IVTD of the total biomass can be impacted by the individual nutritive values of tall fescue, common ragweed or common cocklebur as densities increase. In the 2008b common ragweed trial, CP and IVTD of the total biomass was affected by increased common ragweed density; CP and IVTD values increased as density increased. In most cases, CP of pure tall fescue will slightly decrease as the weed density is increased. The IVTD of pure tall fescue will equalize or be lower in IVTD values than pure weed species as common ragweed or common cocklebur densities increase.

The CP concentration of pure common ragweed or common cocklebur will decrease as densities are increased. For both pure weed species, IVTD is not affected by weed density. The IVTD values of pure common ragweed or common cocklebur are not as easily impacted as CP concentrations in response to increased weed density. As a result of this research we can suggest that IVTD values are better indicators of plant maturity and plant digestibility in the animal's rumen and CP is based upon properties available to the plant. The IVTD values may be impacted more over time or the plant's stage of maturity. These results indicate that nutritive value will not significantly decrease in response to lower densities of common ragweed and common cocklebur in tall fescue pastures and hayfields.

These experiments indicate that yield and nutritive value of the total harvested biomass were only marginally impacted by elevated weed densities. In addition, according to Marten et al. (1987), adequate forage digestibility was achieved with the range of plant densities in this research. The IVTD values in all trials surpass requirements for adequate forage digestibility in most ruminant animals. The pure common ragweed or common cocklebur and tall fescue present within the pasture or hayfield setting can decrease in CP and IVTD as weed densities increase. Given the relatively high IVTD values of pure common ragweed and common cocklebur, additional research is necessary to determine what impacts these respected weed species have on the palatability of the total biomass at various stages of maturity as fed to ruminant animals such as cattle.

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Table 4.1. Comparison of expected and actual densities of common ragweed at each harvest.

Treatment	Treatment Name	Expected Plants/m^2	Actual Plants/m^{2a}		
			2007	2008a	2008b
1	Weed Free Check	0	0	0	0
2	1X Ragweed Density	8	4	25	11
3	2X Ragweed Density	16	7	37	28
4	4X Ragweed Density	32	11	46	52
5	8X Ragweed Density	64	17	60	77
6	16X Ragweed Density	128	27	74	111
7	32X Ragweed Density	256	44	88	143
8	64X Ragweed Density	512	132	137	188

[a] Average of 10 density observations.

Table 4.2. Comparison of expected and actual densities of common cocklebur at each harvest.

Treatment	Treatment Name	Expected Plants/m^2	Actual Plants/m^{2a}		
			2007	2008a	2008b
1	Weed Free Check	0	0	0	0
2	1X Cocklebur Density	8	5	4	12
3	2X Cocklebur Density	16	7	7	24
4	4X Cocklebur Density	32	11	14	46
5	8X Cocklebur Density	64	16	28	73
6	16X Cocklebur Density	128	50	41	134
7	32X Cocklebur Density	256	--	80	--

[a] Average of 10 density observations.

Table 4.3

Near-infrared reflectance spectroscopy calibration and validation statistics for CP and IVTD in 2007.

Constituent	n	R^2	Mean	SEC	SECV	1-VR
			--------------g kg^{-1} dm	--------------		
IVTD	77	0.96	806.0	14.0	20.0	0.90
CP	77	0.97	102.0	2.9	5.0	0.92

SEC= Standard Error of calibration

SECV=Standard Error of cross-validation in modified partial least squares regression

R^2= Coefficient of determination for calibration

1-VR= 1 minus the variance ratio calculated in cross-validation during modified partial least squares regression

Near-infrared reflectance spectroscopy calibration and validation statistics for CP and IVTD in 2008a.

Constituent	n	R^2	Mean	SEC	SECV	1-VR
			--------------g kg^{-1} dm	--------------		
IVTD	91	0.95	785.2	19.9	25.6	0.92
CP	91	0.95	110.4	5.3	7.0	0.92

SEC= Standard Error of calibration

SECV=Standard Error of cross-validation in modified partial least squares regression

R^2= Coefficient of determination for calibration

1-VR= 1 minus the variance ratio calculated in cross-validation during modified partial least squares regression

Near-infrared reflectance spectroscopy calibration and validation statistics for CP and IVTD in 2008b.

Constituent	n	R^2	Mean	SEC	SECV	1-VR
			--------------g kg^{-1} dm	--------------		
IVTD	76	0.94	757.9	14.1	17.0	0.92
CP	77	0.99	98.5	2.3	3.0	0.98

SEC= Standard Error of calibration

SECV=Standard Error of cross-validation in modified partial least squares regression

R^2= Coefficient of determination for calibration

1-VR= 1 minus the variance ratio calculated in cross-validation during modified partial least squares regression

Table 4.4. Influence of increasing densities of common ragweed (AMBEL) or common cocklebur (XANST) on total biomass yield and nutritional values.

		Total Biomass Harvest					
Source	Weed	Yield[a]	p[b]	CP[a]	p[b]	IVTD[a]	p[b]
2007	AMBEL	$1128+13x-0.1x^2$	* (0.02)	$102+0.1x-0.001x^2$	NS (0.34)	$77+0.02x$	NS (0.07)
2008a	AMBEL	$2617-0.8x$	NS (0.68)	$89+0.1x$	NS (0.18)	$69-0.02x+0.0001x^2$	NS (0.58)
2008b	AMBEL	$2916+1x$	NS (0.11)	$78+0.03x$	* (0.03)	$70+0.03x-0.0001x^2$	* (0.04)
2007	XANST	$1002+20x-0.5x^2$	NS (0.11)	$101-0.2x$	NS (0.08)	$76+0.1x$	NS (0.11)
2008a	XANST	$1694+3x-0.03x^2$	NS (0.72)	$95-0.1x+0.002x^2$	NS (0.22)	$75+0.02x$	NS (0.13)
2008b	XANST	$1932-0.8x$	NS (0.32)	$95-0.1x+0.0008x^2$	NS (0.35)	$72+0.01x$	NS (0.26)

[a] Means are presented for equation intercepts and slope.

[b] Correlations were either not significant (NS) or significantly different at $P < 0.05$ (*). Values in parentheses are actual P values.

Table 4.5. Influence of increasing densities of common ragweed (AMBEL) or common cocklebur (XANST) on pure tall fescue or pure weed species CP and IVTD.

		Pure Tall Fescue				Pure Weed Species			
Source	Weed	CP[a]	p[b]	IVTD[a]	p[b]	CP[a]	p[b]	IVTD[a]	p[b]
2007	AMBEL	$96-0.1x$	NS (0.11)	$80-0.02x$	* (0.02)	$123-0.2x$	* (0.01)	$90-0.01x$	NS (0.09)
2008a	AMBEL	$86-0.03x$	NS (0.45)	$75+0.02x$	* (0.05)	$156-0.1x$	NS (0.06)	$86-0.003x$	NS (0.84)
2008b	AMBEL	$71+0.03x-0.0002x^2$	NS (0.78)	$75+0.01x$	NS (0.14)	$127-0.1x$	* (0.03)	$81+0.02x-0.0001x^2$	NS (0.73)
2007	XANST	$101-0.4x$	* (0.01)	$79-0.04x$	NS (0.07)	$110.2+2x-0.04x^2$	NS (0.24)	$90-0.1x+0.002x^2$	NS (0.52)
2008a	XANST	$76-0.2x$	* (0.02)	$82+0.01x$	NS (0.36)	$121-0.2x$	NS (0.31)	$91+0.01x$	NS (0.57)
2008b	XANST	$84+0.4x-0.004x^2$	NS (0.33)	$78+0.01x$	NS (0.35)	$117-0.04x$	NS (0.31)	$90-0.01x$	NS (0.56)

[a] Means are presented for equation intercepts and slope.

[b] Correlations were either not significant (NS) or significantly different at $P < 0.05$ (*). Values in parentheses are actual P values.

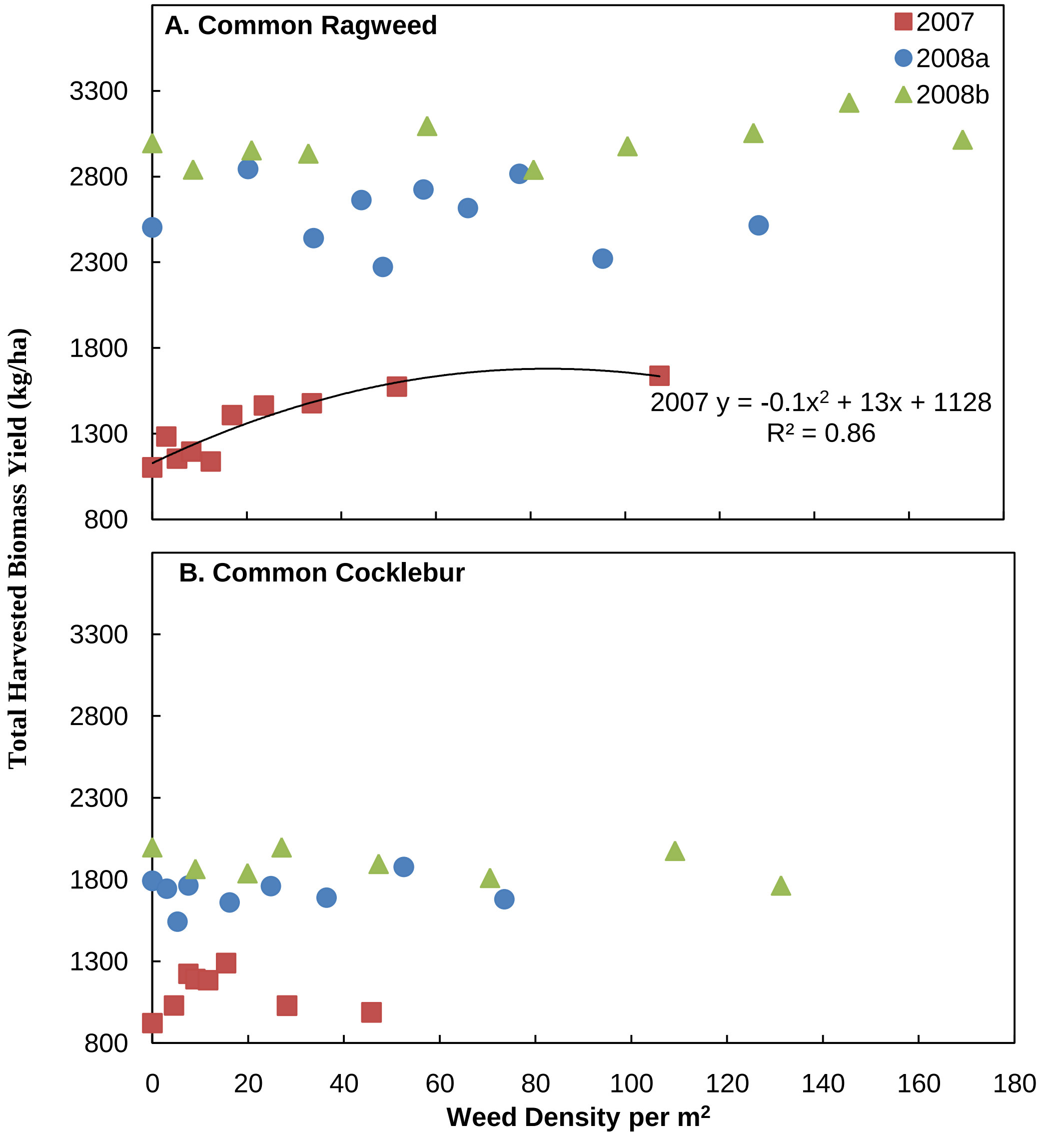

Figure 4.1 Influence of increasing common ragweed (A) and common cocklebur (B) densities on total yield of the total harvested biomass.

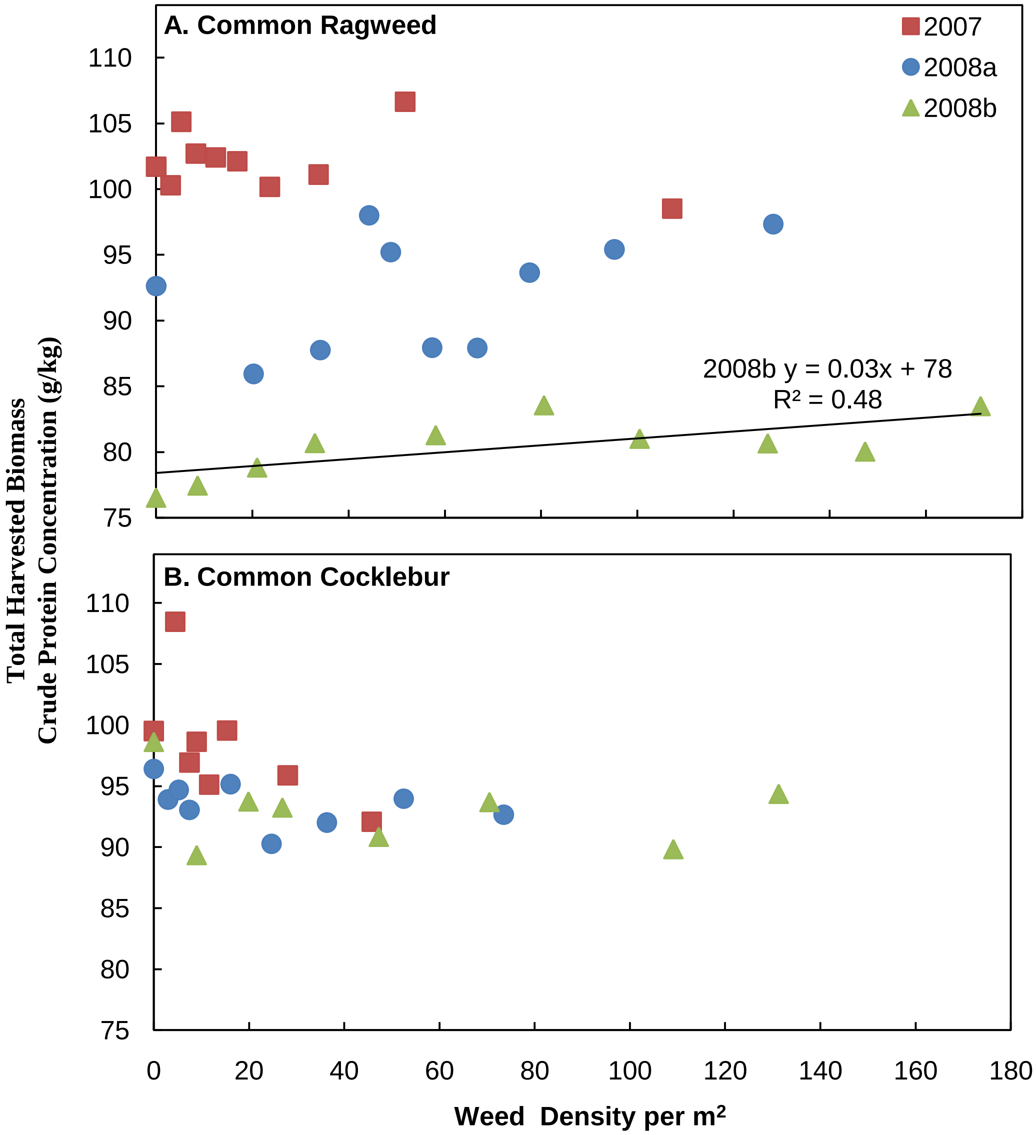

Figure 4.2 Influence of increasing common ragweed (A) and common cocklebur (B) densities on crude protein concentrations of the total harvested biomass.

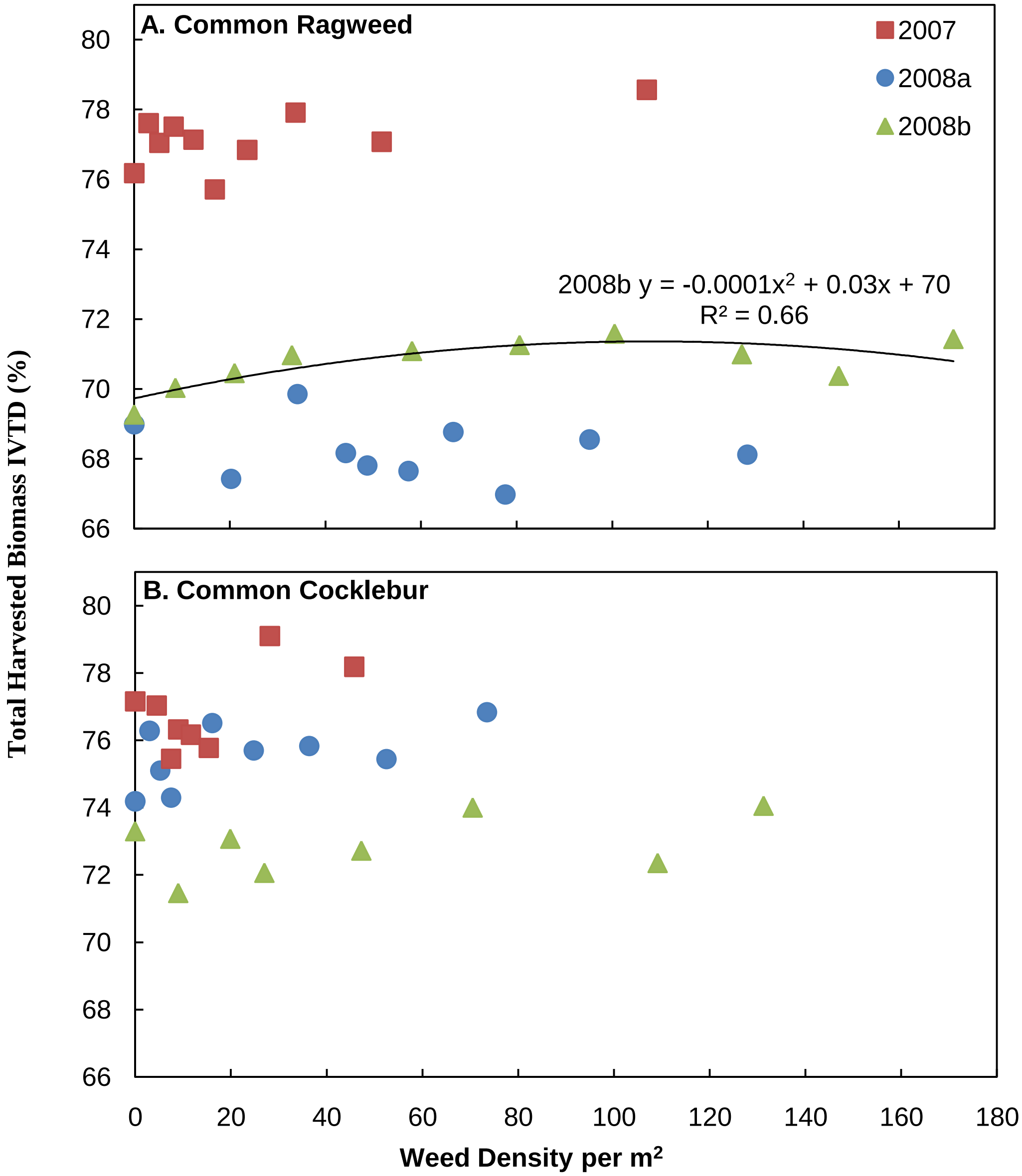

Figure 4.3 Influence of increasing common ragweed (A) and common cocklebur (B) densities on in vitro true digestibility of the total harvested biomass.

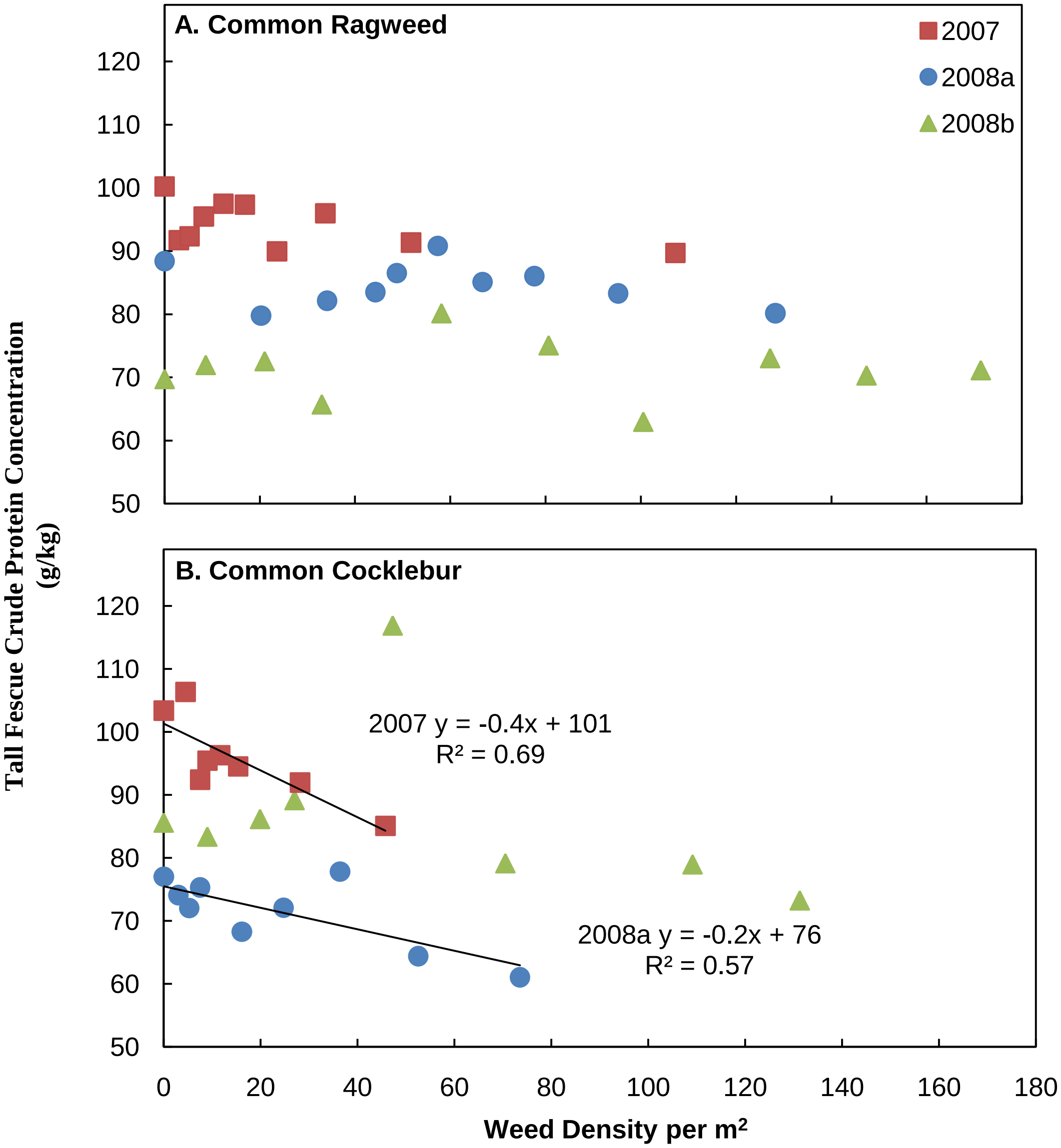

Figure 4.4 Influence of increasing common ragweed (A) and common cocklebur (B) densities on crude protein concentration of pure samples of tall fescue.

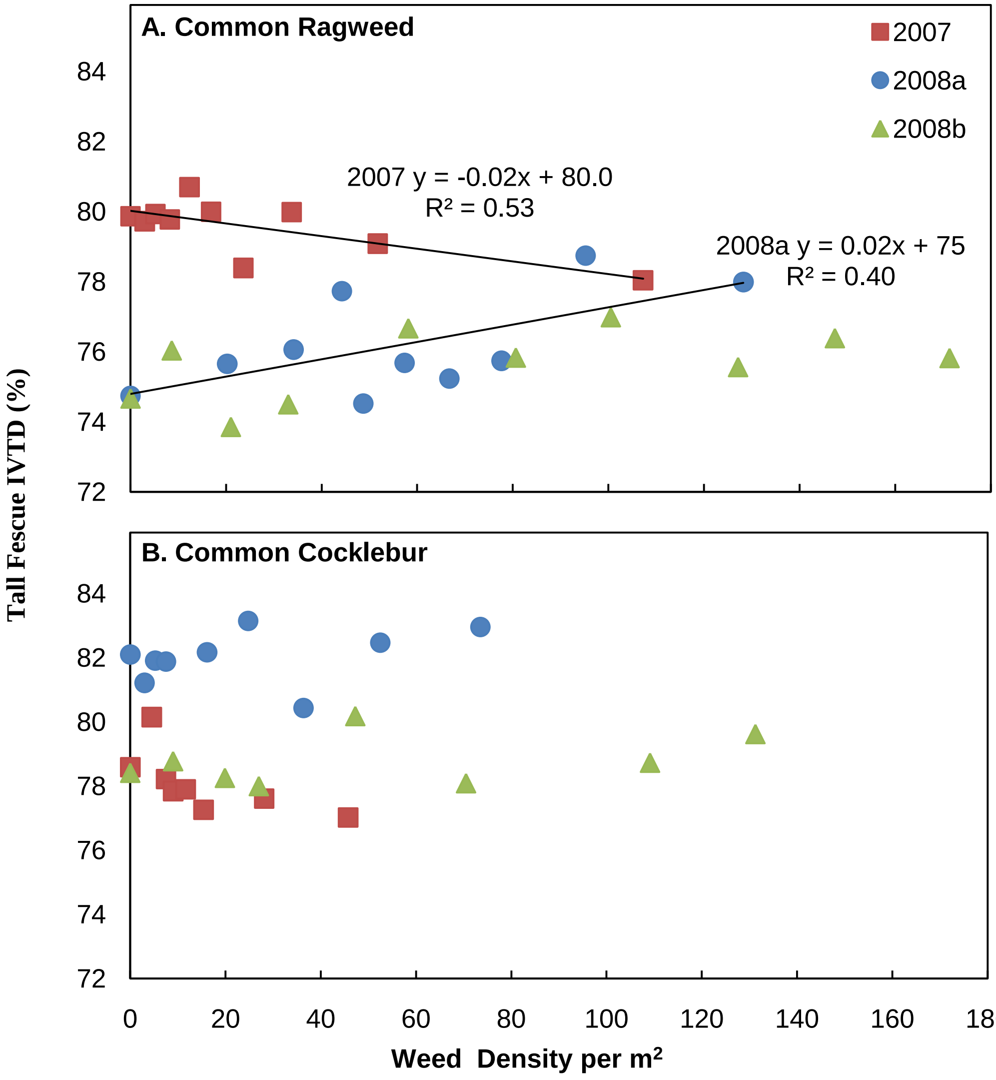

Figure 4.5 Influence of increasing common ragweed (A) and common cocklebur (B) densities on in vitro true digestibility of pure samples of tall fescue.

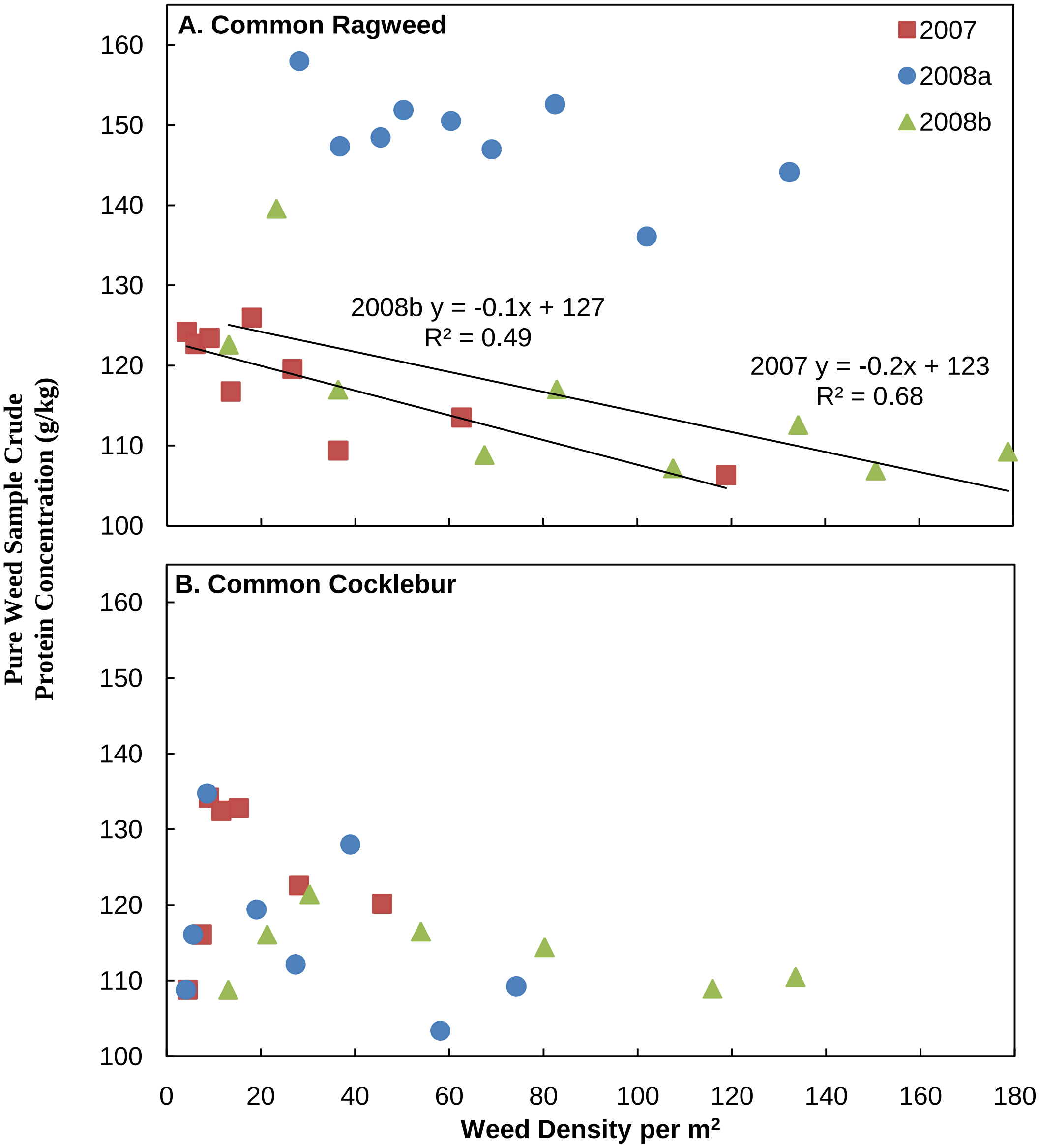

Figure 4.6 Influence of increasing common ragweed (A) and common cocklebur (B) densities on crude protein concentration of pure samples of each respective weed species.

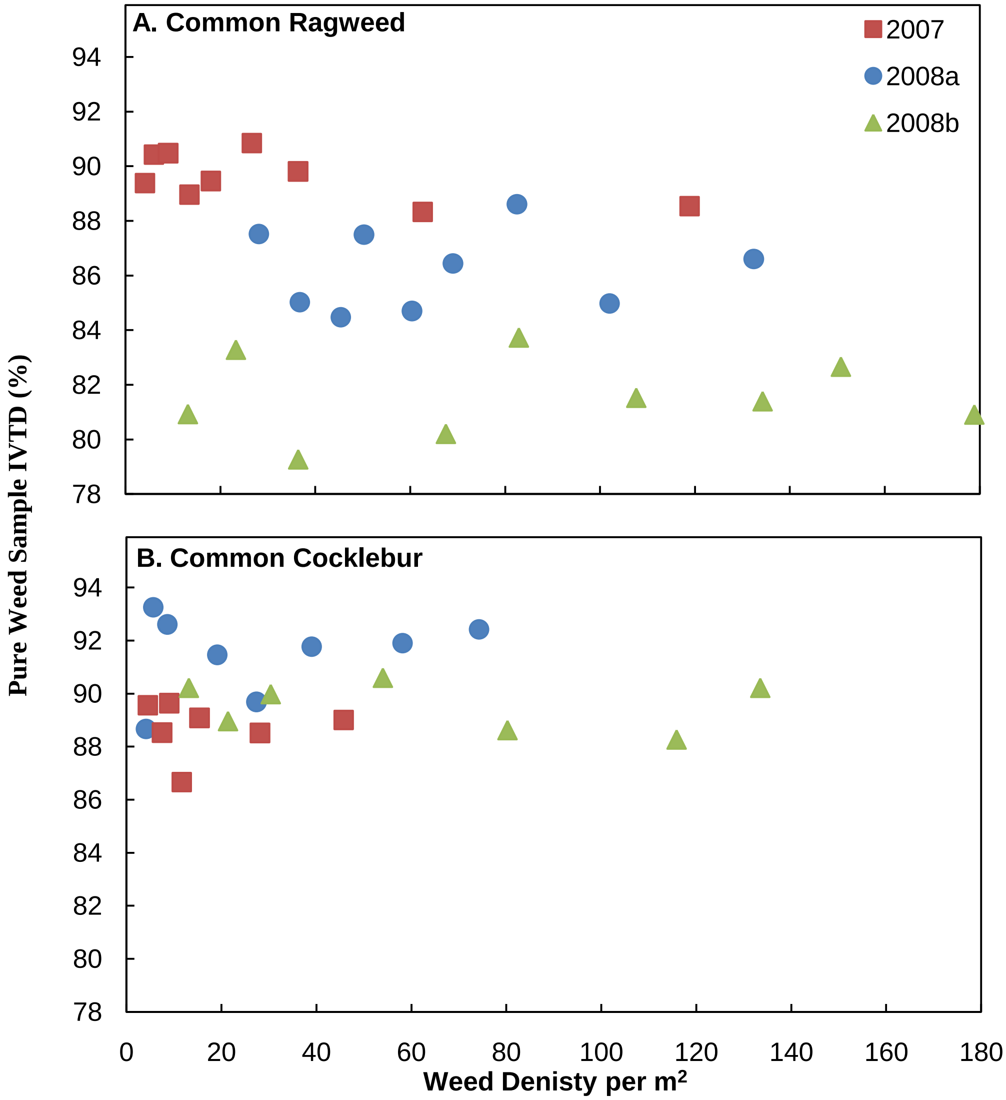

Figure 4.7 Influence of increasing common ragweed (A) and common cocklebur (B) densities on in vitro true digestibility of pure samples of each respective weed species.