Investigations of the Forage Nutritive Value of Common Weeds Encountered in Missouri Pastures and Their Relationships with Soil Fertility

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By

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The undersigned, appointed by the dean of the Graduate School, have examined the

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A candidate for the degree of

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And hereby certify that, in their opinion, it is worthy of acceptance.

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Abstract

During the 2015, 2016, and 2017 growing seasons, a survey of 63 pastures in Missouri was conducted to determine the effects of selected soil and forage parameters on the density of common annual, biennial, and perennial weed species. Permanent sampling areas were established in each pasture at a frequency of one representative 20-m^2 area per 4 ha of pasture and weed species and density in each area was determined at 14-day intervals from a period from mid-April until late September. The parameters evaluated included soil pH, phosphorous (P), potassium (K), magnesium (Mg), calcium (C), sulfur (S), zinc (Zn), manganese (Mn), and copper (Cu) concentration, as well as tall fescue density, forage ground cover density, and stocking rate. An increase of one unit in soil pH was associated with 146 fewer weeds per hectare, the largest reduction in weed density in response to any soil parameter. Common ragweed, a widespread weed of pastures, could be reduced by 3,056 weeds per hectare when soil pH was one unit greater. Additionally, weed and weed-free mixed tall fescue and legume forage samples were harvested from 29 of the surveyed pastures in order to investigate the nutritive value of 20 common pasture weed species throughout the season. Sample collections occurred at 14-day intervals coinciding with the survey during each growing season. At certain times during the growing season many broadleaf weed species had greater nutritive values for a given quality parameter as compared to the available weed-free, mixed tall fescue and legume forage harvested from the same location.

Chapter I

Literature Review

Introduction

Forage production on pasturelands account for 2.8 million hectares in Missouri. Approximately 25% of farmland in Missouri is dedicated to pastures (USDA ERS 2017), and the state has an inventory of 2.1 million beef cattle (NASS 2018). The primary source of feed for these animals is forage from pasture and stored forage from haylands.

Tall fescue (*Schedonorus arundinaceus* Schreb.) is the dominant forage species in pastures in Missouri and throughout the eastern United States (Glenn et. al. 1981). Although tall fescue is widely grown for its competitiveness and drought tolerance, cattle performance on tall fescue is often poor or reduced during summer months (Henning et. al. 1993; Wen 2001). Many pastures are grown in mixtures with legumes, primarily clovers (*Trifolium* spp.) to increase yield and feed quality (Phelan et. al. 2015). Legumes in a tall fescue pasture system provide nitrogen and increase forage availability in summer months when fescue productivity declines (Henning et. al. 1993).

Weed control in mixed grass and legume pastures is difficult with herbicides. Most herbicides labeled in pastures are synthetic auxins that have selective activity on broadleaf weeds and plants but are safe on grasses. As a result, applications of these herbicides in mixed grass and legume pastures will result in legume injury or death and decline in the forage system. Many pasture producers are hesitant to apply herbicides for weed control in order to preserve the legume presence in the field (McCurdy 2013), which often leads to infestations of problematic annual and perennial weed species. Some weed species are eaten, especially during the early vegetative stages of growth

(Harrington 2006). Because weeds can be eaten and account for some portion of the cattle diet, it is important to determine the value or detriment weeds may provide to a forage system and the factors that lead to weed presence in pastures.

Grazing Management and Weeds

Livestock are used to produce food or fiber but are rarely utilized as weed control agents (Popay and Field 1996). However, cattle that graze pastures are likely to ingest weeds while consuming other forage. Grazing management strategies can be integral to the incidence and severity of weed species in pastures. Overgrazing can encourage the spread of weeds in pastures (Olsen 1999). Bailey (1995) found that cattle in pastures with a heterogeneous mix of plant species preferred areas with greater crude protein. In pastures that are more homogenous, cattle generally show no preference for grazing areas. Sather et al. (2013) showed that cattle distribution in herbicide-treated portions of pasture was 1.5 to 4.9 times greater than in non-treated areas. In the presence of weeds, cattle movement and grazing may differ and forage utilization may be reduced (Sather et. al. 2013).

With proper grazing management, weed encroachment into forage systems can be avoided (DiTomaso 2000). Common grazing management strategies used in Missouri include continuous, rotational, and management intensive grazing (Pfost et. al. 2000). Continuous grazing is a common grazing strategy used throughout much of the United States and requires few inputs and little management (Bertelsen et. al. 1993). In a continuous grazing system, animals graze over the entire pasture with consistent accessibility to all areas. Because animals are not moved there are fewer inputs such as fencing and waterers. Some disadvantages include decreased forage production (Jung et.

al. 1985), increased risk of weed infestation, and poor animal productivity (Pfost et. al. 2000). Lack of animal movement across the pasture can also lead to poor manure distribution (Lory et. al. 2006).

Rotational grazing is another common practice in Missouri and throughout the United States. Under this management strategy, cattle are rotated between multiple pastures based on forage utilization. Rotational grazing can reduce overgrazing by increasing the interval between defoliation and regrowth of the pasture (Teague et. al. 2010). Overgrazing can also lead to weed infestations and may leave more resources for weedy species compared to desired forages (Harker et. al. 2000). Forage production can be greater in a rotationally grazed system. Ruane and Raferty (1964) found that a rotational paddock system produced greater forage yields than a continuous system. Manure management can be improved through rotational grazing, but these systems may result in decreased legume prevalence (Pfost et. al. 2000). Rotational grazing systems also require increased management and fencing.

Management intensive grazing utilizes the movement of grazing animals in quick succession through many smaller pasture segments. This approach to grazing management has better utilization of forages, will likely result in fewer weeds, and increases grazing livestock's efficiency and productivity (Henning et. al. 2000). Labor to implement this practice is greater than the other grazing systems and more costs are incurred for fencing and water (Pfost et. al. 2000). Weed infestations in a management intensive system are less severe as weeds are often consumed at regular intervals and in greater quantities than in other systems due to large stocking concentrations on small areas at certain times of the season (Curran and Lingenfelter 2009).

Soil Fertility in Pasture Systems

Maintaining optimum soil fertility and pH is important to maintain healthy stands of forage species. Soil fertility is one of the most important determinants of plant growth (Barker and Collins 2018). Most forage species grow best at a pH of 6.0 (Barnhart et. al. 2013). Soil pH, phosphorus and potassium levels are three of the most important components of soil fertility in grazinglands. Soil pH levels may limit plant growth by reducing nutrient availability and/or nitrogen fixation by rhizobia bacteria on legumes. Low pH or soil acidity is a serious detriment to forage production (Barker and Collins 2018). Forage legumes should not be seeded into fields with a soil pH less than 5.5 (Wheaton and Roberts 1993). Additionally, soil pH should be maintained at 5.8 or greater in order for red clover (*Trifolium pratense L.*) to persist (Henning et. al. 1993)

Phosphorus is the second most limiting nutrient after nitrogen in forage systems (Barker and Collins 2018). Phosphorus is important for stand establishment and legume persistence (Barnhart et. al. 2013). Phosphorus is crucial for legume growth and nitrogen fixation (Barker and Collins 2018). A study by Peters and Lowance (1974) found that applications of fertilizer phosphorus and potassium at 112 kg/ha P_2O_5 and 112 kg/ha K_2O, respectively, resulted in reduced broomsedge (*Andropogon virginicus* L.) cover as compared to the non-treated control.

Potassium is primarily found as a structural component of soils and is unavailable for plant uptake and growth (Kaiser and Rolen 2018). One-tenth to 2 percent of soil potassium is in a plant available form therefore additional applications of potassium may be needed (Bucholz and Brown 1993). Fertilizer applications must be made to minimize losses of plant available soluble and exchangeable potassium that is taken up by the crop

(Barnhart and Collins 2018). The recommended soil potassium level for forages in Missouri is 179 kg/ha (Buchholz et. al. 2004), and potassium availability decreases as soil pH levels drop below 6.0 (Barnhart and Collins 2018).

Livestock-Weed Interactions

Grazing animals can influence weeds in pastures by grazing or avoiding these species. Overgrazing desirable forage species has been implicated in the spread and infestation of weeds (Olsen 1999). Overgrazing can also reduce forage stands. Lym and Messersmith (1985) found that in pastures infested with leafy spurge, forage is lost due to weed competition and avoidance near weed species. Livestock can also influence weed occurrence by moving weed seed throughout the pasture. Livestock can transport weed seed by passing viable consumed weed seeds through their digestive systems or by seed from weeds like cocklebur (*Xanthium strumarium* L.) that attach directly to their hair (DiTomaso 2000). Animals can also influence weed prevalence in pastures by directly grazing or damaging them thereby causing an increase in forage competitiveness (Popay and field 1996). Weed spread in pastures can also be limited by trampling from animal hooves. Due to their growth habit, some weeds are more susceptible to trampling than the desirable forage species. Olsen et. al. (1997) found that oxeye daisy (*Chrysanthemum leucanthemum L.*) was trampled more than forage grasses. Trampling can also cause an increase in weed occurrence via mixing of the upper soil surface (Panetta and Wardle 1992).

A weed in a forage system can only persist if it can compete with the crop. The success of a weed is dependent upon the plant's ability to tolerate or avoid herbivory (Briske 1991). There are multiple strategies to avoid herbivory in a pasture system. These include defense mechanisms such as toxicity, lack of palatability, and spines or thorns (Harington et. al. 2006). Toxic or poisonous plants are found in pastures and pose many risks to grazing animals. There are many poisonous plants found in Missouri including black cherry (*Prunus serotine Ehrh.*), bracken fern (*Pteridium aquilinum (L.) Kuhn),* jimsonweed (*Datura stramonium L.*), nodding spurge (*Chamaesyce nutans Lag.*), perilla mint (*Perilla frutescens L.*), poison hemlock (*Conium maculatum L.*), white snakeroot (*Ageratina altissima (L.) R.M. King & H. Rob. var. altissima)*, and wild indigo (*Baptisia* species). Some plants like johnsongrass (*Sorghum halepense (L.) Pers.*) are poisonous only during certain times of the year or after exposure to certain environmental conditions. (Fishel 2001). A plant can be defined as poisonous based on the toxicity to the animal that consumes it. A poisonous plant is only poisonous and problematic if an animal eats it (James et. al. 1992). Risks associated with poisonous plants include animal death, decreased efficiency, and abortion. Cattle grazing areas infested with poisonous plants should be checked more frequently than areas without poisonous plants for the extent to which they may be grazed (James et. al. 1992). Cattle may not be disposed to consuming poisonous weeds as many species contain chemicals that produce an unpalatable taste.

Weeds may be avoided by cattle because they are unpalatable. Palatability is the collective term for plant characteristics that influence the likelihood that an herbivore will graze or avoid a plant (Olsen 1999). Palatability is influenced by texture, leafiness, fertilization, dung or urine patches, moisture content, pest infestation, or compounds that cause a forage to taste sweet, sour, or salty (Ball et. al. 2001). Upon ingestion, the grazing animal will have a positive or negative experience. In the case of unpalatable plants, the animal will have a negative experience and is less likely to graze the plant in the future (Olsen 1999). Although some weeds are consumed, some are avoided by cattle. Common unpalatable species found in pastures include many poisonous weeds and others including tall ironweed (*Vernonia gigantea (Walter) Trel.)* (Israel and Rhodes 2013) and horsenettle (*Solanum carolinense L.*) (Rhodes and Phillips 2011). In many production systems there is only one grazing species such as cattle in a pasture. In these systems, weed species can be selected for based upon palatability. Selective grazing and pressure against grazing certain weeds can lead to increased incidence (Popay and Field 1996; Curran and Lingenfelter 2009). Plants that are not consumed by herbivores displace desirable forages. Broomsedge is a common weed of pastures that is less palatable than forage species and becomes less palatable as it matures (Peters and Lowance 1974). Given the increasing unpalatability of broomsedge across the growing season, in most instances it is likely to be avoided by cattle.

Weeds in pastures might also be avoided due to the potential for injury due to spines, thorns, or prickles. These defense mechanisms help to deter herbivory by grazing animals. Common pasture weeds such as Canada thistle (*Cirsium arvense (L.) Scop.)* (Beck 2013a), musk thistle (*Carduus nutans L.*) (Beck 2013b), bull thistle (*Cirsium vulgare (Savi) Ten.)* (Renz et. al. 2007), horsenettle (*Solanum carolinense L.*) (Rhodes and Phillips 2011), and multiflora rose (*Rosa multiflora Thunb.)* (Lingenfelter and Curran 2013) deter grazing as a result of their spines and thorns. Without control, species such as musk and Canada thistle can become the dominant species in a pasture and displace the desired forage species. Musk thistle is an aggressive biennial weed that may produce

10,000 seeds per plant (Feldman et. al. 1968), while Canada thistle is a perennial that spreads by both seed and rhizomes (Beck 2013a).

Grazing animals can be conditioned to eat spiny or unpalatable weeds that may otherwise be avoided (Popay and Field 1996). Cattle are selective grazers that prefer grasses and are less likely to consume shrubs and forbs than other grazing animals (Olsen 1999). Sheep are more likely to graze all plants in a pasture evenly, but tend to avoid plants with spines (Popay and Field 1996). Goats are more likely to consume broadleaf plants in a pasture including spiny and brush-like plants (Popay and Field 1996). Various techniques are used to teach cattle that a formerly objectionable plant is acceptable to consume. Animals can be taught to eat weeds by providing supplemental feed that makes the plant more appealing, adjusting stocking densities to levels that require weeds to be consumed, or by introducing lead animals that have experience consuming the novel plant or unpalatable weed that is avoided by the herd (Davison et. al. 2007). Another approach to grazing weeds is to spray reduced rates of phenoxy herbicides on weeds and introduce grazing animals into the pasture seven days after application (Popay and Field 1996; Reeves 2016; Douglas and Moore 2018). Spray-grazing and providing supplemental feed on the weed may lead to consumption of toxic weeds because of increased palatability.

Nutritive value of Weeds

Forage nutritive value is defined as the extent to which a forage has the ability to produce a desired animal response (Ball et. al. 2001). The primary factor that influences nutritive value is plant maturity. Plants tend to have greater nutritive value during vegetative growth stages and quality decreases as the plant matures (Bosworth et. al.

1985). Nutritive value is a collective of herbivore intake, palatability and nutrient content (Collins and Newman 2018). Other factors that influence nutritive value include environment, cultivar or species, and harvest conditions (Volenec and Nelson 2018; Collins and Newman 2018). There are multiple ways to measure and express relative nutritive value including acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), and *in vitro* true digestibility (IVTD), among others.

Acid detergent fiber (ADF) is a measure of the insoluble residues in forage that remain following extraction of herbage with acid detergent (Collins et. al. 2018). It consists of all cell wall constituents except hemicellulose and pectin. ADF is a measure of the least digestible portions of a plant. Lignin and cellulose are the two primary constituents measured by ADF analysis. ADF can be used to calculate digestibility and as ADF increases, digestibility decreases (Ball et. al. 2001). Mature forages typically have ADF values around 40 percent (Collins and Newman 2018). In grass and legume forage crops there is little difference in ADF levels of plants with similar digestibility (Collins and Newman 2018).

Neutral detergent fiber represents the digestible and slowly digestible portions of a plant including cellulose, hemicellulose, lignin, and ash (Ball et. al. 2001). Legume forage species typically have lower NDF concentrations than grasses of similar digestibility. In certain grass species NDF levels may be as high as 80 percent. (Collins and Newman 2018). NDF levels can serve as an estimate of voluntary intake. Plants with NDF values less than 50 percent will be consumed more readily than plants with NDF values greater than 55 percent (Gerrish and Roberts 1999). Subtracting ADF from NDF values provides an estimate of hemicellulose levels in the plant (Collins and Newman 2018).

Crude protein is an estimate of the protein content of a plant. Crude protein values are 6.25 times the total nitrogen content (Ball et. al. 2001). Forage crude protein is comprised of three substituents; non-protein nitrogen, digestible protein nitrogen, and indigestible nitrogen. Non-protein nitrogen is found in small amounts in plants, but is readily available to rumen microbes. Digestible protein nitrogen is used to support rumen microorganisms and the animal (Collins and Newman 2018). Although a pasture may have large levels of crude protein, it may consist of unusable nitrogen sources and animal performance may be limited (Gerrish and Roberts 1999). Legume-grass mixtures provide less crude protein than pure legume pastures. This is useful to maintain proper rumen carbon:nitrogen ratios (Gerrish and Roberts 1999). Tannins found in some leguminous species can slow down microbial activity in the rumen and increase levels of undegraded protein that reach the duodenum and small intestine for absorption by the animal (Collins and Newman 2018).

Digestibility is a measure of the extent that a consumed plant will be absorbed as it passes through the digestive tract of an animal (Ball et. al. 2001). Digestibility is measured in one of two ways. In the lab, IVTD is used. This process utilizes collected rumen fluid and exposes samples to this fluid in anaerobic conditions over a period of time to simulate the ruminant digestive tract. Another method is *in vivo* digestibility. This method results in apparent digestibility rates and is measured by feeding animals a set amount of dry matter and weighing and comparing the fecal dry matter output (Collins and Newman 2018). Digestion rates can vary across plant species. Cell wall fractions of forages are digested slowly, whereas cellular contents are digested quickly (Collins et. al. 2018).

Nutritive value is a term generally used to summarize the value that a forage grass or legume has in a pasture system relative to grazing animal productivity and gain. It can also be used to assess the value of plants that are not traditionally considered forages. In a study of nine cool season weed species, Bosworth et. al. (1985) found that carolina geranium (*Geranium carolinianum L.*), cutleaf evening primrose (*Oenotbera laciniata Hill*), curly dock (*Rumex crispus L.*), henbit (*Lamium amplexicaule L.*), Virginia pepperweed (*Lepidium virginicum L.*), Virginia wildrye (*Elymus virginicus L.*), wild oats (*Avena fatua L.*), cheat (*Bromus secalinus L.*), and little barley (*Hordeum pusillum Nutt.*) contained crude protein levels adequate for a growing beef steer during plant vegetative growth. Digestibility levels of all weeds included in this study except cutleaf evening primrose and curly dock had similar digestibility to rye (*Secale cereale L.*) and ladino clover (*Trifolium repens L.*). In a study of 11 common pasture weeds it was found that redroot pigweed (*Amaranthus retroflexis L.*), common milkweed (*Asclepias syriaca L.*), woolly croton (*Croton capitatus Michx.*), tall morningglory (*Ipomoea purpurea L.*), and horsenettle (*Solanum carolinense L.*) had crude protein levels adequate to meet nutritional requirements for ruminant animals. Of these five weeds, all but horsenettle were found to have acceptable levels of *in vitro* digestible dry matter (Carlisle et. al. 1980). The results of these studies would suggest that during certain life stages, some species of weeds can be nutritious for grazing animals if they were to consume them. Little research has been conducted to evaluate the change in different aspects of forage nutritive value as weedy plants mature during the growing season.

Conclusion

There are many factors that affect weed incidence, severity, and persistence in pasture systems. Weeds are the primary pest of pasture and forage systems and may reduce forage yields, but may also provide fodder adequate to meet the nutritional needs of livestock. Improper grazing techniques and poor soil fertility can lead to an increase in weed incidence in pastures. As weed species increase in a pasture system, there may be a reduction in animal performance. This is primarily due to weed species competition with desirable forage species and animal avoidance behaviors.

Few studies have been conducted on the interactions between weed incidence and severity and soil nutrient and pH levels in pastures. Additionally, there has been little research that illustrates the seasonal changes in nutritive value of common pasture weeds as they mature throughout the growing season. The objectives of this research are to: 1) determine the effects of soil fertility, grazing and forage components on weed incidence and severity in mixed tall fescue and legume pastures, and 2) to determine the seasonal changes in nutritive values of common weeds found in Missouri pastures during the growing season, and to compare these values to the representative forage harvested from the same locations during the growing season.

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Chapter II

Seasonal Changes in Forage Nutritive Value of Common Weeds Encountered in Missouri Pastures

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Abstract

During the 2015, 2016, and 2017 growing seasons, weed and weed-free mixed tall fescue and legume forage samples were harvested from 29 pastures throughout Missouri in order to investigate the nutritive value of 20 common pasture weed species throughout the season. Sample collections occurred at 14-day intervals from a period from mid-April until late September in each growing season. At certain times during the growing season many broadleaf weed species had greater nutritive values for a given quality parameter as compared to the available weed-free, mixed tall fescue and legume forage harvested from the same location. There were no significant differences in crude protein (CP) concentration between the weed-free forage and many weeds throughout the growing season. However, CP content of common burdock, common cocklebur, common ragweed, dandelion, horsenettle, and lanceleaf ragweed was greater than that of the corresponding forage sample for multiple collection periods. Several weed species such as common burdock, common lambsquarters, and ironweed species were consistently lower in neutral detergent fiber (NDF) content than the representative forage for much of the growing season. Annual grass species had similar NDF concentrations to the forage for most collection periods. The digestible neutral detergent fiber (dNDF) content of all broadleaf weeds except lanceleaf ragweed was significantly less than the weed-free

forage at all collection periods. Conversely, large crabgrass had significantly greater dNDF levels than the mixed tall fescue forage for all sampling dates. Dandelion and spiny amaranth had greater in vitro true digestibility (IVTD) content than the forage for the entire growing season. Three perennial weeds; horsenettle, vervain species, and white snakeroot, did not differ in IVTD levels as compared to the mixed tall fescue and legume forage for any collection date. For most summer annual weeds, the trend was towards greater digestibility earlier in the season, with a gradual decline and often lower IVTD by the late summer/early fall. The results of this study can be used to better interpret the effect that weed species have on the overall nutritive value of the forage production system throughout the growing season in mixed tall fescue and legume pastures.

Introduction

Approximately 73 million hectares of agricultural land in the United States are devoted to pastures and haylands (Sanderson et al. 2012). Forage production on pasturelands account for 2.8 million hectares in Missouri. Approximately 25% of farmland in Missouri is dedicated to pastures (USDA ERS 2017), and the state has an inventory of 2.1 million beef cattle (NASS 2018). The primary source of feed for these animals is forage from pasture and stored forage from haylands. Fescue is the primary forage species throughout Missouri and much of the Midwest and eastern United States (Glenn et. al. 1981). Many pastures throughout these regions consist primarily of a mixture of tall fescue and legume species, primarily clovers, in order to increase feed quality (Phelan et. al. 2015).

Weed species are the primary pest of pastures and rangelands throughout the United States and account for at least $2 billion in economic losses annually (DiTomaso

2000). Weeds compete directly with desired species for resources such as soil nutrients, moisture, light and space (Green et al. 2006). In grazing systems, animals are likely to consume weeds as well as the forage species (Popay and field 1996). There have been many comparative studies of weed and forage nutritive values that indicate weeds may be comparable to forage species (Marten and Andersen 1975; Carlisle et al. 1980; Marten et al. 1987; Sleugh 1999; Rosenbaum et al. 2011). However, most of these studies have compared weed and forage species collected at the same time or at a specific growth stage. For example, Marten and Anderson (1975) compared the forage nutritive value of 12 weed species harvested at two timings in late June and mid-July to samples of alfalfa harvested at the same time. Carlisle et al. (1980) tested 11 weed species for chemical composition and crude protein levels at physiological maturity. Both of these studies examined weeds at few or specific maturities and time points.

Annual, biennial and perennial broadleaf weeds are common in pastures. Annual weeds such as common ragweed (*Ambrosia artemisiifolia* L.) and common cocklebur (*Xanthium strumarium* L.) are two of the most common species in Missouri pastures (Rosenbaum et. al. 2011). Bosworth et al. (1985) found that Carolina geranium (*Geranium carolinianum L.*), cutleaf evening primrose (*Oenotbera laciniata Hill*), curly dock (*Rumex crispus L.*), and Virginia pepperweed (*Lepidium virginicum L.*) had similar digestibility and crude protein levels to the forage species cereal rye (*Secale cereale L.*), tall fescue (*Schedonorus arundinaceus* Schreb.), ladino clover (*Trifolium repens L.*), and hairy vetch (*Vicia villosa* Roth) when harvested in the vegetative growth stage. In contrast, crude protein levels of the total harvested biomass in a tall fescue pasture decreased by 0.2 to 0.4 g/kg with each additional increase in common ragweed or common cocklebur plants per square meter, respectively (Rosenbaum et. al. 2011). Research by Marten and Anderson (1975) indicated that common ragweed has crude protein and digestibility equivalent to alfalfa when harvested in mid-July. Conversely, Carlisle et al. (1980) found that common ragweed had crude protein levels lower than that of tall fescue and below what is required for cattle maintenance requirements. The results of these studies indicate that the nutritive quality of common weed species can vary greatly when grown in the absence of competition and are harvested at different maturities.

At present, little research has been conducted to determine the seasonal change in the nutritive value of common weed species throughout the growing season. The objectives of this research were to examine the seasonal variation in forage nutritive values of common weed species found in Missouri pastures in comparison to the representative weed-free forage found at the same location and same time point during the growing season.

Materials and Methods

Weed and representative forage samples were collected during a pasture weed survey that was conducted at 29 locations throughout Missouri from 2015 to 2017 (Figure 1; Table 2.1). Sampling of individual weed species began in mid-April or at emergence and continued at 14-day intervals until senescence or the end of September, whichever came first. Weed species were selected based upon their prevalence in surveyed pastures. Specific site information pertaining to the locations and years of each weed species collected are listed in Table 2.1.

At each location, pure samples of weed species were hand-harvested by clipping weeds at the soil surface. The entire plant was included in the sample and multiple plants were harvested to equal approximately 300 grams of dry biomass. The weed species selected consisted of annual fleabane (*Erigeron annuus* L.), annual marshelder (*Iva annua* L.), buckhorn plantain (*Plantago major* L.), common burdock (*Arctium minus* Bernh.), common cocklebur (*Xanthium strumarium* L.), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), dandelion (*Taraxacum officinale* F.H. Wigg.), horsenettle (*Solanum carolinense* L.), ironweed species (*Vernonia spp*.), lanceleaf ragweed (*Ambrosia bidentata* Michx.), large crabgrass (*Digitaria sanguinalis* L.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), sericea lespedeza (*Lespedeza cuneata* (Dum. Cours.) G. Don), spiny amaranth (*Amaranthus spinosus* L.), vervain species (*Verbena spp*.), tall goldenrod (*Solidago canadensis* subsp. *altissima* L.), white snakeroot (*Ageratina altissima* L.), woolly croton (*Croton capitatus* Michx.), and yellow foxtail (*Setaria pumila* (Poir.) Roemer & J.A. Schultes). Ironweed species and vervain species were grouped as such to eliminate the possibility of misidentification during early stages of growth. Ironweed species were comprised of Baldwin's ironweed (*Vernonia baldwinii* Torr.) and tall ironweed (*Vernonia gigantea* (Walter) Trel), while vervain species was comprised of white vervain (*Verbena urticifolia* L.) and blue vervain (*Verbena hastata* L.). After each survey of a given pasture, an area that best represented the composition of the forage within that pasture was chosen, and a 300 g weed-free sample of grass forage and legume species present were clipped to a height of 2.5 cm.

After collection, weed and forage samples were stored in a freezer, freeze-dried for 14 days at -10°C and then ground in a lab mill (Lab mill, Thomas Scientific, 1654 High Hill Road Swedesboro, NJ 08085) followed by a cyclone mill (Cyclone mill, Udy Corporation, 201 Rome Court, Ft. Collins, CO 80524) to pass through a 1-mm screen. Analysis of forage and weed samples was conducted using near infrared spectroscopy (NIRSystems 5000 Spectrophotometer, FOSS NIRSystems Inc, 8091 Wallace Rd, Eden Prairie, MN 55344) to measure crude protein (CP), neutral detergent fiber (NDF), and *in vitro* true digestibility (IVTD) of each sample. Traditional analytical chemistry was performed on a subsample of all collected forages and weeds in order to determine calibration equations. Chemical analysis consisted of measuring CP, NDF, and IVTD. Crude Protein content was determined by using a true spec N analyzer (True Spec N analyzer, Leco Corp., 3000 Lakeview Avenue, St. Joseph, MI 49085) to determine the total amount of nitrogen in each sample. The total nitrogen concentration of each sample was multiplied by 6.25 to determine the total CP for each sample (National Research Council 1996). NDF levels were measured by washing samples with a NDF solution in a fiber analyzer (Fiber Analyzer, ANKOM Technology, 2052 O'Neil Road, Macedon, NY 14502) (Spanghero et al. 2003). IVTD was determined by incubating samples for 48 hours in rumen fluid collected from a cannulated cow offered a forage-based diet. Optimum calibration equations (Table 2.2) were based on high coefficients of determination and low standard errors calculated during regression and cross-validation. Validation equations were used to predict CP, IVTD, and NDF of the selected weed and forage samples. Digestible neutral detergent fiber (dNDF) concentrations were calculated for weed and forage samples in order to compare the digestible portion of NDF.

Digestible neutral detergent fiber is the measure of the portions of NDF that are digested when consumed by animals at a specified feed intake (Ball et al. 2001). Calculations were made using the formula outlined by Mertens (2009) utilizing indigestible neutral detergent fiber (iNDF) which is 100 - IVTD and NDF levels; where dNDF = NDF – iNDF.

Data Analysis. Nutritive value data for all weed species were analyzed using the PROC GLIMMIX procedure in SAS (SAS 9.4, SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513). Locations were treated as replications and species and date were considered fixed effects. Individual treatment differences were separated using Fisher's protected LSD at $P \leq 0.05$. Comparisons were made by subtracting the statistical mean of CP, NDF, dNDF, and IVTD of the weed-free forage sample from that of the respective weed species sample.

Results and Discussion

Crude Protein. Crude protein is an estimate of the protein content of a plant and is roughly 6.25 times the total nitrogen content (Ball et. al. 2001). The CP content of a forage is made up of non-protein nitrogen, digestible and indigestible protein nitrogen (Collins and Newman 2018). Forage CP levels are considered adequate for maintaining mature beef cows at a level of 105 g/kg (Bosworth et al. 1985, Abaye et. al 2009). The CP content of woolly croton, large crabgrass, annual fleabane, white snakeroot, annual marshelder, Pennsylvania smartweed, yellow foxtail, and vervain species was not different than the representative forage sample at any time point throughout the growing season (Table 2.3). Buckhorn plantain, common burdock, common cocklebur, common lambsquarters, common ragweed, dandelion, horsenettle, lanceleaf ragweed, sericea lespedeza, and spiny amaranth had CP concentrations that were greater than the representative weed-free forage collected at the same time point and location for at least one time point during the season (Table 2.3). However, common burdock, common cocklebur, common ragweed, dandelion, horsenettle, lanceleaf ragweed, and spiny amaranth had greater CP content than the representative forage at multiple time points throughout the season. The CP content of common burdock was 91.1, 70.1, 81.8, and 102.7 g kg^{-1} dm greater than the representative forage sample for the May 17 through June 28 collection dates, respectively. Common cocklebur was 52.2, 46.6, and 42.4 g kg^{-1} dm greater in CP content for the late June and July collection timings. Common ragweed had CP content that was greater than the forage sample for six of the twelve collections, and these values ranged from 46.2 to 85.6 g kg^{-1} dm greater than the representative forage harvested at the same time. These differences equate to actual CP concentrations for common ragweed of 157.6 to 261 g kg^{-1} dm g/kg (data not shown), which is similar to the levels reported by Marten and Anderson (1975) of 251 g kg^{-1} dm. Horsenettle CP concentrations were significantly greater than the mixed tall fescue pastures for 10 of the 11 collection timings with differences ranging from 37.5 to 115.5 g kg^{-1} dm. Crude protein content of spiny amaranth was significantly greater than forage for three of the eight collections. The actual CP content of spiny amaranth was 265 g kg^{-1} dm at the June 14 timing, which is similar to the results reported for other *Amaranth* species by Sleugh (1999).

Crude protein of tall goldenrod and ironweed species were significantly lower than the representative forage for one and three time periods, respectively (Table 2.3). Tall goldenrod at the late September collection was 92.8 g kg^{-1} dm lower than the representative forage. Ironweed species had reduced CP content compared to the representative forage sample during the late July, early August, and early September collections with differences of -43.1, -38.3, and -50.4 g kg^{-1} dm, respectively.

Neutral Detergent Fiber. Neutral detergent fiber is the total fiber or cell wall fraction of a forage (Shewmaker 2005). This measure is often used as an indicator of forage intake and in most instances as NDF levels increase, animal intake of the forage decreases (Ball et al. 2001, Shewmaker 2005). Neutral detergent fiber content of buckhorn plantain, common cocklebur, common ragweed, dandelion, horsenettle, lanceleaf ragweed, Pennsylvania smartweed, spiny amaranth, vervain species, and white snakeroot were less than the representative mixed tall fescue forage sample for all collection periods for each weed (Table 2.4). Spiny amaranth exhibited the greatest differences in NDF concentration from the forage, ranging from 228.9 to 335.1 g kg^{-1} dm less than the representative forage samples collected at the same time and in the same locations.

Grasses consistently have greater NDF than forbs (Marten et al. 1987). The results of this research support those of Temme et al. (1979) who showed that many dicot species have less NDF than monocot species. The monocot weed species collected for this study, large crabgrass and yellow foxtail, contained similar NDF concentrations to that of the predominantly grass-based forage samples for five of the six collection periods for large crabgrass and for all collection timings of yellow foxtail. Annual fleabane, annual marshelder, common burdock, common lambsquarters, ironweed species, tall goldenrod, and woolly croton had less NDF than the representative forage sample at numerous collection timings. Neutral detergent fiber levels of sericea lespedeza were not different than that of the mixed forage sample at any given time point throughout the growing season. Several weed species such as common burdock, common lambsquarters, and ironweed species had consistently less NDF content than the representative forage for much of the growing season until late in the summer and early fall. This trend likely coincides with the maturity of each species and a shift from vegetative to reproductive growth. Lignin levels increase as plants mature (Van Soest 1994), and the increase in lignified materials at more mature growth stages is associated with an increase in overall NDF content. Smaller NDF levels are generally associated with decreased digestibility (Ball et al. 2018). Therefore, as NDF content of weeds decrease in comparison to the representative forage, the potential for increased intake by grazing animals is greater.

Digestible Neutral Detergent Fiber. Digestible neutral detergent fiber is used as a measure of the digestible portions of NDF (Ball et al. 2001). Greater concentrations of dNDF are indicative of a greater quality forage because more NDF is digestible and usable to the animal. Differences of the calculated dNDF levels (Table 2.5) were less than the representative mixed tall fescue forage for all species in the study except lanceleaf ragweed, large crabgrass, sericea lespedeza, and yellow foxtail. In fact, white snakeroot was 239.9 g kg^{-1} dm less than the dNDF of the forage sample from the same location and collection period in mid-April, while woolly croton had 587.4 g kg^{-1} dm less dNDF content than the representative forage during the mid-May collection timing. Digestible neutral detergent fiber levels of sericea lespedeza were not different than the mixed tall fescue forage sample for any collection date from late May until the conclusion of the study in late September.

Large crabgrass had greater dNDF concentration than the representative mixed tall fescue forage for all collection periods (Table 2.5). Differences in dNDF ranged from

70.3 g kg^{-1} dm in early September to 43.4 g kg^{-1} dm for the collection in early August. Yellow foxtail dNDF content was greater than the forage at emergence in late July. Yellow foxtail was not different than the forage for any other collection period from early August to late September. It is expected that grass weed species should have similar or greater dNDF concentrations as compared to the predominantly tall fescue-based forage at each location. The greater dNDF concentrations of large crabgrass may be attributed to the life cycle differences between a warm-season annual and a cool-season perennial. For example, from mid-July to late September, large crabgrass was vegetative and actively growing while tall fescue was mature and had not initiated fall growth. During this time period tall fescue has a reduced level of digestibility (Brown et al. 1955). Additionally, tall fescue during the late summer typically has greater NDF content that is less digestible due to greater levels of lignification associated with plant maturity (Van Soest 1994).

Lanceleaf ragweed had smaller dNDF concentrations (115.3 to 129.2 g kg^{-1} dm) as compared to the mixed tall fescue forage for the collection periods from mid-May until mid-June (Table 2.5). Conversely, for the period from late-June until late-September, dNDF content for lanceleaf ragweed was greater than the forage. During this time period, dNDF concentrations of lanceleaf ragweed ranged from 83.7 to 140.5 g kg^{-1} dm greater than the representative mixed tall fescue forage. During this same time period, common ragweed was 136.9 to 198.2 g kg^{-1} dm lower in dNDF than the representative forage. The differences in ragweed species may be attributed to the shorter stature of lanceleaf compared to common ragweed. With shorter plant heights there should be decreased levels of lignified tissues because of a greater leaf-to-stem ratio. A reduced leaf-to-stem ratio is associated with decreased nutritive values that often occur with maturity (Ball et al. 2001, Foster et al. 2009). In Missouri, tall fescue matures and seed is produced in late-spring/early-summer. Pritchard et al. (1962) found that tall fescue digestibility following reproductive growth in early summer is lower than vegetative stage tall fescue in the spring. The late-June change from lesser dNDF content for lanceleaf ragweed to greater dNDF as compared to the predominantly tall fescue forage may be due to the differences in physiological maturity of both the weed and forage.

***In Vitro* True Digestibility.** *In vitro* true digestibility is determined by incubating a ground forage sample in rumen fluid for a period of 24 to 48 hours (Ball et al. 2001). This analysis gives a measure of the actual digestibility of a forage as well as an indication of animal performance. The IVTD of dandelion and spiny amaranth were greater than the mixed tall fescue and legume forage for all collection periods (Table 2.6). Dandelion ranged from 70.1to 203.6 g kg^{-1} dm greater in IVTD as compared to the mixed tall fescue forage while spiny amaranth IVTD concentrations ranged from 66.8 g kg^{-1} dm greater than the mixed tall fescue forage in late summer to a high of 201.2 g/kg greater than the forage in mid-June at weed emergence. Annual marshelder and common cocklebur had greater IVTD content than the mixed tall fescue forage from emergence until reproductive growth stages were reached in early and late September, respectively. Common and lanceleaf ragweed also had IVTD levels greater than the mixed tall fescue forage for the period from May 3 until July 26 followed by IVTD content similar to the forage from early August to early September. This time period is associated with the initiation of flower development and reproductive growth in these species (Bianchi et al. 1959). By late September, the IVTD content of both ragweed species was less than the forage, which is likely due to the increasing lignification that occurs during reproductive growth.

Large crabgrass and yellow foxtail had initial IVTD greater than the representative mixed tall fescue forage sample (Table 2.5), but for much of the season there were no differences between weeds and the representative forage. Pennsylvania smartweed had greater IVTD content for five of the initial six collection periods, from mid-May until mid-July. Ironweed species were not significantly different than the mixed tall fescue forage for much of the season, but late May to mid-June IVTD levels were greater than the representative forage by 131.8 and 109.5 g kg^{-1} dm, respectively. Although ironweed species may have a comparable or greater IVTD than the forage from the same location and time, it is generally not utilized by grazing cattle. Israel and Rhodes (2013) reported that ironweed is generally avoided by grazing cattle due to a lack of palatability and any potential forage utilization may decline as a result of avoidance. As ironweed matured, IVTD decreased to the extent that during the early August and early September collection dates, the mixed tall fescue forage samples were 79.9 and 158 g kg^{-1} dm greater than the ironweed species, respectively. The lack of quality during this period may further explain the lack of cattle utilization for this species in a pasture setting.

Horsenettle, vervain species, and white snakeroot did not differ in IVTD compared to the representative mixed tall fescue forage available at each location at any point throughout the growing season. Woolly croton IVTD content was lesser during six of ten collection periods. The IVTD content was 141.1 and 126.9 g kg^{-1} dm less than the mixed tall fescue forage for the early and late-September collections, respectively. These dates correspond with flowering and early seed fill of woolly croton and the initiation of fall growth and greater digestibility of the tall fescue forage (Pritchard et al. 1962).

Discussion

The results of this research indicate that, from the standpoint of forage nutritive value, not all weeds in a pasture system are detrimental. At certain times during the growing season many weeds such as common burdock, common ragweed, lanceleaf ragweed and spiny amaranth have greater crude protein levels than the available forage from the same location. *In-vitro* true digestibility of many weeds was also greater than the representative forage from the same location; annual marshelder, buckhorn plantain, common burdock, common cocklebur, common ragweed, and Pennsylvania smartweed were all greater in digestibility than the representative forage at numerous time intervals throughout the season. For most summer annual weeds, the trend was towards greater digestibility earlier in the season, with a gradual decline and often lower IVTD by the late summer/early fall. Dandelion and spiny amaranth IVTD concentrations were also greater than the forage from every collection period.

Although the results of this research indicate that some weed species may provide needed nutrition to grazing animals, many perennial weeds were poor in nutritive values for much of the growing season. For example, ironweed had less CP content for multiple collection dates in summer and early fall while tall goldenrod and sericea lespedeza had similar CP content for most of the growing season and similar or less IVTD content as the available mixed tall fescue forage. Horsenettle also exhibited greater CP concentration than the available mixed tall fescue forage for ten of eleven collections and had similar IVTD for all collection dates.

The results of this study will enable producers to make educated management decisions based upon the potential benefit or detriment a weed may provide to the overall nutritive value of the pasture system. Providing a comparison of weed and forage at different time points across the growing season allows a more thorough assessment of the potential of a weed to positively or negatively affect the pasture system on a seasonal basis. By comparing weed species to the forage available in the same location at the same time, a better estimate of the forage value of the weed is given because potential biotic and abiotic stresses were the same for a given collection period. Additionally, this work will be useful to understand and compare seasonal changes in nutritive value of annual, biennial, and perennial weed species in mixed tall fescue and legume pasture systems found throughout much of the Midwest and eastern United States.

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Figure 2.1. Locations of weed and forage collections, 2015-2017.

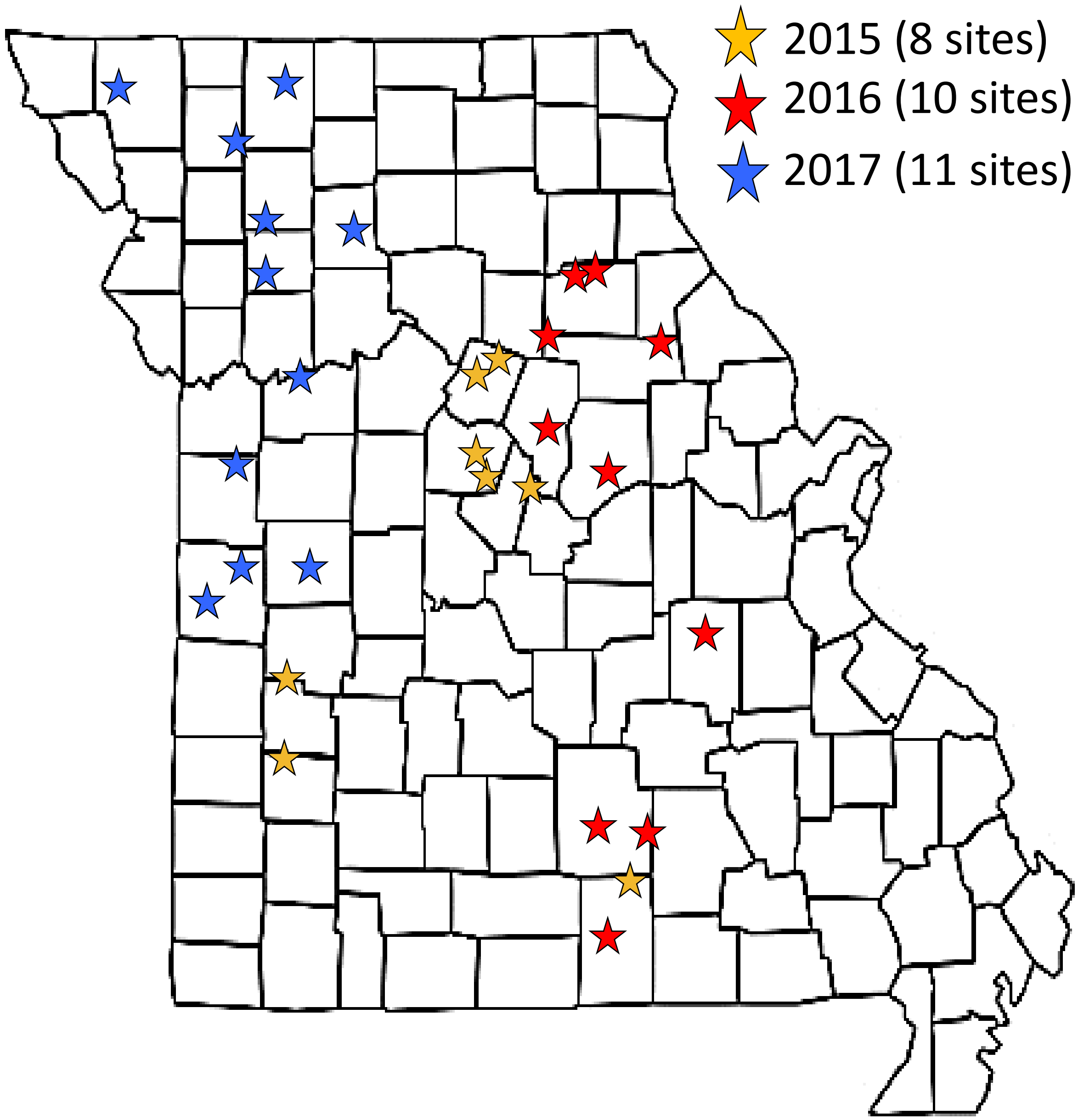

Table 2.1. Site characteristics of locations where weed and forage samples were collected from 2015 to 2017.

Species	Year	GPS coordinate	Soil Series	Soil Properties[a]		
				%OM	pH	CEC
Spiny pigweed	2015	38.85299, -92.47108	Hartville silt loam	3.6	6.5	16
	2016	39.54646, -92.17271	Mexico silt loam	3.7	5.6	16.5
	2017	39.52624, -93.73962	Greenton silty clay	4.1	6.2	24.9
	2017	39.12029, -93.93756	Knox silt loam	2.2	6.7	15.2
Lanceleaf ragweed	2015	39.28156, -92.69848	Grundy silt loam	3.3	5.4	14.2
	2016	36.88707, -91.80091	Taherhill silt loam	3.5	5.8	6.9
	2017	38.70332, -94.30080	Arisburg silt loam	3.6	5.9	15.4
Common ragweed	2015	39.28156, -92.69848	Grundy silt loam	3.3	5.4	14.2
	2016	38.18060, -91.23511	Gravois silt loam	1.7	6.6	7.3
	2017	38.49004, -93.90847	Hartwell silt loam	4.1	6.2	17.7
Common burdock	2017	38.43329, -94.19888	Summit silty clay	4.9	5.9	21.6
	2017	39.52624, -93.73962	Greenton silty clay	4.1	6.2	24.9
Common lambsquarters	2017	38.43329, -94.19888	Summit silty clay	4.9	5.9	21.6

	2017	39.52624, -93.73962	Greenton silty clay	4.1	6.2	24.9
	2017	39.12029, -93.93756	Knox silt loam	2.2	6.7	15.2
Woolly croton	2015	37.39518, -92.33871	Viraton silt loam	3.2	6.6	8.7
	2016	36.88707, -91.80091	Taherhill silt loam	3.5	5.8	6.9
	2017	39.62908, -93.51987	Greenton silty clay	4.1	6.2	24.9
Large crabgrass	2016	37.31615, -92.13366	Mano-ocie complex	2.4	5.2	5.3
	2017	38.43329, -94.19888	Summit silty clay	4.9	5.9	21.6
	2017	39.52624, -93.73962	Greenton silty clay	4.1	6.2	24.9
Annual fleabane	2015	37.47158, -93.85844	Goss silt loam	6.8	6.2	15.2
	2016	39.38357, -91.42166	Crider silt loam	2.2	6.1	10.6
White snakeroot	2015	38.81666, -92.57087	Leslie silt loam	3.5	5.2	12.5
	2016	39.38357, -91.42166	Crider silt loam	2.2	6.1	10.6
Annual marshelder	2017	38.24466, -94.36732	Verdigris silt loam	3.4	5.7	18.4
	2017	38.49004, -93.90847	Hartwell silt loam	4.1	6.2	17.7
Sericea lespedeza	2015	37.83828, -94.05377	Barco-sylvania complex	3.2	5.4	9.8
	2016	38.18060, -91.23511	Gravois silt loam	1.7	6.6	7.3

Buckhorn plantain	2015	37.39518, -92.33871	Viraton silt loam	3.2	6.6	8.7
	2016	39.36586, -91.87598	Mexico silt loam	3.5	5.8	14.6
Pennsylvania smartweed	2015	39.28156, -92.69848	Grundy silt loam	3.3	5.4	14.2
	2016	39.53994, -91.76583	Armstrong loam	3	6.3	11
	2017	39.52624, -93.73962	Greenton silty clay	4.1	6.2	24.9
	2017	38.49004, -93.90847	Hartwell silt loam	4.1	6.2	17.7
Yellow foxtail	2015	38.77083, -92.53566	Bluelick silt loam	3.8	6.1	13
	2016	38.18060, -91.23511	Gravois silt loam	1.7	6.6	7.3
	2017	38.70332, -94.30080	Arisburg silt loam	3.6	5.9	15.4
Horsenettle	2015	38.81666, -92.57087	Leslie silt loam	3.5	5.2	12.5
	2016	38.18060, -91.23511	Gravois silt loam	1.7	6.6	7.3
	2017	39.12029, -93.93756	Knox silt loam	2.2	6.7	15.2
Tall goldenrod	2016	38.88450, -91.71568	Armster cobbly loam	4.8	5.7	16.7
	2017	40.45798, -93.82981	Lagonda silty clay	3.6	5.8	16.7
Dandelion	2015	39.03919, -92.81324	Menfro silt loam	4.1	5.4	20.3
	2016	38.90488, -92.26306	Armstrong loam	3.9	6.8	14

	2017	40.23643, -94.50482	Grundy silt loam	3.9	6.1	20.7
Vervain species	2015	38.81666, -92.57087	Leslie silt loam	3.5	5.2	12.5
	2016	36.88707, -91.80091	Taherhill silt loam	3.5	5.8	6.9
	2017	38.49004, -93.90847	Hartwell silt loam	4.1	6.2	17.7
Ironweed species	2015	38.77083, -92.53566	Bluelick silt loam	3.8	6.1	13
	2016	37.25777, -91.74920	Viburnum silt loam	3.6	5	7.7
	2017	38.43329, -94.19888	Summit silty clay	4.9	5.9	21.6
	2017	39.80560, -93.97551	Lamoni loam	3.4	5.7	18.1
Common cocklebur	2015	39.03919, -92.81324	Menfro silt loam	4.1	5.4	20.3
	2016	38.90488, -92.26306	Armstrong loam	3.9	6.8	14
	2017	38.24466, -94.36732	Verdigris silt loam	3.4	5.7	18.4
	2017	39.52624, -93.73962	Greenton silty clay	4.1	6.2	24.9

[a]Abbreviations: CEC, cation exchange capacity; OM, organic matter; pH = soil pH in water

Table 2.2. Near-infrared reflectance spectroscopy calibration and validation statistics for CP, NDF, and IVTD for 2015 - 2017 data.

Constituent[a]	n	R^2	Mean	SEC	SECV	1-VR
2015 - 2016				g kg^{-1} dm		
CP	130	.95	132.4	8.2	9.5	0.93
NDF	134	.95	433.8	27.9	32.3	0.94
IVTD	136	.92	783.8	32.4	39.2	0.88
2017						
CP	68	.94	164.9	14.4	18	0.93
NDF	68	.96	402.9	20.9	27.3	0.90
IVTD	67	.94	784.6	25.5	34.6	0.89

[a] Abbreviations: CP, crude protein; NDF, Neutral Detergent Fiber; IVTD, In Vitro True Digestibility; 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 2.3. Comparisons in crude protein content between selected weed species and the corresponding weed-free forage sample at each collection timing throughout the season.

	Average Collection Date											
Weed Species[a]	4/19	5/3	5/17	5/31	6/14	6/28	7/12	7/26	8/9	8/23	9/6	9/20
	--g kg^{-1} dm[bc]--											
Annual fleabane	-21.7	-0.6	20.9	2.9	-48.3	-48.1	15.6	-84.5	-9.9	-22.4	----	----
A. marshelder	----	----	----	----	15.6	-5.5	34.9	0.4	-32.7	2.1	37	-10.9
Buck. plantain	22.9	38.8	44.2	61.3*	17.3	30.8	21.6	24.8	19.7	20.2	-3.6	2.5
C. burdock	----	----	91.1*	70.1*	81.8*	102.7*	54.7	9.9	-7.1	-1.3	20.8	43.1
C. cocklebur	----	----	----	30.2	15.1	52.2*	46.6*	42.4*	32.9	10.2	-20.7	-12.1
C. ragweed	53.2*	20.8	59.3*	85.6*	51.3*	47.6*	46.2*	25.9	0.3	-9.8	-14.3	-7.8
C. lambsquarters	----	----	----	68.7	76.5	85.6*	69.6	35.2	16.1	48.6	-12.6	9.1
Dandelion	6.9	36.5*	25.6	30.2	8.4	22.5	58.8*	25.2	78.4*	47.2*	89.7**	44.2
Horsenettle	----	91.1*	115.5**	90.6**	75**	82.8**	76.8**	37.5*	42.1*	49.8*	68*	28.4
Ironweed spp.	3.7	46.1	-15.3	13.9	10	-0.1	11.6	-43.1*	-38.3	-18.3	-50.4	-25.4
L. ragweed	----	21.3	67.6*	62.4*	34.9	30.1	-0.6	11.1	1.2	-1.6	-17.9	-19.9
Large crabgrass	----	----	----	----	----	----	29.6	37.3	10.4	-2.8	-23.5	15.5
Penn. smartweed	----	-8.7	33.8	4.2	-37.3	-1.1	-0.2	-12.6	-26.1	-60.9	-38.8	0.4
Se. lespedeza	----	----	----	53.2*	14.3	10.2	-12.9	-23.5	-33.6	25.2	-7.2	12
Spiny pigweed	----	----	----	----	120.1*	104.2*	65.8*	39.5	47.2	32.1	46.5	42.5
Tall goldenrod	-14.5	-9.2	-46.9	-22.7	-16.5	3.8	-35.2	-39.6	-63.4	-37.7	-28.7	-92.8*
Vervain spp.	----	13.1	1.4	34.0	2.3	0.6	7.9	-29.7	-27.2	-48	-26.7	-11.7
White snakeroot	13.7	38.3	21.3	23.4	11.8	22	46.1	-29.3	19.5	-1.5	-14	-33.9
Woolly croton	----	----	28.5	40.9	7.5	-25.9	-20.9	0.6	5.9	34.4	57.3	-16.2
Yellow foxtail	----	----	----	----	----	----	----	5.4	3.3	-22.5	-29.8	-29.3

[a] Abbreviations: A. marshelder, annual marshelder; Buck. plantain, buckhorn plantain; C. burdock, common burdock; C. cocklebur, common cocklebur; C. ragweed, common ragweed; C. lambsquarters, common lambsquarters; L. ragweed, lanceleaf ragweed; Penn. smartweed, Pennsylvania smartweed; Se. lespedeza, sericea lespedeza.

[b] Values shown are the product of the average crude protein content of the selected weed species minus the average crude protein content of the respective forage sample taken at the same collection location and time.

[c] * indicates significant difference at $P \leq 0.05$; ** indicates significant difference at $P \leq 0.001$.

Table 2.4. Comparisons in NDF content between selected weed species and the corresponding weed-free forage sample at each collection timing throughout the season.

	Average Collection Date											
Weed Species[a]	4/19	5/3	5/17	5/31	6/14	6/28	7/12	7/26	8/9	8/23	9/6	9/20
	g kg^{-1} dm[bc]											
Annual fleabane	-284.7*	-359.2*	-334.4*	-207.5	-151.3	-152.1	-237.6	-209.9	-253.3	-201.1	----	----
A. marshelder	----	----	----	----	-195.5*	-212.5**	-222.9**	-225.5**	-181.4*	-162.3*	-116.7	-64.4
Buck. plantain	-193.1**	-304**	-281.5**	-278.7**	-273.3**	-296.4**	-263.2**	-291.1**	235.2**	-245.6**	-245.6**	-285.4**
C. burdock	----	----	193.2*	-225.2*	-250.2**	-263.8**	-170.6*	-62.2	-38.3	-35.3	-9.8	-111.0
C. cocklebur	----	----	----	-300.7**	-242.1**	-284.9**	-295.4**	-278.1**	-255.4**	-209.3**	-177.2**	-100.0*
C. ragweed	-204.3*	-250.3*	-291.2**	-318.1**	-293.4**	-262.9**	-290.2**	-225.1**	-181.6*	-161.2*	-153.5*	-127.4*
C. lambsquarters	----	----	----	-201.9*	-189.7*	-224.9*	-173.6*	-122.5*	-69.7	-45.7	92.8	7.4
Dandelion	-172.6*	-259.2**	-267.7**	-272.3**	-255.7**	-315.6**	-309.3**	-285.8**	-353.4**	-272.4**	-321.8**	-328.7**
Horsenettle	----	-230.1*	-272.6*	-214.4*	-200.3*	-251.0*	-251.0*	-184.5*	-177.2*	-245.4*	-252.2*	-211.8*
Ironweed spp.	-244.6*	-249.4**	-230.8**	-248.6*	-216.4**	-205.1**	-189.5**	-93.8**	-69.7*	-101.1*	24.8	-64.9
L. ragweed	----	-218.8**	-321.2**	-316.3**	-296.7**	-227.6**	-274.1**	-242.2**	-212.1**	-193.8**	-158.9**	-107.5**
Large crabgrass	----	----	----	----	----	----	-43.2*	-52.5	-15.0	6.4	45.3	-22.8
Penn. smartweed	----	-228.8**	-297.8**	-314.1**	-228.6**	-241.1**	-249.8**	-233.1**	-203.1**	-150.4**	-187.4**	-194.1**
Spiny pigweed	----	----	----	----	-293.1**	-335.1**	-309.8**	-252.4**	-266.5**	-249.9**	-228.9**	-260.6**
Se. lespedeza	----	----	----	168.3	-74.9	-113.9	127.2	148.9	-71.1	-117.1	-98.1	-64.9
Tall goldenrod	-256.5*	-273.3*	-140.4*	-209.2**	-168.3*	-247.4**	-190.1*	-198.8*	-146.4*	-136*	-147.7*	-31.5
Vervain spp.	----	-245.5*	-258.4**	-279.2*	-253.6*	-263.1**	-271.5**	-166.4*	-183.2*	-151.9*	-137.2*	-144.5*
White snakeroot	-232.7**	-276.7**	-262.4**	-242.9**	-269.8**	-297.8**	-316.6**	-205.9**	-274.8**	-192.9**	-137.6*	-113.3*
Woolly croton	----	----	-164*	-166.1*	-132.7	-62.5	-76.2	-71.4	-114.7*	-68.7	-26.6	-45.9
Yellow foxtail	----	----	----	----	----	----	----	-15.9	-37.5	-6.8	40.4	31.2

[a] Abbreviations: A. marshelder, annual marshelder; Buck. plantain, buckhorn plantain; C. burdock, common burdock; C. cocklebur, common cocklebur; C. ragweed, common ragweed; C. lambsquarters, common lambsquarters; L. ragweed, lanceleaf ragweed; Penn. smartweed, Pennsylvania smartweed; Se. lespedeza, sericea lespedeza.

[b] Values shown are the product of the average crude protein content of the selected weed species minus the average crude protein content of the respective forage sample taken at the same collection location and time.

[c] * indicates significant difference at $P \leq 0.05$; ** indicates significant difference at $P \leq 0.001$.

Table 2.5. Comparisons of dNDF content between selected weed species and the corresponding weed-free forage sample at each collection timing throughout the season.

	Average Collection Date											
Weed Species[a]	4/19	5/3	5/17	5/31	6/14	6/28	7/12	7/26	8/9	8/23	9/6	9/20
	------------g kg^{-1} dm[bc]------------											
Annual fleabane	-199.6*	-192.0*	-196.6*	-185.6*	-187.2*	-212.8*	-229.9*	-237.0*	-218.3*	-220.7*	----	----
A. marshelder	---	----	----	----	-74.2**	-80.7**	-110.3**	-100.0**	-93.8**	-75.8**	-93.1**	-102.9**
Buck. plantain	-133.6*	-178.7**	-171.0**	-139.1*	-184.0**	-194.6**	-186.6**	-164.5*	-162.0*	-134.2*	-174.8**	-166.1*
C. burdock	----	----	-111.5**	-78.1**	-82.2**	-115.7**	-89.8**	-104.6**	-97.9**	-116.3**	-112.9**	-106.4**
C. ragweed	-143.4*	-143.8**	-142.7**	-132.9**	-110.3**	-136.9**	-169.7**	-151.8**	-144.7**	-148.8**	-169.5**	-198.2**
C. cocklebur	----	----	----	-134.0**	-105.9**	-139.9**	-135.4**	-132.7**	-138.2**	-137.1**	-123.0**	-130.8**
C. lambsquarters	----	----	----	-54.3*	-101.1**	-77.6**	-88.3**	-81.1**	-92.0**	-105.0**	-127.2**	-123.8**
Dandelion	-102.5**	-170.5*	-134.5*	-89.5*	-122.6*	-145.4**	-123.3*	-119.8*	-158.8*	-119.0*	-118.2*	-133.3*
Horsenettle	----	-152.7**	-126.6**	-141.1**	-152.0**	-157.6**	-193.4**	-203.6**	-188.1**	-207.9**	-194.5**	-206.2**
Ironweed spp.	-196.5**	-161.1**	-142.4**	-116.7**	-106.9**	-141.7**	-150.2**	-146.2**	-139.8**	-127.8**	-133.2**	-124.8**
L. ragweed	----	-53.6	-115.3*	-120.2**	-129.2**	140.5**	97.7**	117.0**	100.4**	98.1**	92.5**	83.7**
Large crabgrass	----	----	----	----	----	----	68.5*	69.7*	43.4*	51.9*	70.3*	44.1*
Penn. smartweed	----	-160.9**	-182.8**	-150.5**	-152.5**	-175.8**	-189.6**	-191.2**	-165.6**	-172.4**	-204.6**	-174.0**
Se. lespedeza	----	----	----	-154.7	-61.3	-172.2	-216.2*	-228.0*	-197.2	-223.7*	-214.7*	-46.6
Spiny pigweed	----	----	----	----	-91.9**	-161.2**	-170.5**	-144.3**	-135.1**	-173.2**	-162.0**	-152.4**
Tall goldenrod	-170.0*	-112.0	-129.6**	-136.0*	-119.6*	-168.0*	-164.8*	-180.4*	-176.6*	-161.3*	-181.5*	-191.1*
Vervain spp.	----	-173.8**	-170.0**	-187.6**	-157.6**	-168.1**	-201.6**	-222.2**	-235.2**	-219.4**	-155.1**	-183.4**
White snakeroot	-239.9**	-194.1**	-174.5**	-167.6**	-178.0**	-208.2**	-234.1**	-240.8**	-232.8**	-246.4**	-202.0**	-217.7**
Woolly croton	----	----	-587.4**	-153.8**	-136.2**	-162.1**	-170.7**	-145.4**	-152.7**	-164.3**	-167.6**	-172.8**
Yellow foxtail	----	----	----	----	----	----	----	85.1*	47.5	-32.8	5.7	29.8

[a] Abbreviations: A. marshelder, annual marshelder; Buck. plantain, buckhorn plantain; C. burdock, common burdock; C. cocklebur, common cocklebur; C. ragweed, common ragweed; C. lambsquarters, common lambsquarters; L. ragweed, lanceleaf ragweed; Penn. smartweed, Pennsylvania smartweed; Se. lespedeza, sericea lespedeza.

[b] Values shown are the product of the average crude protein content of the selected weed species minus the average crude protein content of the respective forage sample taken at the same collection location and time.

[c] * indicates significant difference at $P \leq 0.05$; ** indicates significant difference at $P \leq 0.001$.

Table 2.6. Comparisons of *in vitro* true digestibility content between selected weed species and the corresponding weed-free forage sample at each collection timing throughout the season.

Weed Species[a]	Average Collection Date											
	4/19	5/3	5/17	5/31	6/14	6/28	7/12	7/26	8/9	8/23	9/6	9/20
	g kg^{-1} dm[bc]											
Annual fleabane	85.1	167.2*	137.8	21.9	-35.9	-60.7	-17.9	-64.3	4.5	-39.9	----	----
A. marshelder	----	----	----	----	121.3*	131.9*	112.6*	122.5*	87.6*	86.4*	23.6	-38.5
Buck. plantain	59.5	125.3*	110.5*	139.7*	89.3	101.8	76.6	98.5	129.1*	100.9	70.7	119.3*
C. burdock	----	----	92.8	147.1*	156.9*	148.1*	80.7	-42.4	-59.6	-81.1	-103.2	4.6
C. cocklebur	----	----	----	166.7**	136.2**	144.9**	160.0**	145.4**	117.2**	72.3*	54.2*	-30.8
C. ragweed	60.8	106.6*	148.5**	185.2**	183.3**	126.1**	120.5*	73.3*	36.8	12.4	-15.9	-70.7*
C. lambsquarters	----	----	----	147.6	88.5	147.4*	85.3	41.5	-22.3	-59.3	-220.0*	-131.2
Dandelion	70.1*	88.6*	133.2**	182.8**	133.1**	170.1**	186.1**	166.1**	194.5**	153.5**	203.6**	195.5**
Horsenettle	----	77.3	145.9	73.3	48.4	92.9	57.6	-19.1	-10.8	37.5	57.7	5.6
Ironweed spp.	48.1	88.4	88.5	131.8*	109.5*	63.5	39.4	-52.4	-79.9*	-16.8	-158**	-59.8
L. ragweed	----	165.3**	205.8**	196.1**	167.6**	71.6*	75.1*	75.4*	35.8	8.1	-30.4	-77.3*
Large crabgrass	----	----	----	----	----	----	111.8*	12.2	58.5	45.5	25.0	69.9*
Penn. smartweed	----	67.9	115.0**	163.6**	76.1*	65.3*	60.1*	40.6	36.7	-24.9	-12.1	20.0
Se. lespedeza	----	----	----	13.6	13.6	-58.2	-89	-79.2	-126.2*	106.5*	-116.5*	18.4
Spiny pigweed	----	----	----	----	201.2**	173.8**	139.3**	108.2**	131.5**	76.7*	66.8*	108.1**
Tall goldenrod	86.5	161.4*	10.8	73.2	48.6	79.4	25.4	18.4	-30.3	-25.2	-33.7	-159.6*
Vervain spp.	----	71.7	88.4	91.6	96	95.1	70	-55.8	-51.9	-67.5	-7.8	-38.9
White snakeroot	-7.2	82.7	87.9	75.4	91.9	89.6	82.4	-34.9	41.9	-53.5	-64.4	-104.4
Woolly croton	----	----	1.8	12.3	-3.3	-99.6**	-94.5**	-73.9**	-37.9	-95.6*	-141.1*	-126.9*
Yellow foxtail	----	----	----	----	----	----	----	101.0*	84.9*	-26.0	-34.8	-1.3

[a] Abbreviations: A. marshelder, annual marshelder; Buck. plantain, buckhorn plantain; C. burdock, common burdock; C. cocklebur, common cocklebur; C. ragweed, common ragweed; C. lambsquarters, common lambsquarters; L. ragweed, lanceleaf ragweed; Penn. smartweed, Pennsylvania smartweed; Se. lespedeza, sericea lespedeza.

[b] Values shown are the product of the average crude protein content of the selected weed species minus the average crude protein content of the respective forage sample taken at the same collection location and time.

[c] * indicates significant difference at $P \leq 0.05$; ** indicates significant difference at $P \leq 0.001$.

Chapter III

Relationships Between Soil, Forage and Grazing Parameter Effects on Weed Incidence in Missouri Pastures

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Abstract

During the 2015, 2016, and 2017 growing seasons, a survey of 63 pastures in Missouri was conducted to determine the effects of selected soil and forage parameters on the density of common annual, biennial, and perennial weed species. Permanent sampling areas were established in each pasture at a frequency of one representative 20-m^2 area per 4 ha of pasture and weed species and density in each area was determined at 14-day intervals from a period from mid-April until late September. The parameters evaluated included soil pH, phosphorous (P), potassium (K), magnesium (Mg), calcium (C), sulfur (S), zinc (Zn), manganese (Mn), and copper (Cu) concentration, as well as tall fescue density, forage ground cover density, and stocking rate. An increase of one unit in soil pH was associated with 146 fewer weeds per hectare, the largest reduction in weed density in response to any soil parameter. Increased soil pH was associated with the greatest reduction in perennial grass weed density and an average reduction of 1,410 brush weeds per hectare for each one unit increase in soil pH. Common ragweed, a widespread weed of pastures, could be reduced by 3,056 weeds per hectare when soil pH was one unit greater. A one ppm increase in soil P was correlated with a decrease of 206 biennial broadleaf weeds per hectare. Perennial broadleaf weed density was reduced in soils with greater concentrations of P, K and Ca. Additionally, for every 1% increase of tall fescue ground cover and forage ground cover there was a decrease of 18 and 38

perennial broadleaf weeds per hectare. The results from this research indicate that the density of many common weed species can be reduced with greater soil pH and adjustments to soil macro and micronutrient concentrations, especially P.

Introduction

Approximately 73 million hectares of agricultural lands in the U.S. are devoted to pastures and haylands (Sanderson et al. 2012). Additionally, Missouri has an inventory of 2.1 million beef cattle and approximately 25% of farmland in the state is dedicated to pastures (NASS 2018; USDA ERS 2017). The primary source of feed for these animals is forage from pasture and stored forage from haylands. Tall fescue (*Schedonorus arundinaceus* Schreb.) is the predominant forage species in pastures in Missouri and throughout the eastern United States (Glenn et. al. 1981). Although tall fescue is widely grown, cattle performance on tall fescue is often marginal or reduced during summer months (Henning et. al. 1993; Wen 2001). Many pastures are grown in mixtures with legumes, primarily clovers (*Trifolium* spp.), to increase yield and feed quality (Phelan et. al. 2015; Gerrish and Roberts 1999). Mixed tall fescue and legume pastures have the potential to be productive, but improper soil fertility and grazing management of these systems can limit productivity and allow weed invasions.

Forage production in pastures can be negatively affected by soil fertility and pH (Barker and Collins 2018). Decreased soil nutrient levels can lead to increased densities of certain weed species when forage crop stands are reduced (Curran and Lingenfelter 2009). Soil acidity is a serious detriment to forage production which may limit plant growth by reducing nutrient availability and/or nitrogen fixation by rhizobia bacteria on legumes (Barnhart et al. 2013). Weeds compete directly with desired species for resources such as soil nutrients, moisture, light and space (Green et al. 2006). The presence of certain pasture weeds has been correlated with specific soil nutrient and pH levels. For example, broomsedge (*Andropogon virginicus* L.) was reduced in a four-year study after the addition of phosphorous (P) and potassium (K) at 112 kg/ha P_2O_5 and 112 kg/ha K_2O, respectively (Peters and Lowance 1974). The authors noted that P and K fertilization levels allowed the forage species to effectively compete with the weed. Grekul and Bork (2007) reported decreased Canada thistle density in pastures when the forage crop had been fertilized to soil test recommendations. Both studies indicate that maintaining optimum soil fertility levels in pasture systems may allow the desired forage species to outcompete and reduce the incidence of weed species, and that soil pH, P and K levels are three of the most important components of soil fertility in grazinglands.

P is the second most limiting nutrient after nitrogen in forage systems (Barker and Collins 2018). P is important for forage stand establishment and legume persistence (Barnhart et. al. 2013). Forage crops respond more favorably to smaller levels of P than row crops (Bucholz et al. 2004). In the soil, P is generally found in relatively large quantities with low plant availability (Schachtman et al. 1998). More than 80% of soil P becomes immobile and unavailable for plant uptake (Holford 1997). In P-limited growing conditions, forage crops may have reduced yield (Sanderson et al. 1997). K is another important nutrient in forage systems. K is primarily found as a structural component of soils and is mostly unavailable for plant uptake and growth (Kaiser and Rolen 2018). One-tenth to 2 percent of soil K is in a plant available form, therefore additional applications of K may be needed to meet plant requirements (Bucholz and Brown 1993).

Other macronutrients are needed by the forage crop as well. Magnesium (Mg) is essential to the photosynthetic process of plants and functions as the central atom in chlorophyll a and b molecules in leaf chloroplasts (Wilkinson et al. 1990). Mg concentrations in forages are also important to grazing animals. Small Mg concentrations in the leaves of forages may lead to a condition known as grass tetany. Grass tetany is the clinical manifestation of a metabolic disorder characterized by an abnormally low level of Mg in the blood (Metson et al. 1966). Calcium (Ca) is required for structural roles in the cell wall and cellular membranes of plants and is important to cell division and elongation (White and Broadley 2003; Kelling and Schulte 2004). Ca is relatively abundant in most soils and rarely limits plant growth (Kelling and Schulte 2004). The relative abundance of Ca may explain the limited influence Ca concentration has on weed density. Sulfur (S) is a component of many amino acids vital to plant protein synthesis (Schulte and Kelling 1981). S may become unavailable to plants as it leaches into the subsoil and adsorbs to clay particles (Dick et al. 2008). As S levels rise, there is the tendency for soil to become more acidic (Van Breemen et al 1983).

Micronutrients are vital to plant growth and production, but are needed in smaller quantities than macronutrients like N, P, and K (Voss 1998). Zinc (Zn) is found in largely unavailable forms in the soil and may be toxic to crops at large concentrations (Schulte 2004). Manganese (Mn) is more available in acid soils and may become toxic in soils with a pH of 5.5 or less (Schulte and Kelling 1999[a]). Mn is most responsible for oxygen evolution in plants (Burnell 1988). Copper (Cu) is used in relatively small amounts by crops and is found in mostly plant unavailable forms in the soil (Schulte and Kelling 1999[b]).

Grazing animals may also impact weed and forage balance in a pasture. Grazing intensity and pressure can lead to increased incidences of certain species (Popay and Field 1996; Curran and Lingenfelter 2009). Cattle may also avoid areas with greater weed densities; Sather et al. (2013) reported 1.5 to 4.9 times greater cattle grazing in weed-free areas that had been treated with herbicide than in weedy areas not treated with herbicide in the same pasture. Reduced forage utilization near weeds may also lead to overgrazing in other areas of a pasture. However, with proper grazing management, weed encroachment into forage systems can be avoided (DiTomaso 2000).

At present, little research has been conducted that examines the relationship between soil fertility, stocking density, forage density, and weed incidence and severity in mixed tall fescue and legume pasture systems. Therefore, the objective of this research was to determine the effects that soil fertility, soil pH, and grazing and forage system components have on the incidence and severity of weeds in mixed tall fescue and legume pastures in Missouri.

Materials and Methods

A survey was conducted during the 2015, 2016, and 2017 growing seasons at 63 locations throughout the major cattle and forage-producing areas of Missouri (Figure 3.1, Table 3.1). Each location consisted of a mixed perennial grass and legume pasture. The most prominent grass species was tall fescue and the most common legume across all pastures was white clover (*Trifolium repens* L.), however other legumes such as annual lespedeza (*Lespedeza stipulacea* Maxim.), birdsfoot trefoil (*Lotus corniculatus* L.), and red clover (*Trifolium pretense* L.) occurred sporadically in some locations. Specific information pertaining to each pasture site is presented in Table 3.1. There were no herbicide or lime applications made in the previous or current growing season at any pasture site, and cattle were actively grazing each location throughout the surveyed growing season.

At each site, a 20 square meter sampling area was surveyed for every four hectares of pasture at a given survey location. Pasture size ranged from 11.7 to 48.6 hectares. A minimum of four sampling areas were established at each survey location. Sampling areas were established at random throughout the pasture while trying to maintain an accurate representation of the variations found at each survey location. Upon establishment of a sampling area, a five cm diameter plastic survey marker (Survey marker, Lifetime Plastics Corporation, PO box 268, Bricktown, NJ 08723) was placed in the center of each plot and driven into the ground until flush with the soil surface. Survey markers were placed below the forage to avoid grazing interference. Survey markers were georeferenced using a handheld GPS unit (Trimble GeoExplorer 2008 Series, Trimble Inc., 935 Stewart Drive, Sunnyvale, California 94085) in order to return to the same location for future data collection.

Following the establishment of each sampling area, data was collected on 14-day intervals for a total of 12 surveys with the survey dates beginning in mid-April and continuing through late September. At the time of each survey, all weed species within the 20 square meter sampling area were counted and the average height and physiological maturity of each individual weed species was determined. Additionally, each weed species was visually assessed for indications of cattle grazing or avoidance. Indications of grazing would include obvious symptoms of grazing activity on a given weed species. Evidence of grazing avoidance included clear signs of grazing forage species and/or other weeds up to and around a given weed species, but no evidence of cattle grazing on that specific weed itself. All forage grass and legume species were identified within each sampling area, and a visual assessment of the total groundcover contribution of each forage species was conducted. Visual assessment of groundcover was conducted by first determining how much of the survey area was covered in forage species, weed species, and bare ground. During the sixth survey period (late June to early July), soil samples were collected to a depth of 15 cm from each sampling area. Five soil cores were taken from each sampling area in order to make a composite soil sample. Soil sampling occurred during the sixth survey period in order to allow any fertilizer that may have been applied by the landowner in the spring to incorporate into the soil solution. Soil samples were analyzed (Midwest Laboratories 13611 B Street, Omaha, NE 68144) for soil pH, P, K, Mg, Ca, S, Zn, Mn, and Cu levels. Cattle numbers and animal weight were recorded by the landowner. Changes in cattle numbers were recorded when animals were introduced or removed from a pasture. Stocking density was then determined using cattle numbers, weight, and pasture size.

Data Analysis. Interactions between weed species and the recorded parameters of soil fertility, soil pH, groundcover, and animal stocking density were analyzed using a stepwise linear regression procedure (PROC REG) in SAS (Statistical analysis software, SAS 9.4, SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513) at a significance level of 0.15 in order for all variables to be included and remain in the model. Weed density was the response variable in each analysis. Effect variables included soil pH, P, K, Mg, Ca, S, Zn, Mn, Cu concentration, cattle grazing units, total forage groundcover density, and tall fescue density. Cattle grazing units were recorded using the animal unit system, where one animal unit is equal to one 1000 pound cow with calf by her side per acre or an herbage intake of 29.1 kg/ha/day (Redfearn and Bidwell 2003). Weeds were grouped into one of seven life cycles; annual grass, annual broadleaves, biennial broadleaves, brush species, perennial grass, perennial broadleaves, and sedge species, and 24 weeds encountered in the survey were also analyzed for individual weed and parameter interactions.

Results and Discussion

Weed, soil fertility, soil pH and grazing and forage interactions. Across all 63 sites surveyed from 2015 to 2017, an increase of one unit in soil pH (10 times less acidic) was associated with 146 fewer weeds per hectare, the largest reduction in weeds in response to any individual soil parameter (Table 3.3). A one ppm increase in soil P and Mn was correlated with an average density reduction of 62 and 36 weeds, respectively. Furthermore, an increase of one percent tall fescue and forage ground cover density, as well as a one animal unit increase, were also responsible for fewer weeds per hectare. Conversely, there were greater weed densities in response to one ppm increases in soil K, S, Zn, and Cu levels. There was no significant effect of soil Mg or Ca levels when averaged across all weed species.

Annual broadleaf weeds were found in greater densities than many other species in the survey (Table 3.2). Soil pH had the greatest effect on annual broadleaf density, with a decrease of 1,572 weeds per hectare for each one unit increase in pH (Table 3.3). A one part per million (ppm) increase of K and Zn was correlated with a decrease in annual broadleaf density of 12 and 219 plants per hectare, respectively. Greater forage ground cover and stocking density also resulted in annual broadleaf weed density reductions. A one percent increase in forage ground cover was associated with a decrease of 102 weeds per hectare while an increase of one animal unit was associated with 356 fewer weeds per hectare. Conversely, there was an increase in annual broadleaf weed density for every one ppm increase of Mg, Ca, S, and Mn.

Annual broadleaf weeds encountered during the survey included annual fleabane (*Erigeron annuus* (L.) Pers.), common cocklebur (*Xanthium strumarium* L.), common ragweed (*Ambrosia artemisiifolia* L.), lanceleaf ragweed (*Ambrosia bidentata* Michx.) perilla mint (*Perilla frutescens* (L.) Britton), and spiny pigweed (*Amaranthus spinosus* L.) (Table 3.2). When soil pH occurred at greater levels, there was an associated decrease of common ragweed and spiny pigweed, which supports the findings of Singh and Singh (2009) who reported reduced common ragweed emergence as soil pH was increased above 5. However, there was an increase in common cocklebur density when pH levels were greater. (Table 3.4). Increasing P by one ppm had no effect on any common annual broadleaf weed accept for annual fleabane and common ragweed, which were decreased by 74 and increased by 146 weeds per hectare, respectively. Lanceleaf ragweed density was reduced more than any annual broadleaf weed when soil K was found at greater levels. However, common cocklebur and spiny pigweed density was increased by greater soil K levels. Increased Mg levels were associated with increased densities of common cocklebur and lanceleaf ragweed and a decrease of annual fleabane and perilla mint. Common and lanceleaf ragweed were increased by greater S concentrations. Annual fleabane density was reduced when Mn was increased by one ppm. However, there was an associated increase of common and lanceleaf ragweed as well as perilla mint with the same Mn increase. Greater forage ground cover was associated with reduced densities of common cocklebur, common ragweed, and lanceleaf ragweed. Greater stocking density was also associated with reductions of many common annual broadleaf weeds. Density reductions ranged from 816 to 13,662 weeds per hectare when there was a one animal unit increase. Cattle tended to avoid grazing certain annual broadleaf weed species such as common cocklebur, lanceleaf ragweed, and perilla mint during the survey (Table 3.2). The reductions in density for these two weed species suggest that in underutilized pastures, increasing herbage intake may cause otherwise objectionable plants to be grazed. This is of concern with potentially poisonous species such as perilla mint, which was reduced by 4,803 weeds per hectare when there was a one animal unit increase.

Annual grass weed density in the surveyed pastures increased from mid-June until early September which corresponds with the decreased growth of the tall fescue forage during summer (Pritchard et al. 1962). This reduced growth period often allows for the emergence of annual grass weeds. Average annual grass density was reduced when Mg, and S were found at greater levels (Table 3.3). Additionally, greater tall fescue density and forage ground cover were associated with significant reductions of annual grass species. When tall fescue and forage ground cover were found at a 1% greater occurrence, there was a decrease of 129 and 141 annual grass weeds per hectare. Greater concentrations of Ca, Mn, and Cu were associated with greater densities of annual grass weeds.

The most common annual grass weeds encountered in Missouri pastures were large crabgrass (*Digitaria sanguinalis* (L.) Scop.) and yellow foxtail (*Setaria pumila* (Poir.) Roem. & Schult.) with minor occurrences of other species (Table 3.2). Yellow foxtail is one of the most prevalent annual grasses found in agronomic and forage crops

(Santelmann et al. 1963). In the survey it occurred in 86% of pastures (Table 3.2). When soil pH occurred at greater levels, there was an associated increase of large crabgrass and decrease of yellow foxtail (Table 3.4). Greater P levels were associated with increases in yellow foxtail density, but made no significant difference in large crabgrass density. Increased yellow foxtail density in soils with greater P concentrations is similar to the findings of Sexsmith and Russell (1963) who found greater densities of annual grass weeds in spring wheat when supplemental P fertilizer applications were increased from 0 to 44.5 kg/ha. However, greater Cu concentrations were associated with the largest increases in both annual grass weed species. Greater soil K levels were associated with decreased large crabgrass but increased yellow foxtail density. Greater soil Mg and Ca levels, as well as tall fescue and forage ground cover, were also associated with reductions in large crabgrass and yellow foxtail density.

Increased soil pH was associated with greater biennial broadleaf weed density, as was greater levels of soil K, Ca, S, and Zn (Table 3.3). There were associated decreases when P, Cu and forage ground cover density were found at greater levels. A one ppm increase in soil P was correlated with a decrease of 206 biennial broadleaf weeds per hectare while 1% greater forage ground cover was associated with a reduction of 194 biennial broadleaf weeds per hectare.

The primary biennial broadleaf species encountered in the survey were wild carrot (*Daucus carota* L.) bull thistle (*Cirsium vulgare (Savi)* Ten.), and musk thistle (*Carduus nutans* L.) with sporadic occurrences of poison hemlock (*Conium maculatum* L.). Greater soil pH levels were associated with density reductions for bull and musk thistle, poison hemlock and wild carrot (Table 3.4). Musk thistle and wild carrot density was reduced when P was found at greater concentrations in the soil. Greater K levels were associated with increased weed densities for all common biennial weeds. Greater Mg concentrations are associated with decreased thistle density and increased will carrot density. Bull and musk thistle were decreased by 3 weeds per hectare each, when Mg was found at one ppm greater levels. However, there was not a consistent response of bull and musk thistle, poison hemlock, and wild carrot to Ca, S, Zn, and Mn. Greater forage ground cover and stocking density did not influence weed density for any common biennial broadleaf weed. The lack of interaction between thistles and any ground cover parameter may be explained by the bimodal growth habit of tall fescue. Tall fescue flowers, sets seed and reduces growth in late spring (Pritchard et al. 1962). There may be opportunities for thistle seeds to germinate in the reduced forage canopy that occurs in summer. McCarty et al. (1969) reported that two thistle species, musk thistle and plumeless thistle (*Carduus acanthoides* L.), had no dormancy mechanism and initiate flowering and seed production over an extended period from early June until mid-August. Grazing cattle are unlikely to graze thistles in favor of grasses (Tierney 2013). Additionally, cattle are unlikely to graze many poisonous plants due to low palatability (Fishel 2001) and are likely to avoid weeds that have spines (Popay and Field 1996), which may explain the lack of stocking density effects on these species.

Soils with a one-unit greater pH were associated with an average reduction of 1410 brush weeds per hectare (Table 3.3). Greater copper concentrations were associated with large reductions of brush species (3,438 weeds per hectare) while greater Ca, S, Zn, and Mn levels were associated with reduced densities of brush species. Tall fescue density and forage ground cover density also reduced the density of brush weeds, however brush species density was increased with greater concentrations of P and K.

The primary brush weeds found in Missouri pastures were blackberry species (*Rubus* spp. L.), coralberry (*Symphoricarpos orbiculatus* Moench), and multiflora rose (*Rosa multiflora* Thunb.) (Table 3.2). Greater soil pH caused the greatest reductions of any soil fertility parameter for blackberry species and coralberry, but had no effect on multiflora rose density (Table 3.4). Multiflora rose was influenced by few soil parameters. This lack of interaction with soil nutrients supports the results of Steavenson (1946), who reported that in marginal fertility conditions, multiflora rose is vigorous and may not respond significantly to amendments. Greater P levels were associated with an increase in blackberry species density. Blackberry and coralberry density were increased by 150 and 32 weeds per hectare, respectively, when K was found at one ppm greater concentrations. Blackberry and multiflora rose could be reduced when Ca concentrations are increased. There was no consistent response among the brush species to S or Zn, however weed density for the three most common brush species was reduced when Mn concentrations were greater. Brush weed species interactions with soil Cu levels were variable; when Cu was found at one ppm greater levels, there was a decrease of 6,077 and 4,258 blackberry and coralberry plants per hectare, respectively, but no effect on multiflora rose density. Greater levels of tall fescue did not influence blackberry or multiflora rose, but did cause a decrease in coralberry density. Greater forage ground cover was associated with decreases for all common brush species. Increasing forage ground cover was associated with a reduction of 40 blackberry plants per hectare, which supports the findings of Amor (1973), who reported reduced blackberry seedling survival in the presence of shading.

Average perennial broadleaf weed density in Missouri pastures was greater when soil pH and soil Cu was greater (Table 3.3). There was a reduction in perennial broadleaf weed density with greater soil concentrations of P, K and Ca. Greater tall fescue and forage ground cover density were associated with reductions in perennial broadleaf weed density. For every percent increase in tall fescue groundcover, there was a decrease of 18 weeds per hectare. Each 1% increase in forage ground cover resulted in a reduction of 38 perennial broadleaf weeds per hectare.

Common perennial broadleaf weeds found in the survey were broadleaf plantain (*Plantago major* L.), dandelion (*Taraxacum officinale* F.H. Wigg.), horsenettle (*Solanum carolinense* L.), ironweed species (*Vernonia* spp. Schreb.), sericea lespedeza (*Lespedeza cuneata* (Dum. Cours.) G. Don), tall goldenrod (*Solidago altissima* L.), vervain species (*Verbena* L.), and white snakeroot (*Ageratina altissima* (L.) R.M. King & H. Rob. var. *altissima*) (Table 3.2). Greater soil pHs were associated with greater densities of broadleaf plantain, tall goldenrod, and vervain species (Table 3.4). Greater P concentrations resulted in corresponding decreases in broadleaf plantain and tall goldenrod, but an increase of horsenettle. When K occurred at one ppm greater concentrations there was a subsequent decrease of broadleaf plantain and ironweed and an increase in horsenettle, sericea lespedeza, and vervain density. Similarly, the response of perennial broadleaf weed species to soil Ca, S, and Zn levels was variable in that increases in the levels of these nutrients resulted in increases in the density of some species and decreases in the density of others. Greater Mg levels were associated with decreased broadleaf plantain, horsenettle, and ironweed density. Greater Cu concentrations were associated with a large reduction in sericea lespedeza density; when Cu was one ppm greater there was a decrease of 24,690 sericea lespedeza plants per hectare. Greater tall fescue and forage ground cover densities were associated with decreased densities of many common perennial broadleaf weeds and ironweed and tall goldenrod were reduced when stocking density was increased. Ironweed is unlikely to be grazed in favor of other forage (Israel and Rhodes 2013). The 227 and 816 weed per hectare reduction of ironweed and tall goldenrod in the presence of one animal unit greater stocking density is likely an indication of animal acceptance of these weeds when herbage intake is increased.

Perennial grasses were not commonly found during the survey, but could be numerous in locations where they did occur (Table 3.2). Given the perennial nature of the primarily grass forage, perennial grass weeds occupy a similar niche and are in more direct competition with the forage than other weed types. Increased soil pH was associated with the greatest reduction in perennial grass weed density per hectare. When soil pH was one unit greater, there was a corresponding decrease of 2,224 weeds per hectare (Table 3.3). Greater Ca and Mn concentrations, greater forage ground cover and a greater stocking rate were associated with lower perennial grass density, while greater soil K was associated with a greater density of perennial grass weeds. The reduction of perennial grass weeds in the presence of greater stocking densities is consistent with the results from Rocateli and Manuchehri (2017), who recorded reductions in johnsongrass density in pastures with greater stocking rates.

The most common perennial grass species encountered was purpletop (*Tridens flavus* (L.) Hitchc.), which occurred in 32 percent of surveyed pastures (Table 3.2). Soil pH and P did not influence weed density for purpletop (Table 3.4). As with the perennial broadleaf weed species, the response of perennial grass weed species to the levels of other minor elements like Zn, Mn, and Cu was highly variable. Purpletop density was reduced with greater tall fescue density, but there was no interaction with forage ground cover. Greater stocking rate was associated with a reduction of 1,352 purpletop plants per hectare when herbage intake was 29.14 kg/ha/day greater. The United States Department of Agriculture (USDA 2002) indicates that purpletop is grazed by all classes of livestock and may perform better than cool season forages in summer.

Sedge and sedge-like species (*Carex* spp. L.), (*Cyperus* spp. L.), (*Juncus* spp. L.), and (*Scirpus* spp. L.) were found in 86% of surveyed pastures, but were not encountered at densities as great as other common weed species (Table 3.2). Greater soil pH and P levels had no influence on sedge density (Table 3.3). However, there were significant reductions in sedge density associated with greater soil concentrations of K, Ca, Zn, and Mn. Greater forage ground cover percentage was associated with sedge reductions, but greater tall fescue and stocking density did not affect this weed group. Sedge and sedge-like weeds could be increased in soils with greater S concentration.

The results from this research indicate that the density of many common annual broadleaf weed species can be reduced with greater soil pH and macro and micronutrient concentrations. Common ragweed was reduced by 3,056 weeds per hectare when soil pH was one unit greater. Average weed density changes per hectare were not as pronounced as individual weed species because some weeds were reduced by a specific fertility or forage parameter, while other weed species may have been increased by that same parameter. Greater stocking density was associated with a reduction in weed density for all weeds that were influenced by this parameter. Many of the most common pasture weeds can be reduced with increased competition from greater forage ground cover density. Maintaining a vigorous forage crop may be the most important aspect of pasture weed management and increasing any of the measured soil fertility parameters to soil test recommendations would likely increase forage ground cover. The findings of this research illustrate the most influential soil nutrients and forage parameters as they relate to weed incidence in diverse grazing systems.

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Figure 3.1 Locations of pastures surveyed in Missouri from 2015 to 2017.

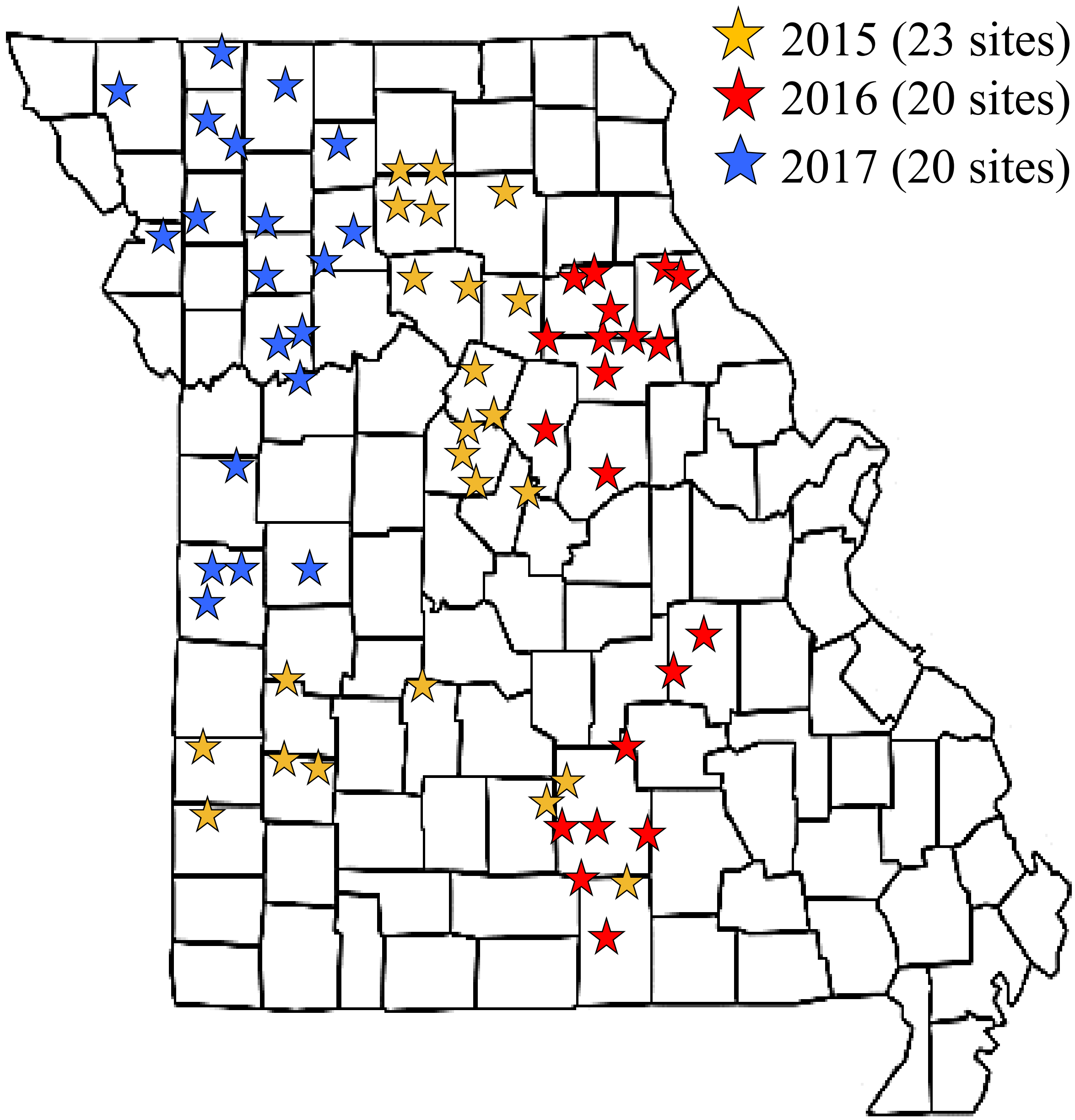

Table 3.1. Site characteristics for each pasture location surveyed from 2015 to 2017.[a]

Location	Soil Series	pH	P	K	Mg	Ca	S	Zn	Mn	Cu
39.36586, -91.87598	Mexico silt loam	5.8	8	82	226	1885	12	0.9	12	1
39.38357, -91.42166	Crider silt loam	6.1	17	65	203	1426	10	0.5	11	0.8
38.88450, -91.71568	Armster cobbly loam	5.7	27	108	197	2268	13	1.3	12	1
39.54646, -92.17271	Mexico silt loam	5.6	25	87	262	1987	11	1.1	11	1.1
39.54578, -91.80221	Leonard silt loam	5.2	7	77	141	1657	11	2.1	11	1
39.53994, -91.76583	Armstrong loam	6.3	16	90	142	1573	10	1	11	1
39.49586, -91.52676	Gorin silt loam	5.8	14	104	169	1815	9	1.4	11	1
39.60349, -91.35433	Winfield silt loam	5.7	12	103	213	1472	10	6.2	14	1.4
39.35274, -91.92041	Leonard silt loam	5.8	16	122	315	1767	15	2	13	1
39.25948, -91.38110	Gorin silt loam	5.7	8	54	125	1168	8	0.4	19	0.7
39.14795, -92.08267	Armstrong loam	5.7	5	84	225	1460	13	0.8	10	0.9
38.85299, -92.47108	Hartville silt loam	6.5	53	221	181	1157	18	2.6	26	1.3
38.81666, -92.57087	Leslie silt loam	5.2	15	203	178	1230	13	1.9	20	1.2

38.90488, -92.26306	Armstrong loam	6.8	52	194	230	2192	13	0.8	10	1.1
39.80560, -93.97551	Lamoni loam	5.7	20	283	626	4528	27	1.8	18	2.3
39.28156, -92.69848	Grundy silt loam	5.4	16	135	232	1549	18	2.1	14	1.4
39.03919, -92.81324	Menfro silt loam	5.4	16	149	441	2056	19	2.1	12	1.4
38.77083, -92.53566	Bluelick silt loam	6.1	43	210	176	1816	16	2.1	16	1
39.62908, -93.51987	Greenton silty clay	6.2	16	217	388	3142	33	3.12	18	1.8
39.52624, -93.73962	Greenton silty clay	6.2	55	341	1192	7350	24	3.03	13.3	2.5
39.61247, -93.57825	Lagonda silty clay loam	5.7	16	200	657	3956	29	3.04	17.6	2.44
39.78806, -93.26204	Armstrong clay loam	5.2	22	112	194	1578	18	2.1	19	1.6
39.78135, -93.30681	Grundy silt loam	5.9	20	163	255	2156	17	2.5	10	1.2
39.88377, -93.31869	Armstrong clay loam	5.7	8	84	167	2669	12	0.9	11	0.7
39.93508, -93.24896	Armstrong clay loam	5.2	7	102	291	1899	12	0.6	8	1.1
39.36348, -92.44735	Leonard silt loam	5.7	14	91	235	2030	40	1.5	13	1.5
39.76684, -92.46246	Keswick clay loam	6.6	6	120	245	2686	12	1.2	6	1.1

38.89027, -92.52972	Menfro silt loam	5.3	28	143	207	1364	11	1.7	20	1.2
39.47081, -92.94082	Grundy silt loam	5.3	12	106	238	1642	16	2.3	12	1.2
39.63022, -92.99381	Armstrong loam	5.9	8	150	338	1829	14	1.5	7	0.9
39.12029, -93.93756	Knox silt loam	6.7	62	424	321	2831	19	3	10	0.9
40.23643, -94.50482	Grundy silt loam	6.1	16	422	936.4	5287	34	2.08	10	2.28
40.45798, -93.82981	Lagonda silty clay	5.8	17	88	295	7445	36	2.28	16.4	1.96
40.32059, -94.99540	Higginsville silty clay loam	6.4	124	888	912	5543	39	6.8	9.5	3.3
40.34711, -94.58754	Lamoni clay loam	5.8	4.8	155.5	433	2831	24	1.6	7.3	1.3
40.03906, -94.78132	Gara loam	6.0	12	298	555	4120	34	5.1	18	2.1
39.63568, -94.60703	Colo silt loam	5.9	19.5	493	678	3984	39	3.5	18.5	2.35
39.35918, -93.80260	Lagonda silty clay	6.0	77	352	666	4798	36	7.13	16.6	2.7
39.24384, -94.10609	Knox silt loam	5.8	10	324	588	3674	34	3.32	17.6	2.08
40.00721, -93.57006	Grundy silty clay	6	68	385	590	4600	24	5.7	18.4	2.8
40.52461, -94.39596	Adair and Shelby loams	6.1	21	326	1036	5398	41	2.9	12.8	2.4

37.47158, -93.85844	Goss silt loam	6.2	23	190	133	2344	15	5.5	21	0.9
37.31187, -94.42010	Barco loam	6.0	68	204	216	1810	27	13.2	9	1.4
37.34872, -93.90533	Pomme silt loam	5.1	35	143	117	1515	18	3.3	25	0.8
37.54884, -94.45826	Barco loam	5.4	9	125	158	1666	14	4.2	15	0.9
37.83828, -94.05377	Barco-sylvania complex	5.4	10	56	133	1125	10	1.1	10	0.5
38.70332, -94.30080	Arisburg silt loam	5.9	9	195	623	3970	23	2.3	16	2
38.24466, -94.36732	Verdigris silt loam	5.7	25	319	561	4480	38	1.8	21.7	2.7
38.43329, -94.19888	Summit silty clay	5.9	15	283	780	5598	27	1.8	18	2.25
38.49004, -93.90847	Hartwell silt loam	6.2	18	214	522	5147	144	5.4	16.4	3.96
38.39251, -94.20122	Coweta loam	5.9	18	506	462	6601	37	6.2	19	3.6
38.18060, -91.23511	Gravois silt loam	6.6	4	55	262	1987	12	0.5	9	0.5
37.39518, -92.33871	Viraton silt loam	6.6	19	152	321	1009	14	1.7	11	0.6
36.88707, -91.80091	Taherhill silt loam	5.8	16	105	188	756	12	1.4	26	0.5
37.38831, -92.13380	Poynor very gravelly silt	5.3	14	116	126	566	12	1.4	22	0.4

37.31559, -92.13347	Mano-ocie complex	6.2	8	92	120	333	13	1.3	37	0.5
37.23875, -91.89613	Tonti silt loam	6.0	6	111	101	398	15	1.3	31	1
37.25777, -91.74920	Viburnum silt loam	5.0	26	128	153	985	10	1	26	0.5
37.40146, -92.32824	Viraton silt loam	5.6	8	52	124	801	9	0.7	23	0.4
37.38098, -92.35349	Viraton silt loam	5.3	10	141	139	770	20	1.8	49	0.7
37.91409, -91.12894	Hildebrecht silt loam	6.4	2	59	387	949	10	1.6	10	1.1
37.72889, -93.13942	Viraton silt loam	6.1	18	142	460	1589	18	2.3	15	1.2
37.58329, -91.71790	Lebanon silt loams	6.0	41	74	222	610	11	0.6	11	0.5

[a] Abbreviations: pH, soil pH in water; P, phosphorous; K, potassium; Mg, magnesium; Ca, calcium; S, sulfur; Zn, zinc; Mn, manganese; Cu, copper. Soil nutrients listed as parts per million (ppm).

Table 3.2 Incidence, density, and grazing frequency of common weeds in Missouri pastures from 2015 to 2017.

Weed Species[a]	Life Cycle	Weed incidence in Surveyed Pastures (%)	Density per hectare	Grazing frequency (%)
Ann. Fleabane	Annual Broadleaf	70	2357	39
Blackberry spp.	Brush	19	5653	2
Brdlf. Plantain	Perennial Broadleaf	77	3012	50
Bull Thistle	Biennial Broadleaf	29	1107	2
C. Cocklebur	Annual Broadleaf	32	3937	6
C. Ragweed	Annual Broadleaf	97	16343	28
Coralberry	Brush	49	5009	2
Dandelion	Perennial Broadleaf	85	3966	86
Horsenettle	Perennial Broadleaf	100	7272	0
Ironweed spp.	Perennial Broadleaf	68	4984	8
L. Crabgrass	Annual Grass	67	19412	54
L. Ragweed	Annual Broadleaf	51	23711	3
Multiflora Rose	Brush	24	980	0
Musk Thistle	Biennial Broadleaf	19	948	1
Perilla Mint	Annual Broadleaf	13	5071	0
P. Hemlock	Biennial Broadleaf	6	2941	0
Purpletop	Perennial Grass	32	4243	28
S. Lespedeza	Perennial Broadleaf	11	2188	6
Sedge spp.	Sedge	87	2762	38
Spiny Pigweed	Annual Broadleaf	14	3179	8
Tall Goldenrod	Perennial Broadleaf	43	4879	14
Vervain spp.	Perennial Broadleaf	72	1410	4
W. Snakeroot	Perennial Broadleaf	43	4879	2
Wild Carrot	Biennial Broadleaf	52	6868	17
Yellow Foxtail	Annual Grass	86	17277	69

[a]Abbreviations: Ann. Fleabane, annual fleabane; Brdlf. Plantain, broadleaf plantain; C. Cocklebur, common cocklebur; C. Ragweed, common ragweed; L. Crabgrass, large crabgrass; L. Ragweed, lanceleaf ragweed; P. Hemlock, poison hemlock; S. Lespedeza, sericea lespedeza; W. Snakeroot, white snakeroot

Table 3.3. Change in density of annual, biennial, and perennial broadleaf, biennial broadleaf, annual and perennial grass, and sedge species in response to a 1 unit increase of a given soil nutrient, forage, or grazing parameter.

	Observed Parameters												
Life Cycle [a]	pH	P	K	Mg	Ca	S	Zn	Mn	Cu	Tall Fescue	Forage ground cover	Animal Units [b]	R^2
	Change in density / ha per 1 unit increase [cd]												
A. Broadleaf	-1572*	----	-12*	9	1*	145	-219*	123	----	----	-101	-355*	0.04
A. Grass	----	----	----	-9*	3*	-149**	----	222	4464*	-129	-141	----	0.13
Bi. Broadleaf	2880	-206	21*	----	2	393	612	----	-1726**	----	-194***	----	0.20
Brush Species	-1410	38	19	----	-1*	-118	-120	-59*	-3438	-15**	-37	----	0.16
Per.Broadleaf	1598	-17	-3**	----	-2	----	----	----	2165	-18	-38	----	0.05
Per. Grass	-2224*	----	46	----	-4	----	----	-373	----	----	-77	-1172*	0.16
Sedge Spp.	----	----	-22	----	-1*	78	-137*	-95*	----	----	-24*	----	0.07
Ave. Change	-146	-62	8	0	0	70	34	-36	366	-54	-87	-764	

[a]Abbreviations: A. grass, annual grass; A. Broadleaf, annual broadleaf; Bi. Broadleaf, biennial broadleaf; Per. Grass, perennial grass; Per. Broadleaf, perennial broadleaf; CEC, cation exchange capacity; P, phosphorous; K, potassium; Mg, magnesium; Ca, calcium; S, sulfur; Zn, zinc; Mn, manganese; Cu, copper.

[b] One 1000 lb cow with calf/acre (herbage intake 29.14 kg/ha/day)

[c] 1 unit increase = Increase of 1 unit soil pH; 1 ppm for P, K, Mg, Ca, S, Zn, Mn, Cu; 1% total ground cover for fescue, forage ground cover; increased herbage intake of 29.14 kg/ha/day.

[d]$P < 0.001$, $P < 0.05$*, $P < 0.10$**, $P < 0.15$***

Table 3.4. Change in density of common weed species encountered in Missouri pastures in response to a 1 unit increase of a given soil nutrient, forage, or grazing parameter.

	Observed Parameters												
Weed Species[a]	pH	P	K	Mg	Ca	S	Zn	Mn	Cu	Tall Fescue	Forage ground cover	Animal Units[b]	R^2
	Change in density / ha per 1 unit increase[cd]												
Ann. Fleabane	----	-74	-14*	----	----	----	----	-75*	----	----	----	----	0.03
Blackberry spp.	-6895	608*	150	----	-11	----	486*	-383	-6077*	----	-40**	-3077	0.54
Brdlf. Plantain	2438	-88*	-18*	-7*	----	104*	1689	-114*	----	----	----	----	0.13
Bull Thistle	-608*	----	5*	-3*	1*	----	----	----	-843*	----	----	----	0.16
C. Cocklebur	3863	----	7**	----	----	----	-634	----	----	----	-67	-1427**	0.29
C. Ragweed	-3056*	146	----	11	2**	182	-298*	227	----	----	-56*	-816*	0.05
Coralberry	-4280	----	32	----	----	-601	-342	-154	-4258	-40*	-55	----	0.25
Dandelion	----	----	----	----	----	----	----	-1152	----	-74	64	----	0.11
Horsenettle	----	47*	10	-5	-1	----	----	----	----	-11**	----	----	0.05
Ironweed spp.	----	----	-17*	-13	2	-43**	----	-149	----	----	-87	-227**	0.15
L. Crabgrass	5473*	----	-47*	-24*	4***	----	----	630	10495*	-138**	-259	----	0.32
L. Ragweed	----	----	-73	59	----	190**	-1499	504	----	----	-361	-13662	0.22
Multiflora Rose	----	----	----	-3	-1	----	----	-73	----	----	-4**	----	0.26
Musk Thistle	-224*	-27	5	-3	-1	----	----	----	1226	----	----	----	0.75
Perilla Mint	----	----	----	-166	----	----	----	229*	26218	----	----	-4803*	0.83
P. Hemlock	-36534	----	----	----	15	-6335	----	----	----	89	----	----	0.94

Purpletop	----	----	40	----	----	-214	310	----	-5541	-24	----	-1352	0.58
S. Lespedeza	----	----	65*	----	7*	-1004*	----	----	-24690	----	----	----	0.35
Spiny Pigweed	-2939*	----	----	----	3*	-467*	1930*	----	-4808*	----	----	----	0.45
Tall Goldenrod	2381*	-179*	----	----	-7	314	761*	-107**	6099	----	-38*	-816*	0.22
Vervain spp.	991*	----	17	----	----	----	-188*	88*	----	16**	-64	----	0.17
W. Snakeroot	----	----	----	----	----	-41*	-745*	----	2269*	61	-72	----	0.15
Wild Carrot	3681	-369	49	----	-1**	243*	710	169*	-2435*	----	----	----	0.23
Yellow Foxtail	-2385**	191	33*	-7*	3*	-275*	----	-426	5868*	-171	-84*	----	0.25

[a] Abbreviations: : Ann. Fleabane, annual fleabane; Brdlf. Plantain, broadleaf plantain; C. Cocklebur, common cocklebur; C. Ragweed, common ragweed; L. Crabgrass, large crabgrass; L. Ragweed, lanceleaf ragweed; P. Hemlock, poison hemlock; S. Lespedeza, sericea lespedeza; W. Snakeroot, white snakeroot; P, phosphorous; K, potassium; Mg, magnesium; Ca, calcium; S, sulfur; Zn, zinc; Mn, manganese; Cu, copper.

[b] One 1000 lb cow with calf/acre (herbage intake 29.14 kg/ha/day)

[c] 1 unit increase = Increase of 1 unit soil pH; 1 ppm for P, K, Mg, Ca, S, Zn, Mn, Cu; 1% total ground cover for fescue, forage ground cover; increased herbage intake of 29.14 kg/ha/day.

[d]$P < 0.001$, $P < 0.05$*, $P < 0.10$**, $P < 0.15$***