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Improving Sustainability Using Cover Crop Grazing to Improve Soil Health and Fertility While Increasing Grain and Livestock Production

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IMPROVING SUSTAINABILITY USING COVER CROP GRAZING
TO IMPROVE SOIL HEALTH AND FERTILITY
WHILE INCREASING GRAIN AND LIVESTOCK PRODUCTION

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Dedicated to my parents, Adam and Kristi Ewing

and my fiancé Shawn.

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IMPROVING SUSTAINABILITY USING COVER CROP GRAZING TO IMPROVE SOIL HEALTH AND FERTILITY WHILE INCREASING GRAIN AND LIVESTOCK PRODUCTION

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Directed by: Dr. Phillip Gunter, Dr. Fred DeGraves, and Dr. Todd Willian

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Cover crops have become an increasingly popular option for alleviating agronomic and environmental concerns, such as erosion. Dual utilization can increase forage use efficiency and increase immediate economic return but understanding the impact on soil health and grain production may affect viability of this strategy. In a two-year study conducted in Bowling Green, Kentucky, soil health was analyzed comparing three treatments: grazed wheat (*Triticum aestivum*; WGR) to un-grazed wheat (W) and grazed tall fescue (*Festuca arundinacea*; TF). Sixteen cow calf pairs were randomly allocated to grazed wheat or tall fescue for two weeks. Soil samples were analyzed following grazing to quantify soil physical and chemical parameters. Grain production was measured for production and quality characteristics. Data was analyzed with treatment x year interaction as a fixed effect and included if significant. Soil pH in fall sampling varied in TF from both W and WGR ($P<0.0001$). pH level varied between all years ($P<0.0001$). Treatment varied for OM with greater levels in TF compared to W ($P=0.0002$) and W compared to WGR ($P=0.0197$). Year varied significantly with 2017 OM (22.81 g/kg) greater than 2018 (3.03 g/kg; $P<0.0001$) and 2019 (3.14 g/kg; $P<0.0001$). TF was greater in N than WGR in both fall ($P<0.0001$) while W was greater than WGR in both spring and fall ($P=0.0052$ and $P<0.0001$ respectively). N was greater in fall 2019 than 2018 ($P<0.0001$) and 2017 ($P<0.0001$) and differed between all years in

spring sampling. NO_3^- varied between treatment in both spring and fall and between years. In spring sampling, 2018 NO_3^- (9.21 ppm) was greater than 2017 (4.40 ppm; $P<0.0001$) and 2019 (4.06 ppm; $P<0.0001$). Fall sampled NO_3^- level was greater in 2019 (11.21 ppm) than 2017 (8.91 ppm; $P=0.0001$) and 2018 (5.16 ppm; $P<0.0001$). NH_4^+ varied between year in fall with the greatest content in 2017 (11.23 ppm) compared to 2018 (3.25 ppm; $P<0.0001$) and 2019 (4.39 ppm; $P<0.0001$). Cash crop production traits were not significantly impacted by treatment during this study. N fertilizer application may have contributed to overall increased soil N levels. Differences in OM could have been due to lack of residue in un-grazed wheat. Overall, minimal location x year interaction suggests that grazing had minor impact on soil health after one grazing period. Further research is required to thoroughly investigate the impact of cover crop grazing on soil health.

I. Review of Literature

Introduction

The erosion of soil has been a concern for producers and environmentalists alike. Erosion can reduce crop productivity and yields (Magdoff and Van Es, 2009) as well as contribute to air pollution, water pollution, and other environmental concerns (Poesen et al., 2003). Cover crops have become an increasingly popular method of reducing erosion on cropland (USDA, 2017). However, implementation of cover crops has been slow, partially due to the lack of immediate economic benefits (Franzluebber, 2007). Grazing by livestock during winter months may improve the economic benefit of using cover crops. The available forage can be used more efficiently and potentially reduce feeding costs through the winter (Penrose et al., 1996). This study was conducted by grazing purebred Angus cow/calf pairs on cover crops. Lactating cows require increased nutrients thus, poor quality forage may lead to nutrient deficiencies, particularly through the winter (Short et al., 1990). Cover crops aid in meeting nutrient requirements of lactating cows (Fraase et al., 2010) and can help maintain cow body condition score, enable rebreeding to occur in a timely manner, and optimize calving interval (Short et al., 1990). Cover crops may also facilitate conditions expected to improve calf preweaning environment and ensuing weaning weight (Jeffery and Berg, 1971). This study investigates the impact of cover crop grazing by cattle on soil physical and chemical parameters and characteristics of both soybean and corn production. The following literature review provides a brief history and description of each of the main components in this study.

Cover Crops

Benefits

Cover crops are defined by the Soil Science Society of America (SSSA, 2008) as "a close-growing crop that provides soil protection, seedling protection, and soil improvement between periods of normal cash crop production". Cover crops are used to improve production of subsequent crops by enhancing physical, chemical and biological soil properties as well as improving many other environmental and agronomic components (Weil and Kremen, 2007; Fageria et al., 2005).

Soil health can be improved with cover crops by improving soil structure, increasing organic matter, and enabling diverse, biologically active microbial populations (Blackshaw et al., 2005). The type of cover crop will affect the impact on these characteristics as will type of soil, tillage and cropping system, management history, and climate (Blanco-Canqui et al., 2011).

Soil organic matter (SOM) contributes to soil fertility through the process of decomposition which results in the release of nutrients (Nelson and Sommers, 1996). SOM can impact availability of nutrients, soil structure, water infiltration, cation exchange capacity, and soil temperature (Nelson and Sommers, 1996). Cover crops can increase organic matter because they often produce high levels of biomass (Reeves, 1997). A large portion of SOM is denoted as soil organic carbon (SOC). Soil organic carbon is vital to quality and productivity of soils, partly by reducing nitrate loss from leaching (Fageria et al., 2005). Deep-rooted cover crops can improve SOC in the soil as root derived carbon (C) has a lower turnover rate than shoot-derived carbon (Fageria et al., 2005). To improve SOC quickly, cereal cover crops are most beneficial as they produce the largest amount of biomass (Cupina et al., 2011).

Decomposition processes that break down organic molecules and convert to plant accessible forms are largely driven by soil biology (Friedel et al., 2001). Cover crops can be utilized to increase populations of biological micro- and macro- organisms such as fungi, bacteria, and earthworms. Vukicevich et al. (2016) reviewed available literature and reported that utilization of cover crops increased microbe diversity, aiding in mitigation of soil-borne pathogens. Biological health is largely impacted by the roots of cover crops which enable restoration and maintenance of soil structure. Fungi produce a glycoprotein which aids in formation and preservation of soil aggregates (Wright et al., 1999). Aggregates function in the soil to regulate microbial structure, water flow, nutrient absorption, and reduce run-off and erosion. When cover crops are utilized earthworm population density increases, which is correlated with aggregate conservation and increased water infiltration (Stavi et al., 2012).

A major concern of cash crop producers is the impact of compaction on subsequent crop production. Usage of machinery, grazing by livestock, and weather conditions may contribute to increased compaction and thus reduced production. This reduced production is caused partially by restricted root growth, limiting plant access to water and nutrients (Williams and Weil, 2004). One method to reduce compaction is deep tillage; however, this is a time and labor-intensive option that may contribute to environmental damage through erosion, water pollution, and nutrient leaching (Horn et al., 2000). Another method is the usage of cover crops to mitigate compaction. Ability of a cover crop species to break compacted layers of soil varies. Tap-rooted species, such as the mustard (*Brassicaacene*) family, may aid in alleviating compaction. Fibrous-rooted species are less effective at penetrating compacted layers in comparison to the long and thick taproot of many Brassica species (Chen and Weil, 2010). Winter killing brassicas initiates rapid decomposition of roots leaving open channels which subsequent crops use to promote root growth (Williams and Weil, 2004). Williams and Weil (2004) found that utilization of a cover crop improved soybean grain yield partially because soybean roots penetrated compacted soil by following channels created by the cover crop. Cores taken to a depth of 55 centimeters had 10 times more corn roots where tillage radish was used as a cover crop versus no cover crop (Weil and Kremer, 2007).

Soil aggregate formation may be amplified by increased porosity from cover crop roots which can increase soil water-holding capacity (Dabney et al., 2001). Residue produced by cover crops may reduce evaporation thus improving water conservation of the soil. This may delay planting during certain weather conditions such as an overly wet spring (Clark et al., 2007). Adversely, cover crops may cause a shortage of water for subsequent cash crops when rainfall is unusually low (Unger and Vigil, 1998). Species of cover crop can impact subsequent crop water use or where water-holding occurs, in the subsoil or the soil above the plow pan (Weil and Kremer, 2007).

Soil that is exposed can lead to erosion by wind and rain, which inhibits crop growth by reducing water infiltration, percolation, aeration, root growth, and nutrient profile of the soil (Magdoff and Van Es, 2009). Soil degradation can also have environmental effects beyond the loss of crop production. It can lead to increased pollution and sedimentation in waterways (Poesen et al, 2003). Degraded soils are often less able to hold water which can lead to increased damage from flooding. Soil degradation by wind can cause air pollution to increase. By increasing soil coverage cover crops can reduce interrill erosion (Kaspar and Singer, 2011). Cover crops can also reduce surface run-off by preventing surface sealing, increasing water-holding capacity, and improving soil structure (Dabney, 1998).

Legume cover crops are capable of fixing nitrogen (N), increasing soil N availability for subsequent crops (Weil and Kremer, 2007). This can provide a cheaper source of N than inorganic fertilizers, depending on market price. Usage of legumes provides a high-quality grazing forage and can reduce N fertilizer application requirements and therefore production costs (Samarappuli et al., 2014). Ability of nitrogen fixation depends on the species of legume, environmental conditions, and management. Legumes are commonly inter-seeded with other species to provide a high-quality forage while mitigating health concerns such as bloat.

Nutrient losses, such as nitrogen and phosphorus, from crop production has become a significant environmental concern. Leaching, denitrification, and ammonia volatilization can contribute to groundwater pollution and eutrophication (Dean and Weil, 2009) while gaseous losses increase acid rain (Robertson and Vitousek, 2009). Ability to scavenge soil N depends upon rate of growth in the root system (Meisinger et al., 1991). Meisinger et al. (1991) reported that usage of cover crops reduced N leaching compared to areas where no cover crops were used. Kristensen and Thorup-Kristensen (2004) found that radish had increased NO_3^- capture versus rye from deep soil layers. Planting date can impact the effectiveness of N capture. Brassicas often grow late into fall, uptaking NO_3^- before it leaches. However, if planting is delayed in cool weather conditions uptake of NO_3^- decreases (Weil and Kremen, 2007). Alternatively, planting of brassicas too early may decrease NO_3^- uptake as the crop will reach reproductive growth (Eichler et al., 2004). This is demonstrated in a study that found turnips planted in sandy soils in August reduced N leaching by over 90% (Macdonald et al., 2005) in comparison to turnips established in later months which only reduced leaching by 19.7% (Vos and van der Putten, 2004). N is utilized by forage species however, N is accumulated in cover crop tissue and as the tissue decomposes N cycles back to the soil (Gieske et al., 2016). The effectiveness of this nutrient release for the next crop varies based on: rainfall, species, temperature, and other factors (Decker et al., 1994). In addition to nitrogen, phosphorus run-off has become a major environmental concern. Brassica species can uptake soil phosphorus (P), accumulate P in their tissue, and provide P to the next crop as they decompose (White and Weil, 2010). This is positive for nutrient recycling but may increase run-off P losses. Compared to other cover crops, Liu et al. (2014) found that perennial ryegrass (*Lolium perenne*) and red clover (*Trifolium pratense*) lost P more quickly when exposed to freezing/thawing cycles.

Cover crops are generally used during fallow periods during which weed pressure is an issue. There are several methods of suppression that cover crops provide to decrease weed presence. Seed germination of weeds may be inhibited by shading of other forage (Holt, 1995). Competition for light, water and nutrients may also inhibit growth of weeds (Holt, 1995). Additionally, brassicas have been found to reduce soil fungal pathogens and increase disease-suppressive bacteria populations (Vukicevich et al., 2016). This is accomplished by the production of isothiocyanate (ITC) and other compounds that negatively impact certain pests (Weil and Kremer, 2007). In a study by Mari et al. (2008) ITC was found to reduce the growth of brown rot fungus (*Monolinia fructicola*). Usage of cover crops may aid in reducing inputs such as herbicide use through allelopathic weed control (Haramoto and Gallandt, 2004).

Challenges

One of the largest concerns with using cover crops is the direct costs associated with cover crop seed, labor, fuel, fertilizer, and herbicide or tillage to terminate the cover crop (Snapp et al., 2005). Another concern is that in some cases, cover crops can reduce the cash crop yield by using water reserves in the soil, immobilizing nitrogen, and by heavy residue cover which can hinder crop stand establishment (Dabney et al., 2001). Plants in the brassica family do not host arbuscular mycorrhizal fungi (AMF) and many species produce anti-fungal isothiocyanates (ITC) which can negatively impact AMF populations of the next crop (White and Weil, 2010). Cover cropped areas may have decreased soil temperature during planting of cash crop compared to conventional tillage due to increased residue (Snapp et al., 2005). This decrease in soil temperature of cover crop soil may slow emergence and development of cash crop seedlings in the spring (Dabney, 2007).

Wheat

History

Domestication of wheat (*Triticum aestivum*) is thought to have occurred approximately 10,000 years ago (Harlan and Zohary, 1966). This domestication arose around the same time that human transition to sedentism occurred (Harlan, 1992). Ancestors of cultivated wheat species likely originated in the Near East (Feldman, 2001). Polyploidy is common among wheat species with diploid, tetraploid, and hexaploid forms

(Levy, 2002). Modern hexaploid wheat species (*T. aestivum*) originated after domestication of diploid and tetraploid wheat species (Feldman, 2001). Wild wheat species are hulled meaning they have glumes that tightly enclose the grains (Feldman, 2001). Free-threshing wheat evolved which had light glumes that can be removed easily (Feldman, 2001). Bread wheat, *T. aestivum*, accounts for approximately 95% of the world's wheat production while durum (*T. durum*) wheat accounts for the other 5% (Peng et al., 2011). The United States produces five major classes of wheat: hard red winter, hard red spring, soft red winter, white, and durum (AG, MRC, 2018). Sixty percent of wheat produced in the U.S. is hard red winter and hard red spring (AG, MRC, 2018). Each class of wheat is generally produced regionally and has differing end-products (AG, MRC, 2018).

In the United States wheat is the third-largest crop following corn and soybeans (AG, MRC, 2018). The U.S. produced 1.2 billion bushels of wheat in 2018 (USDA, NASS, 2019). Approximately 13.17 million hectares were planted to wheat in the U.S. in 2018 (USDA, NASS, 2019). Wheat production in the U.S. has declined; from 2001 to 2017 the U.S. share of the global wheat market declined about 10% (USDA, ERS, 2018). In Kentucky, wheat was planted on approximately 182,108 hectares with approximately 19.8 million bushels harvested in 2018 (USDA, NASS, 2018).

Growth Characteristics, Productivity, and Management

Wheat is an annual C_3 bunchgrass of the family Poaceae (Ball et al., 2002). It stands approximately 0.61 to 1.23 meters tall (Ball et al., 2002). Thirty-five to 45 percent water content in the seed is required for wheat to germinate (Evans et al., 1975). Optimal temperature for germination is 12° to 25° C but may occur between 4° and 37°C

(Acevedo et al., 2002). Although seed size does not impact germination, bigger seeds do have an advantage over smaller seeds in seedling growth and grain yield (Spilde, 1989). This advantage is particularly apparent when the plant is under environmental stress, particularly drought stress (Mian and Nafziger, 1994). Seeding should occur while soil and air temperatures are warm enough to ensure seedling emergence and development of the root system and tillers (Nagelkirk, 2019). Ideal seed depth is dependent on a number of factors but generally should be no deeper than 25.4 to 38.1 millimeters (Nagelkirk, 2018).

Wheat responds to vernalization in two different manners (Flood and Halloran, 1986). Spring wheat varieties have mild or zero response to vernalization and are vulnerable to frost. Winter-type wheat varieties have a strong response to vernalization and are highly resistant to frost during early growth, although this resistance gradually decreases as heading and flowering occurs (Flood and Halloran, 1986). Wheat varieties are sensitive to photoperiod although this varies among genotypes (Acevedo et al., 2002). The majority of cultivated wheat varieties are long-day plants which flower faster as day-length increases (Major and Kiniry, 1991).

Water stress during the spike period of growth negatively impacts grain yield by decreasing grain number (Hochman, 1982). Drought conditions during grainfill do not impact the number of tillers however, it does reduce grain weight (Kobata et al., 1992). High temperatures can negatively impact wheat yield by accelerating plant development (Acevedo et al., 2002). High temperatures during establishment of the potential number of grains has the greatest negative impact on grain yield (Acevedo et al., 2002).

Conversely, severe frosts can negatively impact yield; the more advanced the plant is developmentally, the more vulnerable it is to frost (Acevedo et al., 2002).

A four-year study by Bockus et al. (2001) reported annual losses of 10-22% due to diseases. The greatest loss was caused by leaf rust (*Puccinia triticina*) with an average of 3.48% annual loss, wheat streak mosaic virus with 1.88% loss, and *Septoria* diseases causing 1.6% loss (Bockus et al., 2001). Powdery mildew is an impactful disease of wheat worldwide however, there are resistant cultivars available (Wang et al., 2005). Wheat yields in the U.S. are threatened by armyworms and cereal leaf beetles (Nagelkirk, 2012).

Nutrient Characteristics, and Animal Performance

Both winter and spring wheat cultivars can be used in a double-crop system, generally before soybeans (Bruening, 2007). Wheat may also be used as a dual-purpose crop for both forage and grain production (Cash et al., 2007). Wheat forage may be grazed or cut for hay and silage (Bruening, 2007). It has been established that cereal plants provide nutritious forage for livestock during winter months (Cash et al., 2007). A dual-purpose wheat cultivar needs to be sown as early as mid-August and should have vigorous growth in the fall thus, the seed must be able to germinate in warm soil temperatures (Carver, 2009). Cash et al. (2009) found that in the U.S. dual-purpose wheat varieties average DM yield is approximately 4 t/ha although this is variable depending on cultivar and location.

Wheat can be grazed from complete tillering until the first hollow-stem stage without encumbering grain yield (Carver, 2009). Grazing after the first hollow-stem stage is reported to reduce grain yield by 20-50% (Winter and Musick., 1991). Stocking rate and weather conditions may impact subsequent wheat yield. Wet weather conditions can cause trampling and pugging which damage the plant and reduces yield (Carver, 2009). When cut for hay or silage, wheat should be cut at the boot stage or early head emergence to ensure high palatability and nutritive values (Boyles et al., 2010).

Wheat forage has high nutritional value (Cash et al., 2007). Wheat forage is generally high in crude protein, ranging from 20-30%, less than 25% acid detergent fiber (ADF), less than 45% neutral detergent fiber (NDF), and 80% or greater total digestibility (Lollato et al., 2017).

Gunter et al. (2005) reported that calves grazing wheat and rye mixed swards gained an average 60.5 kg compared to calves grazing tall fescue which gained, on average, 27.5 kg. Netthisinghe et al. (2019) reported that calves grazing wheat gained 153 kg BW while calves grazing tall fescue gained 98 kg. ADG was reported for steers grazing wheat and tall fescue at 1370 g d^{-1} and 879 g d^{-1}, respectively (Netthisinghe et al. 2019). Steers grazing wheat had an ADG of 1.64 g d^{-1} and 306 kg ha^{-1} in a study by Lomas et al. (2011).

Grazing of livestock on wheat can lead to a number of health issues if not managed correctly. Wheat forage can accumulate nitrates and may cause early abortion or reduced breeding performance (Cash et al., 2002). Nitrate accumulation in wheat forage is an increasingly prevalent issue when nitrogen (N) fertilizer has been applied (Boyles et al., 2010). Grass tetany, characterized by low levels of magnesium (Mg) in the blood, can be an issue when grazing livestock on wheat (Dalley, 2004). Lush growing forages, like wheat, may have low Mg after intensive growth particularly after large amounts of precipitation and fertilization as Mg leaches by water and applied fertilizer (Bohman et al., 1983). One of the most common issues when grazing cattle on wheat is bloat. Wheat causes frothy bloat which occurs when rumen gasses are trapped in the rumen and a “froth” builds up preventing eructation and removal of gases (Church, 1998). Wheat is a lush growing forage with low DM and high soluble protein which often leads to bloat occurrence and may result in death (Horn et al., 1977).

Tall Fescue

History

Tall fescue (*Festuca arundinacea*), denoted as a bunch-forming grass species of Festuceae, is thought to have originated from Europe and Northern Africa (Buckner, et al., 1979). Historically, there was trouble differentiating meadow fescue (F. *elatior*) from tall fescue primarily due to morphological similarities of the two species. According to Buckner et al. (1979), tall fescue was described as “more robust” than meadow fescue and gave the denotation F. *arundinacea* in 1771. However, even into the early 1900’s tall fescue was sometimes referred to as F. *elatior* var. *arundinacea* (Buckner et al., 1979).

The exact year of importation to the United States is unknown but it is believed to have occurred in the 1800’s (Hoveland, 2009). It wasn’t until the early-mid 1900’s that tall fescue became a widely utilized forage in the United States (Hoveland, 2009). This was due to the popularity of meadow fescue and cynicism towards tall fescue until grass trials in the transition zone region of the U.S. displayed improved growth, competitiveness, and drought tolerance of tall fescue over meadow fescue (Garman, 1900). From these trials Kentucky-31 (K-31) and Alta were selected as the premier varieties and are, in fact, still in use today (Duble, 2018). It was soon noted that although this forage displayed hardy plant performance, livestock often experienced toxicity problems upon consumption. In the late 1970's it was established that the cause of the toxicity in tall fescue was the production of an ergot alkaloid produced by endophytic fungi (*Acremonium coenophialum*; Bacon et al., 1977). Despite this toxicity component, in 1979 Buckner et al. reported that approximately 15 million hectare (ha) were seeded to tall fescue in the United States.

One method of reducing toxicity by livestock was the creation of an endophyte-free tall fescue (E-) in 1982 (Hoveland et al., 1982). Initially, many E- varieties were developed disregarding the impact of the ergot alkaloid on the plant. Animal performance did increase significantly, unfortunately, stand persistence was severely inhibited and often entire stand loss would occur particularly during periods of drought (Hoveland, 2009). Since then, discovery of other fungi which do not produce ergot alkaloids have allowed for the creation of novel-endophyte (NE) tall fescue. The presence of the fungi provides beneficial effects on the host forage without the negative toxicity effect on livestock (Bouton et al., 2002; Parish et al., 2003; Watson et al., 2004).

Tall fescue is currently the most significant imported grass species in the United States with approximately 35 million acres seeded (Cherney and Johnson, 2007). Other uses for tall fescue include road-side cover and turf. Turf fescue types produce a denser sod and have a finer texture than pasture type varieties (Duble, 2018).

Growth Characteristics, Productivity, and Management

Tall fescue is a perennial grass species that is characterized by high adaptability. This is partially due to the complicated and variable genetic make-up of tall fescue and its close relatives (Craven et al., 2009). Tall fescue is categorized as a C_3 grass, meaning it is a cool-season forage, that grows best in temperate regions (Ball et al., 2002). In the United States, tall fescue is largely utilized in the “transition zone” which is the transition between plants best adapted to mild and harsh winters (Duble, 2018). This zone is highly climatically variable and corresponds to USDA hardiness zones 5 through 7 (Ball et al., 2002). However, tall fescue is widely adaptable to hot summers, drought and low temperature winters (Hannaway et al., 2009).

Endophyte-infected tall fescue is environmentally tolerant and can grow in temperatures ranging from 4-35^{o}C with the optimum growth range being between 20-25^{o}C (Volenec et al., 1984). However, tall fescue can survive temperature fluctuations below and above these temperatures with sufficient hardening. Tall fescue tolerates soil pH of 4.5 (acidic) to 9.0 (alkaline) with optimal growth occurring from a pH of 5.5-7.5 (Belesky and Fedders, 1995). It can persist in a wide array of soil drainage types from excessively drained to slightly poorly drained and can survive long term flooding with tolerance to drought (USDA-NRCS, 2006). Arrested summer growth may occur in drought stress conditions allowing maintenance of low activity despite stress from water deficit (Norton et al., 2006). Tall fescue may reach true summer dormancy should drought conditions persist, allowing survival of the forage and expansion of its adaptation zone. Drying of the soil during winter reduces the buffering effect leading to reduced tall fescue persistence in cold, dry climates (Buckner et al., 1979). Snow cover increases the likelihood of surviving low temperatures because of the insulation effect it provides (Burns and Chamblee, 1979). It is possible, with good management, for tall fescue to survive mean temperatures of -16^{o}C (Burns and Chamblee, 1979). Tall fescue is less tolerant of the cold than Kentucky bluegrass, timothy, and smooth bromegrass (Balasko and Nelson, 2003).

The naturally occurring endophyte in tall fescue has been shown to significantly increase survival during periods of stress, particularly drought (West and Waller, 2007), however, it has also been shown to increase propensity of toxicity in livestock (Strickland et al., 2009). A study in Texas, demonstrated this persistence by reporting that tall fescue fields with a high level of endophyte infection (E+) (94%) infection displayed greater stand persistence versus low level E+ (12%) infection (Read and Camp, 1986). Tall fescue will tolerate a wide variety of soil conditions and will continue to persist under these conditions due partially to the symbiotic relationship with mycorrhizal fungi (Hannaway et al., 2009). There are however, numerous complex factors that contribute to this increased tolerance adaptability of E+. Genetic interaction of the host and endophyte was shown to impact level of tolerance, seen in E+ tolerating soil acidity but not to the same extent in each genotype (Belesky and Fedders, 1995).

Preparing the seedbed is important for stand establishment. To begin renovating a pasture, the current forage should be sprayed and killed with the appropriate herbicides applied twice before planting (Bohmont, 2003). This is to reduce competition of other forages with the emerging seed and, if renovating from E+ to E- or novel-endophyte, is crucial to inhibiting reinfection (Hannaway et al., 2009). Tall fescue seedlings display poor competition against other species thus it is essential to reduce competition (Hall and

Collins, 2018). It is advised to apply fertilizer prior to seeding, at the appropriate rate based on soil testing. Seed should be sown into a firm, worked seedbed for maximum germination (Hall and Collins, 2018). Seedlings of tall fescue establish relatively slowly particularly in low soil temperature (Hamilton-Manns et al., 1995). Probability of weed competition may increase with slow germination and should be taken into consideration. Soil moisture should be adequate, but not excessive, to aid in satisfactory germination and establishment (Hall and Collins 2018). Seed should be drilled no deeper than 12.7 millimeters at a maximum (Duble, 2018). There are generally two seeding periods for tall fescue-early fall and early spring. When seeding in the fall, ensuring 2-3 weeks before a hard freeze is imperative to attain emergence. Likewise, when seeding in the spring, planting should occur after the last killing freeze (Fribourg and Milne, 2009). Usage of 98% pure seeds (free of contaminates) and an 85% or higher germination rate is crucial to achieving exceptional stand establishment (Rolston and Young, 2009). It is advised to avoid grazing until the forage reaches a height of 200-300 mm. A plant height of 80-100 mm is the minimum the forage should be grazed to, particularly during early growth periods or adverse weather. Newly established tall fescue should not be grazed by livestock during excessively wet periods (Hall and Collins, 2018).

There are options for reducing toxicity of E+ tall fescue. One option is to dilute the level of endophyte by interseeding with other grasses or legumes (Hoveland et al., 1981). This method displays the greatest impact during relatively low infection levels (<30%; Hoveland et al., 1981). Studies show that inter-seeding grass with legume species increases animal performance (Bouton et al., 2005). Bouton et al. (2005) reported that cattle grazing E+ inter-seeded with white clover gained 0.52 kg head^{-1} day^{-1} more than cattle grazing E+ tall fescue alone. Another strategy to reduce E+ infection is to completely kill and renovate the infected pasture. If renovating, it is crucial to achieve close to 100% kill and to avoid transference of E+ to E- pastures. The naturally occurring endophyte of endophyte-infected tall fescue is transmitted only by seed (Bacon and Siegel, 1988). Therefore, if E- pasture is exposed to E+ seed including exposure such as: E+ hay, cattle recently grazing E+, and E+ adjacent to E- by wind then endophyte infection can increase in the exposed pastures (Hall and Collins, 2018). Endophyte infection level can be obtained by sampling and diagnostic procedures (Barker et al., 2009).

Most tall fescue growth occurs during cooler months of spring and fall. Summer months are generally characterized by a “slump” in both growth and quality of forage (Roberts et al., 2009). Management strategies can be used to extend the grazing period. Application of nitrogen can improve forage quantity and quality depending upon rate of application, timing of application, N source, and N fixed by legumes (Roberts et al., 2009). Inter-seeding with other grasses or legumes may improve forage quality as well as extend the grazing period, depending on species. Grazing management is a vital part of maintaining persistence of a forage stand (Milne, 2001). According to Milne (2001), coarse-leaved cultivars (cv. Jesup and cv. Quantum) have greater tolerance to overgrazing than soft-leaved varieties (cv. Advance). To ensure stand persistence, tall fescue should not be grazed during periods of drought (Hall and Collins, 2018).

Endophyte infection enhances resistance to pests such as insects, diseases, and nematodes (Ford and Kirkpatrick, 1989). A study by Kimmons et al. (1990) showed that E+ tall fescue had lower nematode populations than E-. However, tall fescue does show susceptibility to some pests and diseases. Two of the most devastating fungal pests are brown patch disease caused by *Rhizoctonia solani* and grey leaf spot caused by *Maggnaporthe grisea* (Dong et al., 2007). Tall fescue may also be susceptible to leaf spot and rust. White grubs, which are the larval stage of certain beetle species, may cause significant damage to tall fescue (Rowan and Latch, 1994). Certain types of armyworms may also cause damage to tall fescue stands (Rowan and Latch, 1994).

<u>Nutrient Characteristics, Yield, and Animal Performance</u>

Endophyte-infected tall fescue is a hardy species providing increased forage during cool-season months. During spring growth (April) endophyte-infected tall fescue was found to have 21.2% CP, 19.2% DM, 24.4% ADF, and 50.1% NDF (Elizalde et al., 1999). Rayburn et al. (1979) noted crude protein levels ranging from 9.4-13.2% in December depending on stockpiling start date and nitrogen application rate. Stockpiled tall fescue had decreased crude protein concentrations from an average 115 g kg^{-1} at stockpiling start (September) to 55 g kg^{-1} in winter (December) while ADF and NDF did not vary with stockpiling length (Fribourg and Bell, 1984). N fertilized tall fescue had higher DM and better quality than non-fertilized stockpiled tall fescue (Rayburn et al., 1979). McMurphy et al. (1990) found that forage digestibility and crude protein are similar in endophyte-infected tall fescue, endophyte-free tall fescue, and novel-endophyte. In vitro dry matter digestibility (IVDMD) of Kentucky 31 tall fescue was 58.1% in the spring and 56.2% in the fall (Carlson and Umbaugh, 1988). It is a well-established concept that most forages have high digestibility during early growth with decreasing digestibility as maturity increases, particularly in the stem, which decreases in digestibility much more quickly than that of the leaf (Terry and Tilley, 1964).

Total yield of tall fescue can range from 4.48-8.97 tonnes/hectare/year (Lacefield et al., 2003). Stockpiling start date impacted DM yield in December with a decrease in yield each month stockpile start date (June-September) was delayed (Rayburn et al., 1979). Fribourg and Bell (1984) reported an average 1.3 Mg ha^{-1} DM accumulated in the first three months of stockpiling (beginning July or August) with a slight decline in DM yield after three months accumulation. During a trial with three nitrogen application levels, Taylor and Templeton (1976) found that DM accumulation from August 15th to December 1st increased significantly with increasing N application. Large losses of DM yield occurred when harvest was delayed from December to January (Fribourg and Bell, 1984). In a study by Rayburn et al. (1979) delaying harvest from December to February decreased DM yield by 60%. In a two-year study K-31 E+ accumulated approximately 20% more herbage mass than E- and NE (Kallenbach et al., 2003).

After tall fescue became a popular choice of forage in the United States, it became increasingly clear that consumption of this forage was contributing to poor animal performance (Pratt and Haynes, 1950). This was termed “fescue toxicosis”. Bacon et al. (1977) identified the causal agent of fescue toxicosis as a fungal endophyte which became known as *Acremonium coenophialum*. Three classes of fescue toxicosis symtoms were classified. The first is characterized by increased respiration rate and gangrene, which led to sloughing of hooves, tail switches, and ears (Stuedemann and Hoveland, 1988). This was coined as “fescue foot”. The second class of symptoms involves bovine fat necrosis, the accumulation of hard fat in the abdominal cavities, disrupted digestion and enabling dystocia occurrance (Stuedemann et al., 1975). The third set of symptoms consists of poor coat quality, intolerance to heat, and decreased gains, milk production, and intake (Stuedemann and Hoveland, 1988).

Endophyte-infected tall fescue (E+) has been shown to decrease animal performance in comparison to endophyte-free (E-) and novel-endophyte tall fescue (NE)(Hoveland et al., 1983; Bond et al., 1984; Hoveland et al., 1997; Read and Camp, 1986; Schmidt and Osborn, 1993; Parish et al., 2003; Gunter and Beck, 2004; Nihsen et al., 2004; Watson et al., 2004; McMurphy et al., 2013). Steers grazing tall fescue with high endophyte infection spend less time grazing during the day and more time grazing at night compared to steers grazing low endophyte levels while total grazing time was reduced by about 20% on high endophyte infection (Bond et al., 1984). Average daily gain (ADG) of steers grazing high endophyte infection is significantly lower than that of steers grazing low endophyte infection pasture (Hoveland et al., 1983; Hoveland et al., 1997; Read and Camp, 1986; McMurphy et al., 2013; Nihsen et al., 2004, Gunter and Beck, 2004; Parish et al., 2003). On average over three years, Hoveland et al. (1984) found that steers grazing E- pasture had an ADG of 0.75 kg day^{-1} compared to steers grazing E+ which had an ADG of 0.34 kg day^{-1}. Hoveland et al. (1984) found that fescue toxicity can impact animal performance year-round however, the greatest impact occurs during increased temperatures. Steers grazing on E+ tall fescue from November to March had a 50% decrease in ADG versus steers grazing E- tall fescue. There was a 59% decrease of ADG in steers grazing E+ compared to grazing E- from April-June (Hoveland et al., 1984). Lower DMI was reported from steers grazing E+ tall fescue in spring and autumn compared to steers grazing E- and NE (Parish et al., 2003). Elizalde et al. (1998) found that supplementing steers (with four different supplement treatments) back-grounded on E+ tall fescue increased ADG and total gain with supplementation of all treatments in comparison to no supplementation. Hyperthermia (abnormally high body temperature) was exhibited in cattle grazing E+ compared to cattle grazing E- and NE (Hoveland et al., 1983; Nihsen et al., 2004; McMurphy et al., 2013). Developing heifers displayed decreased ADG as endophyte infection increased (Schmidt and Osborn, 1993). Pregnancy rate of replacement heifers also decreased as endophyte infection increased. They also displayed decreased milk production post-partum (Schmidt and Osborn, 1993). Cow/calf pairs display a decrease of daily gain in both the cow and the calf as well as a decrease in 205-day weaning weight in calves (Gay et al., 1988; Essig et al., 1989; Watson et al., 2004). Bovine fat necrosis increased when heavy poultry litter or N fertilizer has been applied (Ball et al., 2015). Presence of a rough hair coat was more commonly found in cattle grazing E+ than those grazing E- or NE (Hoveland et al., 1983; Nihsen et al., 2004). Milk yield and body weight change of dairy cattle decreased as level of endophyte infection increased (Strahan et al., 1987). The decrease in milk yield is likely due to decreased concentrations of prolactin (Strahan et al., 1987). Milk production of beef cows grazing E+ tall fescue was significantly lower (25%) than those that grazed E- tall fescue or orchardgrass (Peters et al., 1992). Oliver et al. (1998) reported increased contraction of α_2 adrenergic receptor, a contractile receptor in veins, of cattle grazing E+ versus E- tall fescue. This increased contractile response impacts blood flow and contributes to physiological signs of toxicity in cattle (Oliver et al., 1998). Cattle and sheep grazing tall fescue pastures containing high ergovaline levels, particularly during cool weather, are prone to exhibiting fescue foot which can be indicated by a swollen hock area and limping or sloughing of the hoof if the condition is severe (Tor-Agbidye et al., 2001).

Endophyte infected tall fescue grazing is detrimental to mare reproduction. Mares grazing E- pasture had greater conception rate, delivered more live foals, had decreased agalactia incidence, and had fewer retained placentas (Putnam et al., 1990; Schmidt and Osborn, 1993). Putnam et al. (1990) reported a decrease in gestation length, foal birth weight, foal survival rate, and mare lactation level from mares grazing E+ in comparison to those grazing E-. Removal of mares from E+ pasture one month prior to parturition results in a normal birthing process and mammary development (Schmidt and Osborn, 1993). Parish et al. (2003) found that sheep grazing E+ tall fescue displayed lower prolactin concentrations, increased rectal temperature, increased heat stress symptom prevalence, and decreased ADG and gain/hectare.

Despite the many poor animal performance issues seen with endophyte-infected tall fescue it remains a highly prevalent forage throughout the United States (Cherney and Johnson, 2007). This is primarily due to the highly adaptable, highly stress tolerant, increased survivability qualities that the endophyte affords the plant (West and Waller, 2007). This enables the forage to be utilized in a wide range of environments, during less than ideal conditions, making it a valuable forage species (Ball et al., 2015). There are various strategies to off-set toxicosis symptoms of livestock grazing endophyte-infected tall fescue. Such strategies include: inter-seeding with other grasses or legumes to dilute toxicity, maintaining low levels of infection, removal of seedheads to reduce toxin intake, feeding a supplement, or renovating to endophyte-free or novel endophyte pasture (Ball et al., 2015).

Soybeans

History

The soybean falls into the *Glycine* genus which has a complex taxonomic history. Linnaeus was the first to utilize the name *Glycine* in 1737 (Hymowitz and Newell, 1981). Since then, the assimilation of *Glycine* species has undergone many revisions and all original *Glycine*-named species have been categorized to other genera (Hymowitz and Newell, 1981). Most recently, revision of Glycine occurred by Verdcourt in 1970 who evaluated and assimilated the contemporary arrangement of Glycine (Hymowitz and Newell, 1981). Hymowitz (1970) estimates that the process of soybean domestication occurred during the Shang Dynasty (1700-1100 B.C.) or earlier. Introduction of the soybean into the West occurred many years after the relatively rapid distribution in the East (Hymowitz and Newell, 1981). Utilization of the soybean in the United States was first mentioned in 1804 (Hymowitz and Newell, 1981).

Soybean seeds are the primary consumed product of the cultivated soybean plant and have high protein and oil content (Wilcox, 1970). Usage in the West created two main products from soybeans, oil and protein-rich defatted meal while utilization in east Asia primarily uses whole soybean seeds or oil extraction for food products (Hymowitz and Newell, 1981). Historically, soybeans were primarily used for a variety of food products in the East including: tofu, soy milk, kinako, miso, and soy sauce (Chen, 1962). They are still used for these purposes today, along with being utilized for other food products such as margarine, shortening, mayonnaise, and salad dressing (Hymowitz and Newell, 1981). Recently, there has been development in the utilization of soybean protein for flour and other concentrates (Wolf and Cowen, 1971). One of the most prevalent uses of soybean protein comes from processing to soybean meal and dehulled soybean meal (Cowen, 1971). Hymowitz and Newell (1981) reported that livestock, poultry, and pet feed utilizes about 95% of all soybean meal produced.

Soybeans are vital to producers as a cash crop in the state of Kentucky with an estimated 790,000 hectares planted in 2017 (USDA, NASS, 2018). Production was estimated for 2017 at 262,000 tonnes with an average yield of 545 kg per hectare (USDA, NASS, 2018). Soybeans are an important economic crop in the central Kentucky region with an estimated 173,610 hectares planted in 2017 with an average yield of 554 kg (USDA, NASS, 2018). There are more total hectares planted to soybeans in the central Kentucky region than corn and wheat acres combined (106,837 combined acres; USDA, NASS, 2018).

Growth Characteristics, Management, and Yield

Soybean is a domesticated, commercially important legume plant named *Glycine max*. It is an annual plant ranging in height from 300-1,830 millimeters (Ngeze, 1993). There are two growth habits of the soybean: determinate and indeterminate (Ngeze, 1993). Determinate types are shorter with fewer leaves but generally produce more pods. Indeterminate types are taller with more leaves and more pods from stem to shoot (Ngeze, 1993). The stem, leaves, and pods are covered with fine hairs and its leaves are trifoliate (Rienke and Joke, 2005). Pods grow in clusters of one to five, usually containing two to four seeds (Rienke and Joke, 2005). Soybean growth and development has been described in two primary stages: vegetative and reproductive (Gary and Dale, 1997). The vegetative stage consists of emergence of seedlings, unfolding of unifoliate leaves to fully developed trifoliate leaves, node formation, nodulation, and formation of branches (Gary and Dale, 1997). Gary and Dale (1997) describe the reproductive stage as formation of the flower bud to full bloom, formation of the pod, and pod filling to maturity.

The soybean performs best on well-drained fertile loamy soil which provides adequate nutrients, however, the soybean is tolerant to a wide range of soil conditions (Hans et al., 1997). A pH of 5.5 to 7.0 is ideal for soybean production, although soybean can tolerate acidic soils better than other legumes (Ngeze, 1993). Maintaining a pH of 5.5 to 7.0 enhances microbial breakdown of crop residues and symbiotic nitrogen fixation as well as increasing availability of nutrients (Ferguson et al., 2006).

Ideal temperature for optimum growth is $23^{o}C$ to $25^{o}C$. Minimum temperature that a soybean can develop is $10^{o}C$ and maximum temperature for development is around $40^{o}C$ (Ngeze, 1993). Germination can occur at temperatures between $15^{o}C$ to $40^{o}C$ with the optimum around $30^{o}C$ (Rienke and Joke, 2005).

The soybean grows well in tropical, subtropical, and temperate climates (IITA, 2009). Soybeans are facultative photoperiod sensitive, displaying correlation between flowering period and day length and temperature. There is some debate as to the classification of soybean to photoperiod, however there are arguably three main classifications of varieties that react differently to photoperiod: short day, day neutral, and long day plants (Borget, 1992). When described as a typical short-day plant, Rienke and Joke (2005) stated that the soybean is best adapted to temperate climate conditions. In the tropics, some varieties have adapted to the hot, humid climate by shortened growth period, 90-110 days with a maximum of 140-day maturity (Osafo, 1997). Sensitivity to day length impacts growth duration which consequently affects vegetative growth, viable pollen production, pod filling, and maturity characteristics (Norman et al., 1995).

Germination of soybean seed requires optimum moisture to grow well. The seed absorbs 50% of its weight in water before germination may occur, thus the soil needs to be saturated with water from 50% to 85% (Bohnert et al., 1995). Bohnert et al. (1995) stated that there are two main roles of water in plants: aiding photosynthesis as an electron donor and as a transport medium of plant nutrients. According to Ngeze (1993), the optimum rainfall is between 350 to 750 millimeters distributed throughout the growth period. There are two stages of development that are critical to obtain optimum moisture for adequate soybean production: from sowing to flowering and pod filling. Bohnert et al. (1995) reported that water requirements increase as growth occurs, peaks at the vegetative stage, and decreases to reproductive maturity. The soybean is highly susceptible to water stress (Troedson et al., 1985). The water use efficiency of the soybean has direct impacts to physiological development particularly during drought stress (Earl, 2002). Water use is less efficient in soybeans due to high evapotranspiration and low photosynthetic rates (Passioura, 1997). Sionit and Kramer (1977) found that drought stress during flowering and pod formation induces the greatest reduction in pod number and seeds at harvest. Increasing drought stress progressively reduces leaf area and crop growth rate limiting soybean yield (Pandy et al., 1984).

Another major factor impacting plant growth following photosynthesis is nitrogen acquisition and use (Sadowsky, 2005). Protein and oil are the primary components of soybean grain (Yazdi-Samadi et al., 1977). These large amounts of protein result in high N requirement for grain development (Beuerlein, 2009). Generally, the soybean plant does not benefit from supplemental nitrogen fertilizer application. This is because it is a legume plant which can meet its own nitrogen needs by symbiotic relationship with a nitrogen fixing bacteria *Bradyrhizobia japonicum* (Sarkodie-Addo et al., 2006). This relationship results in the creation of nodules on the roots which fix N as early as the second trifoliate growth stage (Conley and Christmas, 2005). Nitrogen fertilizer application negates the benefit of Rhizobia bacteria as bacteria will not convert atmospheric nitrogen when soil nitrogen is readily available (Gary and Dale, 1997). Biological fixation accounts for approximately 52% of N uptake in soybeans, and biological fixation rate decreases when N fertilizer is added to the crop (Salvagiotti et al., 2008). If Rhizobia aren't present in the soil, then they must be established to promote growth. This can be accomplished by inoculation of seed with the bacteria (Conley and Christmas, 2005). Inoculation is the process of applying N-fixing bacteria to the seed prior to planting (Conley and Christmas, 2005). Inoculant may be applied in different forms, the most common form is powder (Stephens and Rask, 2000). When used in accordance to label rates most inoculant will be applied at a rate of 500,000 to 1,000,000 Rhizobia cells per seed (Conley and Christmas, 2005). N fixation is affected by soil type, soil pH, nutrient availability, water stress, plant genetics, agronomic practices, and environmental conditions (Sadowsky, 2005).

Plant population and row spacing studies have reported mixed findings as to the effect on soybean yield and dry weight production. Weber et al. (1907) found that at higher populations, plants were taller and set fewer pods than plants at lower density indicating an effect of more severe plant competition at higher densities. In another study seed yield was also greater in narrow rows (250 mm) versus wide rows (760 mm;

Ethredge et al., 1907). A later study in 2008 by De Bruin and Pedersen reported similar results with greater yield in narrow rows than in wide rows indicating that the narrow row soybean production may be sufficiently beneficial to the producer. However, optimal plant populations and row spacing is impacted by region with aforementioned studies taking place in the upper Midwest. A study taking place in dryland conditions reported that optimum seeding rate in this trial was below the normal recommendation of 60,702 to 64,750 plants/hectare of the region (Epler and Staggenborg, 2008). Alessi and Power (1982) found that soybean plants in narrow rows exposed to water stress had less pod-fill significantly reducing yields, whereas wider rows which had greater access to water reserves, displayed greater yield than narrow rows under similar drought conditions.

The incidences of soybean disease have increased in occurrence and severity due to reduced tillage practices and greater production intensity (Dorrance et al., 2002). Septoria brown spot (*Septoria glycines*) and sclerotinia stem rot (*Sclerotinia sclerotiorum*) are two of the diseases which cause the most soybean yield loss worldwide. (Wrather et al., 2000). Dorrance et al. (2010) reported yield losses of 2.5% to 9.5% due to Septoria brown spot in Ohio. Soybeans are vulnerable to the soybean rust pathogen (*Phakopsora pachyrhizi*; Morton and Staub, 2008) which has been identified in Kentucky (IPM PIPE, 2014). Fungal diseases such as Septoria tritici (*Mycosphaerella graminicola*) and powdery mildew (*Blumeria gramminis*) have also been shown to harm soybean production (Bryson et al., 2000). Damage due to predation by insects may also be incurred and can harm soybean growth and subsequent yield. Insect species that can damage soybeans include: the bean leaf beetle (*Cerotoma trifurcate*; Buyung et al., 2012), soybean aphid (*Aphis glycine*; Tilmon et al., 2011), green cloverworm (*Hypena* *scabra*; McCarville et al., 2010), and stem borers (*Dectes texanus*; Wright and Hunt, 2001).

Corn

History

The modern maize (*Zea mays*), or corn plant, is thought to have been domesticated from a Mexican wild grass known as Balsa teosinte, *Zea mays* spp. *parviglumis* (Wang et al., 1999) around 7,000 to 10,000 years ago (Smith, 1989). In the southwestern United States there is evidence of maize production by 2100 BC (Merrill et al., 2009). The "Corn Belt" in the United States was the product of crossing two main types of corn: Northern flint corn and Southern dent corn (Troyer, 1999). Northern flint corn was characterized by earlier maturity and greater cold tolerance while Southern dent corn was higher yielding (Troyer, 1999). Yellow and white corn production were similar in production numbers until results of a study reported increased nutritive value in yellow corn (Poneleit, 1994). Afterwards, the percentage of white corn produced dropped greatly and had decreased to only 1% by 1970 (Poneleit, 1994). Average corn production yields in the U.S. from 1865 to 1935 were stagnant with the national average yield exceeding 762 kg/hectare in only 4 of those 60 years (Hallauer, 2008). By the early 1900's, hybrids that yielded over 5,080 kg/hectare had been produced (Troyer, 2003). This displayed that hybrid corn types produced a significant yield increase however, the process of creating these hybrids increased inputs to the point of reducing profit (Hallauer, 2008). In 1921 D. F. Jones commercially produced the Burr-Leaming double-cross hybrid which was cheaper to produce, allowing wide-spread adaptation to occur (Jones, 1927). During the time that this double-cross hybrid was produced, a number of other high input advances were being adopted including: usage of inorganic nitrogen (Gardner, 2009), mechanization of management operations (Egli, 2008), increasing plant populations, irrigation (Troyer, 2003), and increased herbicide use (Naylor, 1996). During this period, research was being done to improve inbred line yield and weed control (Crow, 1998). By the 1980's single cross hybrid seed was the standard, increasing the annual national yield by an average of 17.57 kg/hectare a year during the single cross era (Crow, 1998). Other methods besides crossing to create genetic variation in corn included the use of chemicals or radiation to induce mutation (Schouten and Jacobsen, 2007) and by genetic engineering (Bevan et al., 1983). Genetically modified crops, including corn, were planted on approximately 140 million hectares in 2010 (Barrows et al., 2014).

Corn has become a widely cultivated crop throughout the world surpassing both wheat and rice in tonnes produced (International Grains Council, 2017). The U.S. produced 371 million tonnes of corn in 2017 (UN, FAOSTAT, 2017). Very little of this corn is used for food consumption despite it being a staple food throughout the world. Most is used for production of ethanol, animal feed, alcoholic beverages, and other corn products (Gibson and Benson, 2002). There were approximately 667,731 hectares of corn planted in Kentucky in 2019 (USDA, NASS, 2019).

<u>Growth Characteristics, Management, and Yield</u>

The corn plant is a highly genetically diverse species with variation in physiology. Maize can be average from 2.44 to 12.19 meters tall (Wellhausen, 1952). The fruit of corn is the female inflorescences (ears) which are enveloped by the husk while the tassel represents the male inflorescence (Wellhausen, 1952). Silks are elongated stigmas which connect to a carpel that develops into a kernel if fertilized by pollen (Grobman, 1961). An ear holds an average of 600 kernels which may vary in color (Grobman, 1961).

Corn is adaptable to growing on a variety of soil types but generally provides optimum performance on well-drained, medium to coarse textured soil with adequate moisture (McClure, 2015). The ideal seedbed for corn is a firm, clean, uniform seedbed that will allow for proper seed placement at approximately 50.8 millimeters deep. Placing seed too shallow or too deep can negatively impact root development and emergence time. It is critical that the seed furrow is fully closed to prevent herbicide injury, predation by birds and animals, and other factors that result in poor, uneven emergence. It is also important to plant at an appropriate rate as planting too fast can result in uneven seed placement and an increased number of skips. Planting may occur from late March to May depending on weather conditions and location (McClure, 2015). McClure (2015) recommends avoiding planting corn when excessively cold or wet conditions are expected. The ideal seeding rate per hectare varies with location, seed hybrid, and row spacing. However, approximately 5-10 percent more seed than the desired plant population should be seeded (McClure, 2015).

Corn is susceptible to several fungal species which cause seed rot and seedling blight, as well as diseases such as leaf blight, leaf spot, northern leaf blight, common rust, and eyespot (Robertson and Munkvold, 2019). Diseases in corn, such as anthracnose may invade the stalk and cause rotting which can lead to lodging while ear rot such as *Fusarium* can cause yield and quality to decrease (Robertson and Munkvold, 2019). Corn is vulnerable to pests including: billbugs, wireworm, cutworms, southern corn rootworm, corn leaf aphids, corn earworm, armyworms, and southern and European cornstalk borer (Griffin, 2019).

Grain yield of maize is complex and impacted by many factors including growth and development of the plant, genotype, management, and environmental factors (Fageria et al., 2006). The growth of maize occurs in vegetative and reproductive stages (Abendroth et al., 2011). The reproductive stage is a highly vulnerable period for crop production as this is when the number of kernels on an ear is determined (Westgate et al., 2004). Once the plant is physiologically mature environmental stresses do not impact yield but, physical damage to the plant such as stalks breaking or ear droppage can negatively impact yield (Abendroth et al., 2011). The number of ears per plant is generally impacted by early-season growing conditions, mid-season conditions impact kernels per ear, while late-season conditions affect kernel weight (Abendroth et al., 2011).

The components that ultimately make up total yield vary between years with different temperature, rainfall amount, and rainfall distribution (Novacek et al., 2013). Hu and Buyanovsky (2003) found that high yield averaging years were characterized by below average rainfall paired with warm temperatures before and during planting, above average rainfall and warm temperatures from planting to May, above average rainfall and below average temperature June through August, and below average rainfall and above average temperature September through October. Drought stress early in vegetative growth can result in a reduced ear number (Pandey et al., 2000). During the process of silking, drought stress can cause arrested ear development or ear abortion which can impact both number of ears and number of kernels (Jacobs and Pearson, 1977). The component most impacted by drought stress is number of kernels (Classen and Shaw, 1970). When kernel numbers are reduced by drought stress, kernel weight may increase in compensation for the lower kernel number (Eck, 1986).

Temperature can impact grain yield components and total yield. Heat stress prior to tasseling, and between tasseling and silking, reduced yield and kernel number but had no significant effect on kernel weight (Cicchino et al., 2010). Extreme temperatures, both high and low, during grain fill have been reported to have similar negative effects to kernel weight (Jones et al., 1984). The most detrimental period of extreme temperatures negatively impacting kernel weight occurs during early grain fill rather than late grain fill (Jones et al., 1984). Above average temperatures between June and October can shorten maturity thus decreasing yields (Novacek et al., 2013). Conversely, below average temperatures between June and October can delay maturity and extend grain fill positively impacting yield (Novacek et al., 2013).

Both drought stress and nitrogen deficit have been shown to reduce the number of kernels (Moser et al., 2006). However, the interaction of nitrogen application rate and drought stress also impacts yield with greater yield reductions when drought stress is more severe at high N rates (Pandey et al., 2000). Kernel number increased as N rate increased with ideal water availability but decreased as N rate increased in drought conditions (Moser et al., 2006). A decrease of kernel weight due to drought stress was greater at high nitrogen application rates (Pandey et al., 2000).

There are varying reports as to the impact of plant population on grain yield in corn. Newer hybrids allow for increased populations without reducing yield primarily attributed to increased tolerance to crowding (Duvick, 2005). Lower lodging frequencies

(Tollenaar, 1989), higher nitrogen use efficiency (McCullough et al., 1994), and greater leaf photosynthesis rates (Dwyer et al., 1991) contribute to the increased ability of modern hybrids to tolerate crowding. The current ideal population ranges from approximately 81,000 plants ha^{-1} (Robles et al., 2012) to 98,600 plants ha^{-1} (Coulter et al., 2010). This topic is highly controversial; some studies report little increase in yield over population increases from 60,000 plants ha^{-1} (Hammer et al., 2009; Nielson, 2012). Increasing plant population increases the number of ears per square meter (Novacek et al., 2013) but ears per plant decreases (Otegui, 1995). Kernels per ear also decreases with increasing population (Maddonni and Otegui, 2006).

Competition of corn for resources such as nutrients, water, and light can greatly impact yield (Rajcan and Swanson, 2001). Corn has been reported to be particularly vulnerable to competition from adjacent corn plants (Maddonni and Otegui, 2006). To prevent yield loss from competition the critical stage to reduce and prevent competition from occurring is from V3 (third leaf with collar visible) to V14 (fourteenth leaf with collar visible; Hall et al., 1992). The number kernels per ear is the most sensitive yield component to weed competition (Evans et al., 2003). Evans et al. (2003) found that the longer corn was weed-free the more kernels per ear increased and thus increased yield.

One of the first genetically modified corn hybrids included a gene from *Bacillus thuringiensis* Berliner (Bt) for an insecticidal protein which is toxic to certain pests but not to humans (Barrows et al., 2014). In 1996 the first Bt-corn hybrids were released commercially (Andow, 2001). Other traits that have since been incorporated include: herbicide traits such as Round-Up Ready™ and DroughtGard™ among others (Waltz, 2014). Incorporating various genetic material into plant species has provided better pest protection and reduced the need for chemical application (Barrows et al., 2014). Genetically modified crops have increased yield, averaging a 2.3% increase in net returns (Fernandez-Cornejo et al., 2014).

Soil

Nitrogen Cycling

Nitrogen is present in all living organisms, thus it is a fundamental element for life (Brady and Weil, 2000). Galloway et al. (2003) reported that although nitrogen is abundantly present on Earth, the available nitrogen for living organisms is only a small portion of Earth's total nitrogen. For plant species, nitrogen aids in chlorophyll production which is critical for photosynthesis to occur (Brady and Weil, 2000).

On Earth the atmosphere is 78% nitrogen gas (N_2) which has a strong triple bond holding the atoms together making it an inert molecule (Galloway et al., 2003). The bond of nitrogen gas can be broken causing atoms to become reactive (N_r) allowing the atoms to bind with other molecules in the atmosphere, water, and soil (Galloway et al., 2004). N_2 in the environment is broken in two ways: by bacteria that fix atmospheric N_2 or by lightning (Schlesinger and Bernhardt, 2013). Nitrogen can enter the soil by biological or chemical N fixation from atmospheric NO_x, decomposition of plant and animal matter, or mechanical application (Galloway et al., 2003). Plants can take up small organic compounds directly or they can be converted to NH_4^+ by mineralization (Näsholm et al., 1998). Mineralization occurs by heterotrophic organisms in the soil that first depolymerize large proteins to smaller peptides then mineralize to inorganic N (Robertson and Groffman, 2007). Jones and Kielland (2012) indicated that the depolymerization rate is thought to be the primary limiting step for the nitrogen cycle in natural ecosystems because nitrogen from proteins to NH_4^+ is slower than amino acids to NH_4^+. A process called immobilization, in which organisms such as microbes take up nitrogen thus, making it unavailable to plants, is a portion of what determines nutrient status (Robertson and Groffman, 2007). If the percentage of immobilization is greater than mineralization the soil is depleted of nitrogen, whereas, if mineralization is greater than immobilization there is a surplus of nitrogen available (Robertson and Groffman, 2007). If NH_4^+ is not utilized by plants or microbes it can enter the process of nitrification which can occur autotrophically or heterotrophically (De Boer and Kowalchuk, 2001). Nitrification is a major source of soil acidity in many regions (Liu et al., 2010). Autotrophic nitrification occurs by oxidation of NH_4^+ to NO_2^- and then subsequent oxidation from NO_2^- to NO_3^- (Prosser, 2007). Fungi and heterotrophic bacteria carry out heterotrophic nitrification (Zhang et al., 2015). While NO_3^- can be utilized by plants it is a volatile molecule that can leach into groundwater or be denitrified back into the atmosphere (Robertson and Groffman, 2007). Denitrification is impacted by various factors including: temperature, carbon (C) content, pH, and oxygen levels; if the process of denitrification is incomplete N_2O is released (Robertson and Groffman, 2007). NO_3^- may also enter an anaerobic process called dissimilatory nitrate reduction to ammonium (DNRA) (Tiedje et al., 1982). In certain environments DNRA may be a more energetically efficient pathway than denitrification (Tiedje et al., 1982).

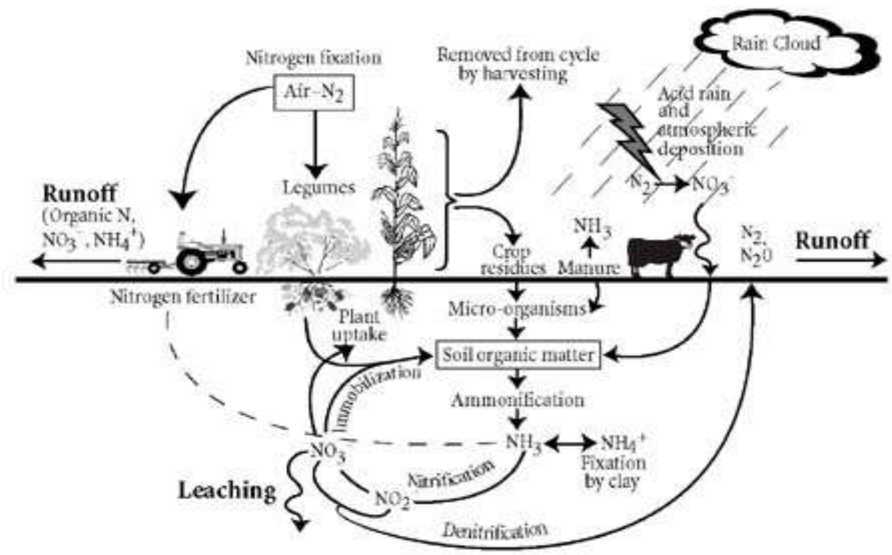

Figure 1. The nitrogen cycle in agroecosystems (Schalau, 2007).

A 35% increase was seen in corn yields when 224 kg N ha^{-1} were applied compared to 0 N (Crozier et al., 2014). Yield plateaued at 179 kg N ha^{-1}, with no additional increase in yield reported following increased N application. Yield components displayed similar trends, increasing kernel size, rows per ear, and kernels per row as N increased up to 179 kg N ha^{-1}, plateauing at greater N application rates (Crozier et al., 2014). Ciampitti et al. (2013) and Barbieri et al. (2008) both reported that grain yield increased as N application rate increased. Producer applied N rate on corn in the U. S. averaged 163 kg N ha^{-1} in 2016 (USDA-ERS, 2017). Soybeans have a symbiotic relationship with nitrogen-fixing bacteria (Sarkodie-Addo et al., 2006). Due to this relationship the soybean plant generally does not benefit from supplemental nitrogen fertilizer application. When soil nitrogen is readily available, nitrogen-fixing bacteria will not convert atmospheric nitrogen for use by the soybean thus negating the benefit of Rhizobia bacteria (Gary and Dale, 1997).

Phosphorus Cycling

Phosphorus (P) is a component of all living organisms and the availability of phosphorus often limits the productivity of plants and other organisms (Richardson et al., 2005). Less than 1% of the total P on Earth is found in the atmosphere, plant biomass, and soil combined (Stewart et al., 2005). While a large percentage of this P is found in the soil, only a small portion (<1%) is available to plants (Richardson et al., 2005). Phosphorus is often referred to as “labile” or “non-labile” which denotes whether P in the soil is available to plants (labile) or not available (non-labile; Pierzynski et al., 2005). Phosphorus is a component of multiple cell structures and contributes to various cell processes (Taiz, 2002).

Phosphorus can enter the soil by decomposition of animal matter or plant residue, atmospheric deposition, mineral fertilizers, and breakdown of primary apatite P in rock (Ruttenberg, 2014). Soluble P is converted to secondary components, organic P, or adsorption to mineral surfaces (Walker and Syers, 1976). Processes such as oxidation-reduction and mineralization-immobilization impact the availability of P from these forms (Turner et al., 2005). The main source of available P for plants and other organisms comes from the soluble P which is generally in the form of $H_2PO_4^-$ or HPO_4^{2-} (Pierzynski et al., 2005). When this pool is depleted of available phosphorus the inorganic, organic, and microbial pools can replenish the source for plant use (Pierzynski et al., 2005).

Inorganic phosphorus applied as fertilizer can move only 30 to 50 mm (Havlin et al., 1999). Most of this P binds quickly with soil and minerals making it unavailable for plant use (Koopmans et al., 2004). Generally, 20% or less of applied inorganic phosphorus is taken up by the plant in the first few days following application (Foth, 1990). Approximately 4% of phosphate is still available after 10 days (Foth, 1990). The availability of phosphorus is impacted by land use, physical and chemical soil characteristics, type of vegetation cover, and microbial culture (Chen et al., 2000). Inorganic phosphorus availability is usually high in young soils however, as soil ages the availability of phosphorus decreases due to organic immobilization, leaching, transformation into unavailable forms, and erosion (Pierzynski et al., 2005). The removal of crops is another major factor which can decrease the phosphorus concentration in the soil (Pierzynski et al., 2005). Extreme soil pH, either acidic or basic, can cause phosphorus deficiencies (Carrow et al., 2001). Soil composition can impact available phosphorus. For example, sandy soils with low organic matter do not absorb as much inorganic phosphorus as finer textured soils (Beard, 1973). Le Boyona et al. (2006) reported that earthworm activity significantly impacts availability and distribution of phosphorus. Freezing/thawing and wetting/drying cycles can cause phosphorus to release into surrounding soil (Turner, 2005). Decreasing available phosphorus may impact both carbon and nitrogen cycling (Condron et al., 2005). Conversely, soil nutrient level can also impact the availability of phosphorus. For example, calcium and magnesium absorb phosphorus in alkaline soils (Foth, 1990). Nitrogen is a critical nutrient aiding in phosphorus uptake by the plant. Nitrogen allows for increased root mass, thus increased surface area which enables roots to uptake phosphorus more efficiently (Wang et al., 2007). Nitrogen is also required for phosphatase production (Wang et al., 2007). Applying nitrogen fertilizer has been shown to increase phosphorus availability (Wang et al., 2007).

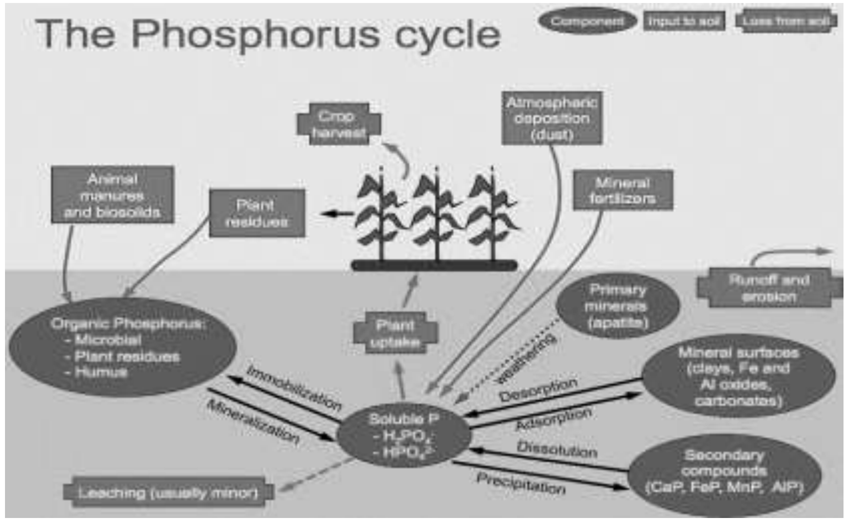

Figure 2. The phosphorus cycle in agroecosystems (Ruttenburg, 2014).

Applied phosphorus was found to increase soybean yields over 4 years on soils that were very low (<20 g/kg) or low (21-50 g/kg) in phosphorus (Borges, 1998). Sites that were adequate (50.5-75 g/kg) or above adequate (75.5- >100.5 g/kg) in phosphorus did not display an increase in soybean yields with phosphorus application (Borges, 1998). This is similar to results found by Webb et al. (1992) who reported that applied phosphorus did not increase yields when soil phosphorus levels were adequate or above. Wortmann et al. (2009) found that corn yields were impacted the most by phosphorus application when the previous crop had been corn compared to when the previous crop was soybeans. Corn following corn with 20 kg P ha^{-1} applied resulted in 0.70 Mg ha^{-1} increase in grain yield compared to 0 kg P ha^{-1} applied. This yield increase was associated with an increase in ears m^{-2} and kernels m^{-2} (Wortmann et al., 2009). Conversely, phosphorus levels may be very high in certain soil types, geographical locations, or in excessively fertilized fields (Sundermeier, 2010). Cover crops can be used to absorb and recycle nutrients which prevents nutrient loss and may lower excessively high soil nutrient levels, such as very high phosphorus (Sundermeier, 2010).

Carbon Cycle

Carbon in the soil makes up approximately 80% of the total carbon found on Earth (Lal, 2008). Soil carbon is primarily accrued through photosynthesis where plants acquire CO_2 from the atmosphere for photosynthate production and may be stored in the soil carbon pool (Lal, 2008). Soil organic matter is a mixture of organic materials that are high in carbon (Havlin et al., 1999). Organic matter in soil can improve water holding capacity, nutrient availability, improved soil structure and reduced erosion which aids in improving plant productivity and ultimately improving food security (McNeill and Winiwarter, 2004). McNeill and Winiwarter (2004) reported that soil productivity is linked with soil organic matter levels with depletion of soil organic matter having large negative impacts on the ecosystem. Soil carbon is a product of both growth and decomposition of plant roots, as well as from C-enriched components transferred from roots to soil microbes (Lal, 2002). One example of this is a symbiotic relationship formed between certain plant species and mycorrhizae fungi. Roots of plants provide carbon to the fungi species and in turn the fungi provide the plant with nutrients such as phosphorus, which is often limiting (Lal, 2002). Biomass decomposition by microbes releases carbon in the soil as CO_2 due to microbial respiration and produces a small amount of humus (Alexander and Fairley, 1983). Different forms of soil organic carbon, such as humus, differ in resistance to decomposition (Alexander and Fairley, 1983). Climate factors such as soil temperature and moisture impact photosynthesis, decomposition, and respiration (Lal, 2004). For example, cold, wet climates have photosynthesis rates exceeding decomposition and therefore produce high levels of soil organic carbon while arid regions have low levels of soil organic carbon (Lal, 2004). Other factors such as soil texture, mineralogy, erosion, and deposition can impact soil organic carbon levels and impact total soil carbon stocks (Lal, 2004). Lal (2009) reported that the conversion of natural ecosystems to agricultural land has depleted the soil organic carbon levels, releasing carbon to the atmosphere which ultimately reduces soil carbon levels. Reduced organic matter, increased soil tillage, and increased erosion have contributed to the depletion of soil organic carbon (Lemus and Lal, 2005).

Erosion

Erosion of soils is detrimental to soil productivity. This is due to a variety of factors including reduced water infiltration, percolation, aeration, and root growth (Magdoff and Van Es, 2009). Soil degradation can also have environmental effects beyond the loss of crop production. It can lead to increased pollution and sedimentation in waterways (Poesen et al., 2003; Owens et al., 2005) as well as air pollution (Piper, 1989). Factors that affect erosion include: climate, soil properties, topography, vegetation, and tillage management (Weesies et al., 1994). Degraded soils have decreased water-holding capacity which can lead to increased damage from flooding (Poesen et al., 2003). Erosion by water occurs by splash erosion, inter-rill erosion, channelized rill, sheet erosion, and gully erosion (Torri and Borselli, 2012). Splash erosion occurs by the kinetic energy of raindrop splash impact initiating the soil detachment process and allowing surface runoff to detach and transport the soil (Torri and Borselli, 2012). Rill and sheet erosion can occur particularly in tilled fields dependent on tillage tracks and topography (Torri and Borselli, 2012). Gullies form when water cuts deeply into the soil horizon

(Sidle et al., 2018). Wind erosion of soil occurs when wind velocity is sufficient to move unstable particles allowing for detachment of soil (Shao et al., 1996). Tillage erosion is impacted by slope of the topography and displaces soil over the length of the slope (Van Oost et al., 2006). Erosion from tillage rarely transports soil off-site however, it does leave soil vulnerable to water and wind erosion (Van Oost et al., 2006). The primary effects of erosion on cash crop growth and yield include: denser subsoil into surface layer, removal of fertile surface horizon, and potential decrease of the rooting zone (Van Oost and Bakker, 2012). In most soils the surface horizon (A) has a greater soil organic matter level, and thus soil organic carbon level, than lower surface horizons (Guo and Gifford, 2002). Erosion losses on crop and pasture land in the United States is approximately $44 billion while world-wide costs are estimated at $400 billion per year (Jones et al., 1997). Soil formation occurs very slowly, as such eroded soil surfaces cannot renew degraded soil (McCormack et al., 1979). Corn yields in Indiana on slightly eroded soils were 9% to 34% greater than yields on severely eroded soils while soybean yields were 14% to 29% lower on severely eroded soils (Schertz et al., 1989). This same study found that levels of organic matter and phosphorus were significantly greater in slightly eroded versus severely eroded soils (Schertz et al., 1989). In addition, Schertz et al. (1989) reported available water supply was 50% to 75% lower in severely eroded soils compared to slightly eroded soils. Strategies to reduce erosion have been investigated and four categories were identified (FAO, 2017). First is the minimalization of deforestation or conversion of grassland to cropland. Second is the adaptation of no-till or reduced tillage farming to protect the surface and reduce runoff. Third is the construction of terraces or other physical barriers primarily to reduce runoff. Lastly is the incorporation of vegetation that protects the soil surface from both wind and water erosion (FAO, 2017).

Compaction

Weight of tractors in the United States has significantly increased since 1950 which contributes to compaction (Sloane and Ouwerkerk, 1998). Soil compaction increases bulk density which is often used as a measurement of compaction (Kooistra and Boersma, 1994). The optimum bulk density level depends on soil texture but when bulk density reaches a certain threshold, root growth is restricted (USDA, 1999). When bulk density increases, porosity of soil decreases (Kooistra and Boersma, 1994). Macropores important for air and water movement through the soil are negatively impacted by compaction, reducing root growth and function (Kooistra and Boersma, 1994). As penetration resistance increases in compacted soils root penetration is limited (Taylor et al., 1966). A study by Taylor et al. (1966) reported that root growth decreased linearly with penetration at 100 psi until growth is halted completely at 300 psi. Negatively impacted root growth contributes to reduced nutrient uptake by the plant along with increased dentrification, leaching, organic nitrogen losses, reduced nitrogen mineralization (Douglas and Crawford, 1993), and phosphorus uptake inhibition (Lipiec and Stepniewski, 1995). Compaction negatively impacts soil structure by reducing organic matter, infiltration, biological activity, and decreasing aggregate stabilization (Kooistra and Boersma, 1994). Micro-, meso-, and macrofauna in soils can be negatively impacted by compaction which will decrease biological activity and slow organic matter decomposition (Radford et al., 2001). Due to a reduction in macropores, water infiltration rate and saturated hydraulic conductivity decreases (Douglas and Crawford, 1993).

Tillage is often used to reduce compaction however, determining whether the topsoil or the subsoil is compacted can impact whether tillage reduces compaction (Hakansson and Reeder, 1994). Hakansson and Reeder (1994) found that on sandy soils tillage can reduce compaction in one year however, on clay-like soils topsoil compaction continues to reduce yield despite tillage. Subsoil compaction occurs below normal tillage depth and, after a 10 year study, yield losses were estimated at 3% which was considered permanent and likely due to high axle loads on wet soils (Hakansson and Reeder, 1994). Tillage of compacted soils has been shown to make that soil more vulnerable to re-compaction (Kooistra and Boersma, 1994).

Grazing Impacts on Soil

Soil type and quality are determining factors in plant growth and yield. Soil composition determines the liquid and plastic limits and plasticity index which impact the soils vulnerability to experiencing leaching, compression, and compaction (Nguyen et al., 1998). Treading on soil surfaces can reduce pore space and contribute to compaction which inhibits transportation of nutrients, water, and gases, hinders root and plant growth, and may increase nutrient runoff (Horn et al., 1995).

Franzluebbers and Stuedemann (2010) reported that although grazed pastures had lower soil surface bulk density than ungrazed, deeper layers of soil were more compacted in grazed pastures with subsequent increased bulk density in intensely grazed forage. During periods of intense grazing penetration resistance also increased past the threshold (2 MPa) and impaired root growth (Donkor et al., 2002). High stocking density grazing increases the probability of compacting soils (Franzluebbers and Stuedemann, 2010) however, freeze-thaw cycling may mitigate some compaction (Horn et al., 1995).

Intensely grazed pastures, after a minimum of two years of rest, had similar bulk density values to pastures that had not been grazed for 27 years (Greenwood et al., 1998). However, Nguyen et al. (1998) reported that six months of rest improved filtration rates of intensely grazed ground while short-term grazing periods did not impact infiltration rate.

In an effort to more efficiently utilize available land resources integrated crop-livestock systems have become of great interest (de Oliveira et al., 2013). However, there are concerns as to whether grazing negatively impacts cash crop yield (Clark et al., 2004). Compaction by cattle may occur when grazing moist cropland soils, especially when there is no vegetation, which can lead to a reduction in crop yields (Krenzer et al., 1989; Mapfumo et al., 1999). There is conflicting data on whether cattle grazing cover crops during appropriate (dry) weather conditions impacts compaction. Clark et al. (2004) reported that cattle grazing did not impact subsequent soybean plant production under normal conditions however, grazing negatively impacted yield when soil penetration resistance increased. Results indicated that grazing has minimal impacts on soybean yield if occurring during periods of soil temperature below 0°C or if the soil is tilled before planting (Clark et al., 2004). In both tillage and no-till systems, a study by Drewnoski et al. (2016) reported that grazing improved soybean yield or had no impact on soybean yield under both fall and spring grazing conditions. Krenzer et al. (1989) and Mullins and Burmester (1997) indicate that winter grazing of cattle on cropland can lead to compaction and reduced crop yields however, Tracy and Zhang (2008) reported no significant negative effect on cropland and suggested cattle presence may have helped increase yield in comparison to continuous cropland fields.

Soil compaction can reduce air-filled porosity and affect surface CO_2 (Conlin and van den Driessche, 2000). If severe, root growth can be negatively affected, ultimately impacting crop growth (Linn and Doran, 1984). Torbert and Wood (1992) and Shestak and Busse (2005) reported similar findings in which respiration rates were reduced in compacted soils compared to non-compacted soil. In year two of a study by Tracy and Zhang (2008) respiration rate was greater in pasture, 3.6 umol CO_2 m^{-2} s^{-1}, compared to crop fields, 2.3 umol CO_2 m^{-2} s^{-1}. However, respiration rate between cover crop oat pasture and continuous corn did not differ.

Compaction negatively impacts forages as well as cash crops. Undersander (2003) reported up to 37% losses due to normal field traffic with losses increasing five days after cutting versus two. Methods of avoiding soil compaction include decreasing trafficked area, decreased number of trips, avoiding wet soil when using machinery, decreasing pressure by using tracks, flotation tires, or doubles, axle loads below 9.07 tonnes (Taylor and Gill, 1984), increase soil organic matter and biodiversity, sparing use of tillage, and usage of cover crops (Raper et al., 2000).

Soil moisture is impacted by the temperature, precipitation, grazing system, and degree of compaction (Donkor et al., 2002; Bell et al., 2011). Grazing on plastic or wet soil increases compaction and enables pugging and poaching to occur (Drewry et al., 2008). Bell et al. (2011) reported that water infiltration rate decreased the summer following winter grazing on wet soils compared to dry pastures. This is suggested to be due to compaction from grazing which inhibits water infiltration and subsequently reduces soil moisture (Donkor et al., 2002). High stocking density for short durations resulted in reduced soil moisture in comparison to lower stocking density continuous grazing (Donkor et al., 2002). Banerjee et al. (2000) reported conflicting data indicating that neither stocking system nor stocking rate impacted soil moisture. Moisture impacts the ability of soil to recover after grazing (Dexter, 1991).

Management strategies of livestock can impact various soil characteristics (Conant et al., 2003). In grazed cropland-pasture rotations organic matter and total carbon concentrations were greater than un-grazed cropland (Tracy and Zhang, 2008). Acosta-Martinez et al. (2004) reported that in comparison to un-grazed cropland, grazed croplands microbial biomass carbon and nitrogen, soil organic carbon, enzyme activity, protozoa, and fungi populations were increased.

Cattle

History

Loftus et al. (1994) indicates that the domestication of cattle occurred in at least two domestication events approximately 10,000 years ago. Cattle domestication followed the trend of sheep and goat domestication and was one of the earliest forms of capital (Conolly et al., 2012). Cattle quickly became the most important domestic animal species by supplying meat, milk, hides, and labor and are still a critical domestic species today (Price, 2000). *Bos taurus* and *Bos indicus* cattle make up the majority of all domesticated cattle (Lenstra, 1999). Both are thought to have descended from the wild aurochs, *Bos primigenius*. (Ho et al, 2008). The British Agricultural Revolution led to major changes in animal husbandry with the development of breeds, deliberate selection of sires, and documentation of mating selection and pedigree (Thomas, 2005). British breeds including

Herefords and Aberdeen-Angus were developed during the 1800s (Briggs and Briggs, 1980). Aberdeen-Angus breed originated as a cross between two cattle breeds native to Scotland (Sanders, 1928). According to Sanders (1928), polled and black coloring characteristics were common in the native breeds thus becoming staple traits in modern Angus cattle. The arrival of cattle into what is now known as North America was facilitated by Spanish explorers who discovered the Americas and initiated importing cattle to the area (Payne and Hodges, 1997). Angus cattle were first imported to the United States in 1873 (Association, 2012).

Because the beef market is local, national, and international, several associations have been developed to maintain a high level of communication and quality. These include the American Angus Association (established 1886) and National Cattlemen's Beef Association (established 1898; Ball, 2000). According to a study by Short in 2001, beef production in the United States had risen over the previous 30 years despite a reduction of numbers in national cattle numbers. In 2017 cash receipts for cattle and calves brought $67.1 million (USDA, ERS, 2018). As of 2019, beef cattle are raised in all 50 states and number approximately 94.8 million total head and 31.4 million beef cows (NCBA, 2019). Cow/calf production is the most prevalent sector of the beef industry in the state of Kentucky (USDA, NASS, 2018). Kentucky ranks 14th in the U.S. in total cattle production and has an estimated 1.03 million head of beef cows making it the largest beef cow producing state east of the Mississippi River (USDA, NASS, 2018). According to the Kentucky Department of Agriculture total estimated expenses per cow in fall 2018 was estimated at $585 with revenue per cow valued at $718. A large portion of the estimated expenses is due to feed, especially the increased requirement for supplemented feed during winter months (KDA, 2018).

Maternal Characteristics

Cow/calf operations are largely dependent on the longevity of a cow within the herd to recoup initial purchase price, cost of heifer development, and cow maintenance (Snelling et al., 1995). Longevity is impacted by numerous factors including calving interval, postpartum interval (PPI), and calf performance (Snelling et al., 1995). Given an average 285-day gestation length, a cow has approximately 80 days to recuperate from calving and to conceive, in order to maintain a 365-day calving interval which is vital to recuperating costs (Frazier et al., 1999). If PPI increases, a cow resumes estrous cycling late in the breeding season or fails to resume cycling within the breeding season (Williams, 2005). This limits the number of days for rebreeding to occur. Calves are likely born late in the calving season leading to smaller calves at weaning, and calving interval could increase potentially past the optimal 365-days (Dunn et al., 1980).

Nutritional requirements during lactation contributes to determining length of PPI (Short et al., 1990). Lactation following calving increases nutritional requirements of the cow which can delay resumption of estrus cycling (Short et al., 1990). If nutritional requirements aren't met the release of gonadotropin releasing hormone (GnRH) from the hypothalamus is reduced which leads to a subsequent decrease in anterior pituitary secretion of luteinizing hormone (LH). Decreased secretion of LH diminishes ovarian activity, possible failed resumption of estrous cycle, and potentially decreases longevity (Williams, 2005). Lactating cows are particularly vulnerable to nutrient deficiency during winter months if not supplemented appropriately (Short et al., 1990). Milking ability of the cow greatly impacts the performance and weaning weight of a calf. Marston et al. (1992) reported that calves from cows with higher EPD's for milking were heavier than calves born from lower milk EPD cows. However, increasing milk production, particularly in poor nutritional environments, may have a negative impact on female fertility (Cammack et al., 2009).

Body condition score (BCS) can be a beneficial tool for judging body reserves and optimizing reproduction (Short et al., 1990). Optimum BCS is subjective based on breed, amount of milk production, and dystocia. Studies have reported an interaction between BCS at calving and PPI as lower BCS can elongate PPI and higher BCS can decrease PPI (Short et al., 1990). Low BCS cows will have an elongated PPI due to nutrient restriction which decreases secretion of hormones necessary for estrous cycling (Wettermann et al., 2003). Having a calf that is still suckling the cow has been reported to lengthen PPI (Short et al., 1990). Short et al. (1990) found that complete weaning, partial weaning, or short-term weaning (48 hours) can shorten the PPI.

Cattle have requirements for certain nutrients such as protein, energy, and water however, there is generally no requirement for dry matter intake (Hibbard and Thrift, 1992). Intake is limited by the capacity of the digestive tract and is highly correlated with forage quality (Hibbard and Thrift, 1992). Lactating cows will consume more forage than gestating cows although frame size and mature body weight contributes to determining amount of forage consumed. It is estimated that on low quality forage lactating cattle have the capacity to consume 2.2% dry matter as a percentage of their body weight. However, if adequate protein is not provided dry matter intake will decrease. Lactating cows require nearly twice the daily protein of dry cows. Larger sized cows require more energy than smaller cows (Hibbard and Thrift, 1992). A 590 kg lactating cow has a daily DM intake of approximately 14.5 to 15.40 kg/day, 8.21 to 8.94 kg TDN, 17.6 to 19.2 Mcal NEm, and 7.98 to 8.71 kg CP (NRC, 2000). A lactating cow weighing approximately 590 pounds also requires 46.18 to 54.89 liters of water per day (NRC, 2000). Nutrient requirements are impacted by stage of production, environmental conditions, breed, age, weight, gender, and other factors (NRC, 2000).

Beef cows are often managed in less intensive systems which can provide challenges in meeting nutrient requirements under grazing conditions. Nutritional requirements for a cow vary depending upon pregnancy status, lactation, and environmental conditions such as extreme weather and limitation of available forage (Hawkins et al., 2000). According to the Nutrient Requirements of Beef Cattle net energy and protein requirements are highest during peak lactation (NRC, 2000). When nutritional requirements are not met body reserves are used to meet the demand (Jenkins and Ferrell, 1992). According to Hawkins et al. (2000), cows grazing low quality forage such as dormant native range may not gain the required nutrients for rebreeding. A study by Montano-Bermudez et al. (1990) demonstrated the energy increase required by a lactating cow, the energy needed to improve BCS during lactation, and additional increase in energy to gain weight back after a loss during lactation. Producing 1 kg of milk was estimated to require 1.0 ± 0.13 MCal of energy; to gain 1 kg of weight during lactation energy required was 1.05 ± 0.83 MCal; when 1 kg of weight is lost the energy required to regain lost weight was 2.94 ± 0.52 MCal (Montano-Bermudez et al., 1990). This same study reported that maintenance requirements are positively related to milk production thus reporting that medium and high milk producing cow groups have higher energy maintenance requirements per unit of metabolic body weight ($MW=kg^{0.75}$) than low producing cows (Montano-Bermudez et al., 1990).

Miller et al. (2001) reported that feed costs are the largest expense for cow-calf producers, accounting for over 60% of the variation in total annual cow costs making it vital for producers to achieve maximum performance with the fewest inputs thus becoming more efficient. Overall efficiency of cow-calf producers' herds can be calculated by measuring both cow and calf feed intake over a production cycle-defined as time from weaning one calf to the weaning of the next (Shuey et al., 1993). This allows for conversion to kilograms of calf weaned per kilogram of feed intake (Shuey et al., 1993). An individual cows feed efficiency is affected by intake, digestion, body composition, metabolism and protein turnover, activity, thermoregulation, and other factors (Richardson and Herd, 2004).

Growth and Production of Pre-Weaned Calves

Preweaning average daily gain significantly impacts the profitability of a cow-calf operation and is a similar measure of growth as weaning weight (Kennedy and Henderson, 1975). Breed of dam was found to influence preweaning ADG with dairy influenced dams tending to wean heavier calves than purebred and crossbred beef cows (Brown et al., 1970; Butson et al., 1980). Mendonça et al. (2019) and Frigerio (1961) reported that crossbreds generally produced the heaviest calves, while purebred Angus cows produced heavier calves than purebred Hereford. However, Rovira (1966) found no significant difference between breeds and Warren et al. (1965) reported Herefords to be heavier than Angus at weaning. Crossbred cows produced calves with greater weaning weights than purebred cows (159 kg and 125 lbs respectively; Franke, 1999). Charolais calves were heavier at weaning than Limousin, Hereford, and Angus calves (Cundiff et al., 2001). In a study by Franke (1999) weaning weights were greatest in calves from Charolais (160 kg) cows consecutively followed by calves from Angus (135 kg), Hereford (177 kg), and Brahman (90 kg) cows.

Age of dam impacts weaning weight with Brown et al. (1970) reporting a rapid incline in weaning weight from 3 to 6.5 years of age of the dam, a gradual incline to 8.5 years of age, followed by a decline to 11 years of age. Da Silva et al. (2016) reported similar trends between dam age and calf weaning weight. Results indicating an impact of age of dam on preweaning ADG were reported by Schaeffer and Wilton (1974) and Butson et al. (1980).

Differences in calf weight is due to an average increase in milk production as dam age increases (Neville, 1962; da Silva et al. 2016). Marshell et al. (1976) reported correlation values for average milk weight with weaning weight to be 0.50 to 0.80. Cortés-Lacruz et al. (2017) estimated milk yield correlation to calf weight to be 0.54. Average milk yield accounts for approximately 60% to 71% of the variance in preweaning ADG (Jeffery and Berg, 1971). Butson et al. (1980) found that, after adjustments for variable effects such as sex, age of calf, age of dam, and breed, a 1 kg increase in average daily milk yield was associated with an average 7.65 kg increase in weaning weight. Similar increases in preweaning ADG and weaning weight were conveyed by other studies including Jeffery and Berg (1971) who reported 0.06 to 0.09 kg/day increase in preweaning ADG per 1 kg increase in milk yield. A 1% weight loss in the dam during lactation was found to be associated with increasing weaning weight from 0.14 to 1.09 kg (Singh et al., 1970). The authors of this study indicated that cows that were higher milk producers lost more weight while nursing but increased weaning weight of suckling calves (Singh et al., 1970).

Sex of calf has a highly significant effect on weaning weight with males generally heavier at weaning than females (Butson et al., 1980; Paterson, 2015; Fahmy and Lalande, 1973; Botkin and Watley, 1953; Harwin et al., 1966). Paterson (2015) reported that bull and steer calves averaged 254 kg weaning weight while heifers averaged 241 kg. An increase of 11 kg at 210-day weaning in bull calves compared to heifers was reported by Botkin and Whatley (1953). Similarly, Harwin et al. (1966) reported an increase of 10 kg in bull calves compared to heifers.

Butson et al. (1980) reported an average increase of 1.7 kg weight at weaning for every kilogram increase in weight at birth which is similar to results reported by Lawson (1976), and Singh et al. (1970). However, increased birth weight is associated with increased occurrence of dystocia and reproductive issues (Berg et al., 1978). Age of calf at weaning is also a significant source of variation in weaning weight (Butson et al., 1980; Schaeffer and Wilton, 1974). In addition, environmental impacts such as climate, management, and grazing conditions have a significant impact on weaning weight. These factors vary from year to year and have been reported to account for 6 to 8% of variation in weaning weight (Brown, 1960) while numerous studies have experienced a significant year effect on weaning weight (Peacock et al., 1960; Meade et al., 1963; Warren et al.,1965; Harwin et al., 1966).

Forage and Grazing Factors

Plant cell walls contain cellulose, a carbohydrate that is a main component of the cell (Van Soest, 1994) and is the largest carbohydrate source on Earth (Voet et al. 2013). Mammals are limited in their ability to digest cellulose because enzymes in mammalian digestive tracts cannot degrade glycosidic bonds and other structural bonds (Church, 1988). However, ruminant species digestive tracts have evolved and contain anaerobic micro-organisms which can degrade these bonds. Micro-organisms then produce by-products (e.g. acetic acid, propionic acid, butyric acid, others) that allow ruminants to utilize plant material. A large portion of land area is unsuitable for crop production but can be utilized by grazing. Ultimately, this allows ruminants to utilize a food source that humans are not able to readily consume, producing high quality animal protein available for human consumption (Church, 1988).

Grazing removes leaves, thus photosynthetic ability, from plants who respond by mobilizing resources to facilitate regrowth (McInenly et al., 2010). If grazing occurs during the regrowth period carbohydrate reserves are depleted faster than they can be replenished which can harm yield and long-term growth of the plant (Cullen et al., 2006). Forage regrowth rate, mass, and nutritional quality depend upon defoliation interval and intensity (Kydd, 1964). Defoliation interval is the resting phase between grazing, and as this interval increases leaf area and root reserves have increased time to recover and forage mass increases (Phillip et al., 2001). Defoliation intensity is the degree of leaf area removal and as this increases leaf area, root reserves, and mass decreases (Phillip et al., 2001). Therefore, overgrazing decreases regrowth and mass both by repeated grazing of the same plant and excessive removal of plant mass (Phillip et al., 2001). There is data suggesting that removal of some forage can increase productivity and efficiency. Kydd (1964) found that at optimum stocking density defoliation opened the canopy allowing sunlight to penetrate the sward and promote tillering and new leaf development (Kydd, 1964). If adequate rest is provided, short periods of high intensity grazing aids in increasing yield (Motazedian and Sharrow, 1990). However, if severe defoliation occurs with each event, regrowth will be impaired (Phillip et al., 2001).

Quality of a forage is affected by both species (Sanderson et al., 2004) and maturity (Roth et al., 2011). Legume species generally contain more protein than grass species which are usually more fibrous (Pavlů et al., 2003). Young, or less mature forage, has higher quality than the mature forage of the same species because it is less fibrous and contains more protein (Donaghy et al., 2008). Temperature can impact quality of forages, demonstrated by lower digestibility and yield of alfalfa grown in high temperatures (21°C to 27°C) compared to lower temperatures (10°C to 16°C; Vough and Marten, 1971). Available water reserves may also affect forage quality. Heinrichs (1970) reported that extreme flooding for five or more days reduced crude protein and diminished root and shoot growth. Under drought conditions forage mass (Vough and Marten, 1971), protein, and digestibility were reported to be reduced compared to forages supplied with adequate water (Asay et al., 2002).

When consuming poor-quality forage, which may occur during winter grazing, dry matter intake may be regulated first by bulk fill before nutritional requirements have been met (Provenza, 1995). When dry matter digestion fell below 67% bulk fill regulated dry matter intake (Van Soest, 1994). Poor-quality forage intake slows passage rate and increases rumination and rumen retention. This contributes to reduced time grazing and subsequently less dry matter intake (Church, 1988).

Differences in movement and sleep patterns which are influenced by temperature and photoperiod impacts grazing behavior of cattle (Ruckebusch, 1988). Cattle will spend 5 to 12 hours per day grazing depending on various factors, generally during morning and dusk (Welch and Hooper, 1998). Ruckebusch (1988) found that when experiencing cold stress cattle graze for longer periods of time daily and dry matter intake is increased. During periods of heat stress more grazing occurs at night as heat inhibits activity level; water availability can modify grazing behavior and is critical to mitigating heat stress (Kendall et al., 2007).

Topography and plant species growth can impact grazing behaviors (Senft, 1987). Cattle are prone to graze valley bottoms and land that is level and near water while tending to avoid slopes that are greater than 10 degrees, although this may vary by breed (Cook, 1966). *Bos indicus* influenced cattle are more likely to travel further from a water source than *Bos taurus* influenced cattle (Rook et al., 2004). Regardless of breed, cattle are more likely to remain in one area or return more frequently to an area with abundant, high-quality, palatable forages compared to expanses of poor-quality forage (Bailey, 1995).

When describing management strategies, stocking rate and stocking density are important terms to understand. Stocking rate is the animal to land relationship over time while stocking density is the animal to land relationship at a certain point in time (Allen et al., 2011). Distinguishing effects between available forage and animal density may be difficult when comparing increased stocking density with decreased available forage and continuously grazed systems (Allen et al., 2011). Decreased weight gain of livestock has been reported with increasing stocking density without constant available forage (Curtis et al., 2008). Curtis et al. (2008) found that gain per acre increased with increasing stocking density until available forage was limited. For example, soil organic matter accumulation is increased by forage trampling and fecal deposition under high stocking density management (Conant et al., 2003). Franzluebbers and Stuedemann (2010) reported that high grazing intensity decreased soil carbon level in sandy loam soils that had been eroded in comparison to low density grazing. However, both grazing intensities had higher soil organic carbon level than un-grazed (Franzluebbers and Stuedemann, 2010).

The type of grazing method utilized impacts forage removal by cattle. When available forage is not limited, cattle are more selective and will consume a higher crude protein, lower fiber diet than the average available forage (Hinata et al., 2012). Cattle are less selective and will consume forage based increasingly on quantity instead of quality when hunger increases (Hirata et al., 2012). Rotational stocking reduces access to forage and prevented selective grazing in comparison to continuous stocking (Phillip et al., 2001). Studies have reported that ideal livestock performance occurs by rotating frequently to allow selection of more palatable and digestible forages (Taylor et al., 1980; Olson et al., 1989). Walton et al. (1981) reported that weight gains in the third and fourth years of the study were nearly double in rotationally grazed areas (218 kg/ha) than gains from continuous grazed areas (119 kg/ha). In addition, digestibility and nutritional quality was increased in forage that was rotationally grazed as compared to continuously grazed forage (Walton et al., 1981). Rotational grazing and continuous grazing had no difference in average daily gains when grazed at equal stocking rates and grazing pressure (Hart et al., 1976).

Grazing of crop residues and cover crops has been reported to have conflicting effects on subsequent cash crop yield. Krenzer et al., 1989 and Mullins and Burmester, 1997 found that winter grazing by cattle can reduce cash crop yields. Winter grazing on corn stalks was reported to have only slight impacts on subsequent soybean yield by Clark et al. (2004) and effects were even less when grazing occurred when soil was frozen or if tillage occurs before planting. Grain yield effects due to compaction are amplified when crops experience drought stress (Sidhu and Duiker, 2006). Therefore, adequate or above average moisture levels mitigate some of the effects of compaction on yield (Tracy and Zhang, 2008). Stalker et al. (2015) found no significant difference between corn yields of grazed versus un-grazed cropland. Wheat yields have been reported to decrease with the presence of cattle grazing (Trent et al., 1988; Edwards et al., 2011). Conversely, Baumhardt et al. (2009) found no significant difference between grazed and un-grazed wheat yields or subsequent soybean yields. Both studies suggested that grazing by livestock positively impacted soil nutritional and functional components in comparison to un-grazed systems (Acosta-Martinez et al., 2004; Tracy and Zhang, 2008). De Oliveira et al. (2013) reported that the overall gross margin was lower in cash crop system than in an integrated crop-livestock system with no impact of grazing on soybean yield.

Weaned calves grazing oats and brassicas had an average daily gain of 0.85 kg/day (Drewnoski et al., 2018). Beef cows grazing annual turnips had an average daily gain of 1.89 pounds/day over 4 years with increasing bodyweight and body condition score from 2007-2009 (Fraase et al., 2010). Gaugler et al. (2014) reported heifer ADG of 0.62 kg/day grazing a two species mixture cover crop with stagnant and increasing body condition scores in 2012 and 2013 respectively. Additionally, the dual crop system had the greatest return per acre compared to single cover crop, half-use of single crop, half-use of dual crop, and drylot treatment (Gaugler et al., 2014).

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II. Article Section

Improving sustainability utilizing cover crop grazing to improve soil health while increasing grain and livestock production

Introduction

Agronomic and environmental concerns about erosion and overall soil health during periods of rest between crops has generated interest in cover crop utilization. Erosion of soil can limit the capacity for growing crops due to reduced supply of adequate nutrients for crops and failure to maintain soil microorganism biodiversity (Magdoff and Van Es, 2009). This is due to a variety of factors including reduced water infiltration, percolation, aeration and root growth (Magdoff and Van Es, 2009). Soil degradation can also have environmental effects beyond the loss of crop production. It can lead to increased pollution and sedimentation in waterways (Poesen et al., 2003) as well as air pollution (Piper, 1989). Degraded soils have decreased water-holding capacity which can lead to increased damage from flooding (Poesen et al., 2003). Cover crops are used to improve production of subsequent crops by enhancing physical, chemical and biological soil properties as well as improving many other environmental and agronomic components (Weil and Kremen, 2007; Fageria et al., 2005). A study by Franzluebber (2007) showed that usage of cover crops has the potential to aid in soil management, crop production, and increasing long-term economic benefits however, the practice of using cover crops has yet to be widely applied due to the lack of immediate economic benefit. Cover crops can be utilized to help reduce issues with soil health and the negative environmental impact associated with erosion. One of the largest concerns with using cover crops are the direct costs associated with cover crop seed, labor, fuel, fertilizer, and herbicide or tillage to terminate the cover crop (Snapp et al., 2005). There are strategies that can be taken advantage of that will aid in more efficient use of the forage with a relatively immediate economic benefit. One such strategy is the usage of cover crops as grazing fodder for livestock. Grazing species of animals have the ability to convert cellulose, the predominant carbohydrate source in the world, into products for human use (Oltjen and Beckett, 1996). Utilization of livestock grazing on cover crops allows for an immediate economic benefit while reducing input costs (Franzluebber, 2007; Magdoff and Van Es, 2009). Extending grazing into fall-winter period reduces feed costs increasing efficiency of forage utilization and profitability (Penrose et al., 1996). In comparison to native grass pastures, cover crops generally provide higher quality forage for grazing animals (Franzluebber, 2007; Magdoff and Van Es, 2009). This was demonstrated by Choet et al. (2003) who reported increased average daily gains from steers grazing winter wheat compared to native-pasture grazed steers. Redmon et al. (1995) noted a positive effect on grazed winter wheat with increased grain yield when wheat cultivars were grazed until the joint stage compared to un-grazed winter wheat. Studies have shown that total soil carbon concentration increases in grazed cover crop systems resulting in an overall positive effect on soil organic matter despite potential compaction caused by livestock grazing (Tracy and Zhang, 2008).

The first objective of this study was to measure soil health properties and cash crop production characteristics of a grazed cover crop field and an un-grazed cover crop field. The second objective was to identify effects of utilizing cover crop forage for grazing by livestock and evaluate strategies to identify whether cover crop grazing is an adequate approach that will increase available forages without harming soil health or grain production.

Material and Methods

Field Management Practices

This study was conducted from 2017 to 2019 at the Western Kentucky University Research and Education Complex located in Bowling Green, Kentucky. For four years prior to establishment of experimental plots, the 10.8 hectares used in this study were managed and maintained as grazed tall fescue (*Festuca arundinacea*; cv. Kentucky 31) pastures. For the purposes of this study 7.2 ha of tall fescue was tilled and converted for use as cropland. Three adjacent fields at 3.6 hectare each were established for data sampling with a comparison of soil physical and chemical parameters, and soybean and corn characteristics between an un-grazed cover crop field, in this case wheat (*Triticum aestivum*; W), grazed cover crop field (WGR), and grazed endophyte-infected tall fescue field (TF). Previously reported data from this study with comparison between treatments includes cattle performance, wheat yield and characteristics, and tall fescue yield and characteristics (Netthisinghe, 2019). The primary soil type of the three sites is Crider silt loam. Crider silt loam soil is characterized by being well-drained, moderately permeable, high water holding capacity, and neutral to strong acid pH (USDA, NRCS, 2004). Cover crops used in this study include: a soft red winter wheat cultivator (cv. Branson) seeded in November 2016 and 2017; annual ryegrass (*Lolium multiflorum*) established December

2018; and red clover (*Trifolium pratense*) and turnip (*Brassica rapa*) mixture seeded November 2019. Wheat cultivars were harvested in June 2017 and 2018 while annual ryegrass was terminated May 2019. Following harvest or termination of cover crop, the two cash crop fields were planted to either soybeans (*Glycine max*), 3.9 maturity group Syngenta variety, (2017 and 2018) or corn (*Zea mays*), 112-day maturity LG variety, (2019) and harvested. Subsequently, the selected cover crop was then sowed into crop stubble. Cash crop fields were managed and maintained in a no-tillage system. For grazing, tall fescue was stockpiled starting in September and maintained by mowing two times a year. To meet fertilizer requirements, 54 and 32 kg ha^{-1} urea nitrogen was applied to wheat grazed and wheat fields respectively in February or March of each year of the study. Tall fescue was fertilized with urea nitrogen, phosphorus, and potassium (N-P-K) as required by soil test in February and with 43-43-32 kg ha^{-1} N-P-K in September of each year. Different sets of 16 Angus cow/calf pairs of similar body weights were used each year in this study, allocated randomly to grazing winter cover crop or endophyte-infected tall fescue. Cattle grazed for three weeks in 2017 (March 21-April 12), two weeks in 2018 (March 14-March 28), and were unable to graze in spring 2019 or spring 2020. Grazing during spring 2019 was inhibited by excessive rain and polar vortex winter conditions while grazing in spring 2020 was prevented due to late soybean harvest which delayed cover crop planting thus resulting in inadequate stand establishment for grazing. The grazing period length was determined by available forage and weather conditions. Cattle body weights were established at day 0 of grazing and taken again once each week of grazing. Cattle were supplemented with an 11.7% crude protein concentrate and mineral. Initial soil sampling occurred prior to experimental start date in fall 2016 to determine baseline analysis of each field. Soil samples was taken at a depth of 101.6 mm using a 19 mm diameter soil probe (Oakfield Apparatus Co., Fond du Lac, Wisconsin). Bulk density samples were taken using a 173.4 cm^3 compact slide hammer corer (AMS-Samplers, American Falls, Idaho). Soil core samples and bulk density samples were taken in all plots March, June, and October 2017-2019.

Grain Yield and Quality, Soil Physical and Chemical Parameters, and Cattle Analysis

Soybean and corn grain was hand-harvested from a sample area of 1 m^2 at six geo referenced locations in each cash crop field and yield was measured as weight threshed. Four replicates of each of the cash crop fields were measured to determine yield. Soybean plants were cleaned and measured for various plant, pod, and seed characteristics. Grain moisture content was determined by a grain moisture meter (Dickie John, Minneapolis, MN). Twelve soil core samples and one bulk density sample were taken from 1 m^2 areas at 12 geo referenced locations within each field. Extractable nutrient samples were then air-dried at room temperature to a constant weight and kept in bags until they were processed. Before analysis, soil was ground to pass through a 2-mm screen. Nitrate and ammonia samples were separated and stored in a freezer until arrival at laboratory for analysis. Soil samples were then analyzed for pH, P, K, Ca, Mg, Fe, Cu, and Zn using Mehlich-3 (M-3). Emission spectroscopy on an inductively coupled spectrophotometer (Vista Pro Varian Analytical Instruments, Walnut Creek, California) was used to determine Mehlich-3 (Mehlich, 1984) extractable nutrient concentrations. A 2-gram soil sample in high-temperature combustion in a Vario MAX C-N analyzer (Elementar America Inc.) was used to measure total soil carbon and nitrogen contents. Sample analysis was conducted by the Waters Agricultural Laboratory in Owensboro, Kentucky. Cattle body weights were recorded weekly by a 9' weighbridge (For-Most 30, Hawarden, Iowa; Netthisinghe, 2019).

Statistical Analysis

The statistical analysis for soybean characteristics, corn characteristics, and soil physical and chemical parameters was conducted using the MIXED procedure of SAS 9.4 (SAS, 2011). Treatments included un-grazed wheat, grazed wheat, and grazed tall fescue. Treatment x year interactions were analyzed as a fixed effect and included if significant. Cultivars, sowing rate, and plant densities were also considered fixed effects. Dependent variables evaluated for soil sampling included soil macro- and micro-nutrients including: N, NH_4, NO_3, C, pH, CEC, OM, P, K, Mg, Ca, S, B, Zn, Mn, Fe, and Cu and bulk density. Soybean and corn characteristics were evaluated on grazed and un-grazed wheat fields. Dependent variables for soybean characteristics include: plant number, average plant height, average number of branches, nodes on main stem, total nodes on branches, pods on main stem, total pods on branches, pods per branch, seeds per pod, 100 seed weight, total seed weight, chaff weight, dry matter, and seed moisture. Corn sampling dependent variables included yield and seed moisture. Main effects were treatment, year, and their 2-way interactions. For dependent variables that did not have a 2-way interaction detected when evaluating, their sum of squares and associated degrees of freedom were apportioned to the model error term (residual) for significance testing. The PDIFF option of LSMEANS was used to separate means when protected by F-test at α=0.05, with trends declared at $\geq$ 0.05 to $\leq$ 0.10.

Results and Discussion

Temperature and Precipitation

120-year average monthly temperature and average monthly temperature, January-December, from each year of the study are presented in Figure 3. 120-year average monthly precipitation and total monthly precipitation over the duration of the study are presented in Figure 4. Average monthly temperatures from January-April 2017 were greater than 120-year average temperatures. Mean monthly temperature May-December 2017 were similar to 120-year averages. Monthly accumulative precipitation in 2017 was greater than 120-year averages April-October with the exception of July. Peak accumulative precipitation occurred during May and September 2017. Average monthly temperature in 2018 differed from 120-year mean temperatures exhibited by lower temperatures in January, April, and November and higher temperatures in February, May, June, September, and December. In 2018, monthly accumulative precipitation was, on average, greater than 120-year mean with the greatest increase above average seen in February. This led to inadequate pasture soil conditions for grazing during spring months resulting in a shortened grazing period of 14 days and delayed planting of cover crops during the fall. Mean monthly temperatures in 2019 were similar to 120-year monthly averages except for February and September which were greater than the 120-year average and November which was lower than the 120-year averages. Monthly accumulative precipitation was extremely variable in 2019 compared to 120-year averages. Peaks were seen in February (303.78 mm) and June (230.89) with a sharp decrease in accumulative precipitation (7.37 mm) in September 2019. Due to delayed planting the previous fall, extreme increase in precipitative accumulation in February, and polar vortex weather conditions (-12.11°C) forage growth and soil conditions did not facilitate livestock grazing during 2019.

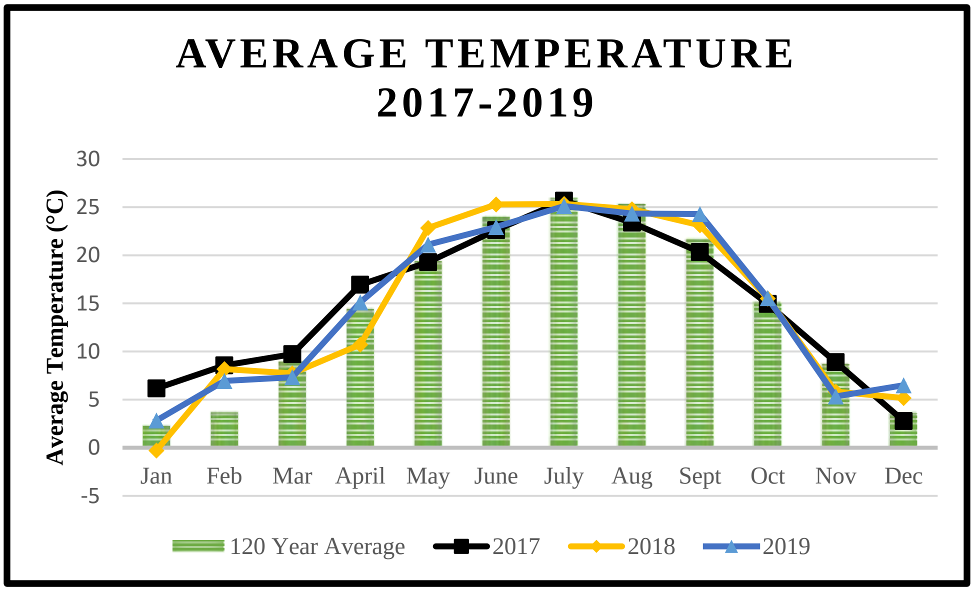

Figure 3. Monthly and 120-year average temperatures from January to December by year at Western Kentucky University Research and Education Complex,

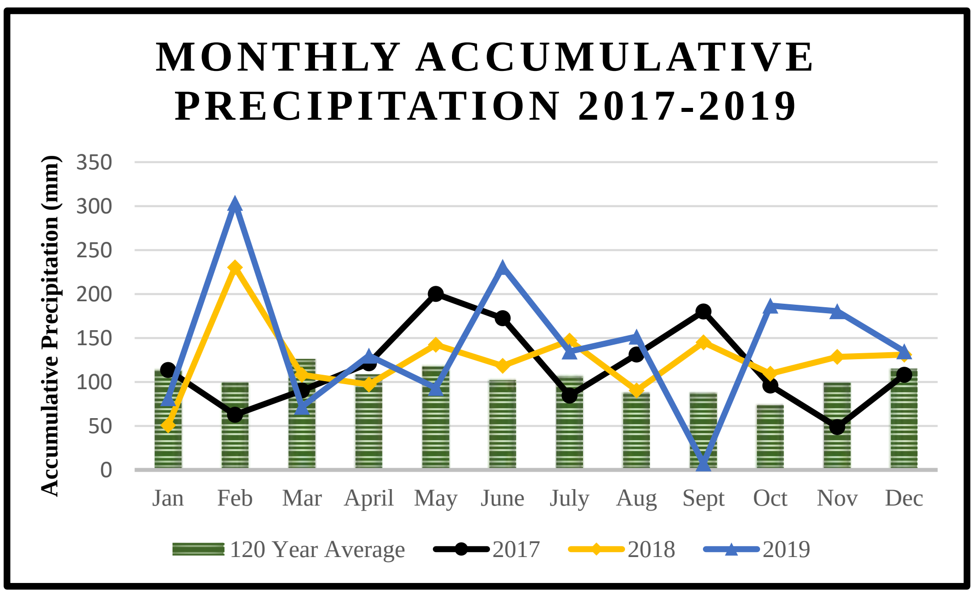

Figure 4. Monthly and 120-year average temperatures from January to December by year at Western Kentucky University Research and Education Complex, Bowling Green, KY.

Base-Line Soil Nutrient Levels Prior to Experiment

Table 1. Initial soil values in fall 2016 prior to start of experiment

Item	Treatment[1]		
Parameter	TF	W	WGR
pH	6.33	5.99	6.04
OM (g kg^{-1})	21.55	22.61	20.61
CEC (C M 100g soil^{-1})	16.36	17.10	15.77
P (g kg^{-1})	12.15	21.04	23.00
K (g kg^{-1})	260.55	299.00	248.00
Mg (mg kg^{-1})	253.7	244.67	208.08
Ca (mg kg^{-1})	2020.95	2012.75	1919.71
S (mg kg^{-1})	19.30	19.42	17.88
B (mg kg^{-1})	0.68	0.73	0.75
Zn (mg kg^{-1})	2.59	2.63	3.27
Mn (mg kg^{-1})	218.35	146.71	221.58
Fe(mg kg^{-1})	94.85	118.00	110.83
Cu (mg kg^{-1})	1.80	2.28	1.68

[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Soil Physical and Chemical Parameters

<u>Spring Soil Sampling</u>

Soil nitrogen (Table 2) content was impacted by treatment (P=0.0198), year (P<0.0001), and treatment x year interaction (P=0.0034) during spring sampling. N differed between W and WGR treatments with greatest content seen in W, intermediate content in TF, and lowest content in WGR. TF did not differ from W or WGR. N level was different between all three years of the study with highest N level seen in 2018 followed by intermediate level in 2019 and lowest level in 2017. The difference between treatments could be due to a spike in N requirements for regrowth after grazing in wheat grazed compared to only wheat (Sundermeier, 2010). Nitrogen is a highly variable nutrient, susceptible to leaching, which could also account for the difference in treatments

(Follett, 1995). Franzluebbers and Stuedemann (2008) reported similar results with lower N concentration in grazed treatments compared to un-grazed due to the increased nutrient requirement following grazing.

Table 2. Total soil nitrogen (g kg^{-1}) from spring sampling as impacted by forage management and year

Item	Year			
Treatment[1]	2017	2018	2019	Mean
TF	2.37^{c}	$3.68^{a,d}$	$3.51^{a,d}$	$3.18^{f,g}$
W	2.35^{c}	$4.46^{b,d}$	$3.35^{a,b,e}$	3.38^{f}
WGR	1.93^{c}	$4.19^{b,d}$	$2.91^{b,e}$	3.01^{g}
Mean	2.21^{h}	4.11^{i}	3.25^{j}	

^{a,b} within a column, means without a common superscript differ (*P*<0.05; SEM=0.16).
^{c,d,e} within a row, means without a common superscript differ (*P*<0.05; SEM=0.16)
^{f,g} within a column, means without a common superscript differ (*P*<0.05; SEM=0.09)
^{h,i,j} within a row, means without a common superscript differ (*P*<0.05; SEM=0.09)
[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

NO_3^- (Table 3) level was also impacted by treatment (*P*=0.0404), year (*P*<0.0001), and treatment x year interaction (*P*=0.0003). TF and WGR treatments differed with TF containing lower NO_3^- levels than WGR. Between years, 2018 was greater in NO_3 than both 2017 and 2019 which did not differ. In the nitrogen cycle, ammonia can be converted to nitrate which is potentially why there is a decrease in ammonia concentration from 2017 to 2018 (Tables 5 and 12) while nitrate concentration increases during this time (Follett, 1995). Franzluebbers and Stuedemann (2008) found that NO_3^- did vary slightly between cover crop management strategies, however, this difference was not biologically significant. The decrease of NO_3^- seen in 2018 to 2019 could be due to increased leaching due to large amounts of rainfall during this period.

Table 3. Nitrate (ppm) from spring sampling as impacted by forage management and year

Item	Year			
Treatment[1]	2017	2018	2019	Mean
TF	5.79	5.77^{a}	3.39	4.99^{e}
W	3.33^{c}	10.35^{b,d}	3.92^{c}	5.87^{e,f}
WGR	4.07^{c}	11.51^{b,d}	4.88^{c}	6.82^{f}
Mean	4.40^{g}	9.21^{h}	4.06^{g}	

^{a,b} within a column, means without a common superscript differ (P<0.05; SEM=0.88).
^{c,d} within a row, means without a common superscript differ (P<0.05; SEM=0.88)
^{e,f} within a column, means without a common superscript differ (P<0.05; SEM=0.51)
^{g,h} within a row, means without a common superscript differ (P<0.05; SEM=0.51)
[1]TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

pH (Tables 4 and 5) was impacted by treatment (P<0.0001) with TF differing from W and WGR which were not different. There was a trend for pH between years (P=0.0581) with 2017 being more basic than 2019 and a trend for increased pH in 2017 compared to 2018. Conversion of grassland to cropland for purposes of the experiment could have contributed to decreasing soil pH due to increased tillage (USDA, NRCS, 1998). W and WGR were more acidic than TF treatment which may be due to increased urea nitrogen fertilizer application and soil tillage (USDA, NRCS, 1998).

Organic matter (Tables 4 and 5) was significantly affected by both treatment (P<0.0001) and year (P<0.0001). Within treatments, TF and W values did not vary from each other but did differ from WGR. TF and W were greater in OM than WGR. Between years, 2018 was greater than 2017 but did not differ from 2019. 2017 was also lower than 2019. The difference in wheat grazed is potentially due to the removal of forage material by grazing and mechanical removal by harvesting (USDA, NRCS, 1996). 2018 is likely greater in organic matter than 2017 as the level of material built up from year one to year two. Galantini and Rossell (2006) reported results supporting the data in this study showing a slight decrease of OM in wheat grazed however, this is ultimately an increase from the basal level of organic matter seen in fallow winter fields and over the duration of the study, increases in OM were noted.

Cation exchange capacity (Tables 4 and 5) values were significantly impacted by both treatment (P<0.0001) and year (P=0.0008). TF had the greatest CEC value and differed from WGR which was also lower than W. 2017 and 2018 had similar CEC values and were both different than 2019 which had a significantly lower value. Cation exchange capacity is impacted by organic matter, which is likely the reason the data reflects similar findings to that of organic matter between treatments (Mengel, 1993).

Treatment and year impacted C (Tables 4 and 5) values (P=0.0022 and P<0.0001 respectively). WGR was lower than both TF and W which were not different. Year values for C were different between all treatments with the highest value in 2018 followed by intermediate values in 2019 and lowest values in 2017. A large component of organic matter is carbon which is why we see a similar trend in significant values of carbon as seen in organic matter (USDA, NRCS, 1996). Similar results were reported by Franzluebbers and Stuedemann (2008) who found that C was lower in grazed cover crop fields compared to un-grazed cover crops.

NH_4^+ (Tables 4 and 5) was impacted by year (P<0.0001) but not by treatment (P=0.9505) during spring sampling. 2017 had a higher NH_4^+ value than either 2018 or 2019. 2018 and 2019 also differed with greater values in 2018. During the nitrogen cycle, ammonia can be converted to nitrates which is likely why there is a decrease in ammonia concentration from 2017 to 2018 while nitrate concentration increases during this time.

This treatment result is similar to Franzluebbers and Studemann (2008) who reported that NH_4^+ was not impacted by cover crop management.

Soil phosphorus (Tables 4 and 5) level was not impacted by treatment or year in this study (P=0.9553 and P=0.6183 respectively). There were no differences in phosphorus levels, and throughout spring sampling biological levels of soil phosphorus content was moderate (20.5-50 g kg^{-1}; WAL, 1976).

Potassium (Tables 4 and 5) level differed both by treatment and year in spring sampling (P=0.0422 and P=0.0366 respectively). TF had the greatest K level and differed from WGR but not from W. 2019 K value differed from both 2017 and 2018 with a lower value. 2017 and 2018 did not differ. K is an essential nutrient for plant growth (Kaiser and Rosen, 2018a). Wheat grazed treatment underwent removal of forage by grazing which would have increased nutrient requirements to facilitate regrowth decreasing K (Kaiser and Rosen, 2018a). Even with decreased K level WGR had high (163-212.5 g kg^{-1}) to very high (>213 g kg^{-1}) levels of K to facilitate crop production (WAL, 1976).

Magnesium (Tables 4 and 5) content differed between all three treatments (P<0.0001) with the greatest value seen in TF followed by W and WGR which had the lowest value. 2017 and 2018 did not differ but were both greater in Mg content than 2019 (P=0.0075). Although, there was an increased level of magnesium in tall fescue versus wheat un-grazed and wheat grazed this was due to a divergence in the initial soil value as compared to a treatment effect (Table 1). However, magnesium was lower in WGR than the two other treatments likely for similar reasons seen with K (Kaiser and Rosen, 2018b). Magnesium has been found to be of importance, primarily for prevention of grass tetany, particularly in the southern Kentucky region where it is often deficient (NRC, 1986). Magnesium values in this study, even when decreased, were very high (>150.5 mg kg^{-1}; WAL, 1976).

Spring sampling of calcium (Tables 4 and 5) displayed both treatment and year effects (P=0.0007; P=0.0044 respectively). Between treatments, TF and W did not differ but were greater than WGR. 2019 was lower in Ca than 2017 but did not differ from 2018. 2017 and 2018 were not different in Ca content. Due to increased uptake of nutrients during regrowth after grazing Ca may have been lower in WGR (Loneragan and Snowball, 1969).

Sulfur (Tables 4 and 5) values were not affected by treatment (P=0.2262) but were impacted by year (P<0.0001). 2017 had the highest S value and was different from both 2018 and 2019 which did not differ. Throughout the study, soil S content was considered to be at moderate (300.5-500 mg kg^{-1}; WAL, 1976) levels even though between years were different.

Treatment (P=0.4703) effects were not seen in soil B (Tables 4 and 5) content during spring sampling. There was, however, a year effect (P<0.0001). 2019 values were lower than 2017 and 2018. 2017 and 2018 did not differ in soil B level. Boron levels ranged from adequate (0.80-1 mg kg^{-1}) in 2018 to medium (0.50-0.75 mg kg^{-1}) in all other years and treatments (WAL, 1976).

Treatment (P=0.2173) and year (P=0.5454) effects were not exhibited in zinc (Tables 4 and 5) values from spring samples. Zinc levels did not differ however, biological levels did range from adequate (3.05-5 mg kg^{-1}) to very high (>7.0 mg kg^{-1}) between effects (WAL, 1976).

Manganese (Tables 4 and 5) was significantly impacted by both treatment (P<0.0001) and year (P=0.0014). WGR Mn level was greater than both TF and W which were not different. Between years, 2019 was lower in Mn content and differed from both 2017 and 2018 which did not differ in Mn.

All treatments (P<0.0001) were different for soil Fe (Tables 4 and 5) level with W having the highest level followed by WGR with intermediate levels and TF with the lowest level. 2017 (P=0.0121) had the lowest soil Fe content compared to both 2018 and 2019 which were not different. Although Fe levels differed, biological values remained in the high range (100.5-200 mg kg^{-1}; WAL, 1976).

Copper (Tables 4 and 5) level was different between TF and WGR (P=00184) with increased levels in WGR. W did not differ from TF or WGR. In comparison across years, 2017 (P<0.0001) was greater than both 2018 and 2019 which did not differ. There were differences among Cu content between treatments and years however, biological levels maintained an adequate (1.55-3.00 mg kg^{-1}; WAL, 1976) level to enable growth.

Table 4. Soil parameters from spring sampling as impacted by forage management

Item	Treatment[1]			
Parameter	TF	W	WGR	SEM
pH	6.28[a]	5.86[b]	5.86[b]	0.07
OM (g kg^{-1})	30.44[a]	29.47[a]	25.03[b]	0.68
CEC (C M 100g $soil^{-1}$)	15.12[a]	14.67[a]	12.46[b]	0.42
C (g kg^{-1})	27.28[a]	26.49[a]	23.53[b]	0.78
NH_4 (ppm)	9.51	9.34	9.38	0.41
P (g kg^{-1})	30.79	29.14	28.69	5.23
K (g kg^{-1})	274.88[a]	251.53[a,b]	204.99[b]	19.95
Mg (mg kg^{-1})	238.51[a]	205.18[b]	178.79[c]	8.56
Ca (mg kg^{-1})	1829.38[a]	1676.85[a]	1434.54[b]	72.52
S (mg kg^{-1})	14.46	13.62	13.72	0.37
B (mg kg^{-1})	0.66	0.72	0.68	0.03
Zn (mg kg^{-1})	3.74	7.84	4.32	1.75
Mn (mg kg^{-1})	154.53[a]	134.79[a]	225.69[b]	9.10
Fe (mg kg^{-1})	115.06[a]	183.32[b]	159.00[c]	6.99
Cu (mg kg^{-1})	1.98[a]	2.23[a,b]	2.39[b]	0.10

[a,b,c] within a row, means without a common superscript differ (P<0.05)

[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Table 5. Soil nutrients from spring sampling as impacted by year

Item	Year			
Parameter	2017	2018	2019	SEM
pH	6.15	5.96	5.90	0.08
OM (g kg^{-1})	25.72[a]	30.11[b]	29.11[b]	0.68
CEC (C M 100g $soil^{-1}$)	14.60[a]	14.88[a]	12.76[b]	0.42
C (g kg^{-1})	20.03[a]	31.94[b]	25.33[c]	0.78
NH_4 (ppm)	19.19[a]	5.26[b]	3.77[c]	0.40
P (g kg^{-1})	28.16	33.66	26.80	5.23
K (g kg^{-1})	259.91[a]	269.88[a]	201.61[b]	19.95
Mg (mg kg^{-1})	223.82[a]	212.63[a]	186.03[b]	8.56
Ca (mg kg^{-1})	1811.18[a]	1664.08[a,b]	1465.08[b]	72.49
S (mg kg^{-1})	15.48[a]	13.38[b]	12.95[b]	0.37
B (mg kg^{-1})	0.74[a]	0.82[a]	0.51[b]	0.03
Zn (mg kg^{-1})	4.19	4.87	6.84	1.76
Mn (mg kg^{-1})	193.93[a]	175.10[a]	145.97[b]	9.10
Fe (mg kg^{-1})	135.12[a]	161.12[b]	161.12[b]	6.99
Cu (mg kg^{-1})	2.63[a]	1.99[b]	1.99[b]	0.10

[a,b,c] within a row, means without a common superscript differ (P<0.05)

Post-Wheat Soil Sampling

Tables 6 and 7 represent June soil sampling taken post-wheat harvesting for treatment and year effects respectively. C, N, NO_3, and NH_4 values were not reported for this sampling period. Sampling did not occur in June 2019 for cost savings purposes due to inclement weather and inadequate forage growth of rye grass preventing grazing from occurring.

pH (Tables 6 and 7) was not impacted by year (P=0.8124) but was impacted by treatment (P=0.0002). TF had the highest pH and varied from both W and WGR however, W and WGR were not different. The differences between treatments follow a similar trend as both spring and fall sampling.

Treatment affected OM (Tables 6 and 7) content (P<0.0001) but year did not impact OM (P=0.5105). Between treatments, TF was greater than both W and WGR with a trend for increased values in W versus WGR. These are results are similar to spring and fall where TF is greater than WGR.

Cation exchange capacity (Tables 6 and 7) value for TF was greater than WGR (P=0.0448) with a trend for greater values than W. W and WGR CEC values were not different. Year did not have an effect on CEC values (P=0.7540). OM has high CEC and so CEC generally follows the trends of OM. As seen here, with an increase in TF of 7.43 C M 100 g soil^{-1} and 10.22 C M 100 g soil^{-1} compared to W and WGR respectively.

Phosphorus (Tables 6 and 7) level in June sampling was not impacted by treatment (P=0.6645) or year (P=0.5970). Biological levels of phosphorus remained in the moderate region (20.5-50 g kg^{-1}; WAL, 1976).

Treatment did impact K (Tables 6 and 7) level in soil for June sampling (P=0.0355) and although year was not significant (P=0.0680) there was a trend for greater levels in 2017 compared to 2018. Between treatments, TF varied from WGR with a greater level reported in TF. TF did not vary from W nor did WGR vary from W. Greater values for K in TF versus WGR was comparable to spring and fall results.

Treatment (P<0.0001) and year (P=0.0047) effects were both significant for Mg (Tables 6 and 7). TF had the greatest value for Mg and differed from both W and WGR. W had intermediate value for Mg and WGR had the lowest value. Mg was greater in 2017 than 2018. Although WGR had the lowest value for Mg, biological values still ranged in high (125.5-150 g kg^{-1}) levels (WAL, 1976).

Calcium (Tables 6 and 7) was impacted by treatment (P=0.0019) and year (P=0.0374). TF and W did not differ but were both greater than WGR. 2017 had greater Ca content compared to 2018. Differences in Ca followed similar tendencies in spring and fall values with values being greater in TF and W and WGR having the lowest concentrations.

Treatment did not impact S (Tables 6 and 7) level (P=0.4073) however, year did have a significant impact (P=0.0161) with 2018 having a lower value than 2017. Although 2018 was lower, biological values stayed within medium (13-25 mg kg^{-1}) range (WAL, 1986).

Year 2017 was greater in B than 2018 (Tables 6 and 7; P=0.0199) but treatment did not impact B content (P=0.3941). This year difference is opposite of both spring and fall sampling results where B was greater in 2018 than 2017.

Zinc (Tables 6 and 7) content was not impacted by treatment (P=0.4071) but there was a trend for increased values in 2017 versus 2018 (P=0.0741).

Treatment (P<0.0001) and year (P=0.0045) affected Mn (Tables 6 and 7) content in June soil sampling. Greatest value for Mn was reported in WGR, TF was intermediate and did not differ from either WGR or W, and W had the lowest Mn levels. 2017 had increased Mn content compared to 2018. WGR had the greatest Mn content in all sampling periods. Biological levels of Mn ranged from high (100.5-200 mg kg^{-1}) to very high (>201 mg kg^{-1}; WAL, 1976).

Iron (Tables 6 and 7) was greater in 2017 than 2018 (P=0.0441). Treatment impacted Fe level (P=0.0049). TF and WGR value for Fe was lower than W. TF and WGR were not significantly different.

Year value for Cu (Tables 6 and 7) was greater in 2017 than 2018 (P=0.0011). Treatment did not impact Cu content in soil during June sampling (P=0.8052). Although year had an effect on Cu levels, biological levels remained within the adequate (1.55-3 mg kg^{-1}) range (WAL, 1976).

Table 6. Soil parameters from June sampling as impacted by forage management

	Treatment[1]			
Parameter	TF	W	WGR	SEM
pH	6.50^{a}	5.68^{b}	5.73^{b}	0.11
OM (g kg^{-1})	38.98^{a}	30.82^{b}	27.75^{b}	1.29
CEC (C M 100g $soil^{-1}$)	22.82^{a}	$15.39^{a,b}$	12.60^{b}	2.57
P (g kg^{-1})	39.38	27.40	29.43	8.56
K (g kg^{-1})	318.76^{a}	$256.40^{a,b}$	195.48^{b}	31.10
Mg (mg kg^{-1})	276.23^{a}	205.32^{b}	167.21^{c}	14.11
Ca (mg kg^{-1})	2087.11^{a}	1736.05^{a}	1402.46^{b}	122.20
S (mg kg^{-1})	16.20	15.30	15.27	0.47
B (mg kg^{-1})	0.64	0.63	0.56	0.05
Zn (mg kg^{-1})	4.99	5.41	4.42	0.62
Mn (mg kg^{-1})	$171.90^{a,b}$	137.09^{a}	210.79^{b}	13.02
Fe (mg kg^{-1})	134.96^{a}	180.89^{b}	139.67^{a}	11.21
Cu (mg kg^{-1})	2.01	2.08	1.97	0.14

^{a,b,c} within a column, means without a common superscript differ (P<0.05)

[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Table 7. Soil parameters from June sampling as impacted by year

Item	Year		
Parameter	2017	2018	SEM
pH	5.95	5.99	0.10
OM (g kg^{-1})	33.03	32.01	1.07
CEC (C M 100g $soil^{-1}$)	17.42	16.45	2.13
P (g kg^{-1})	34.79	29.35	7.09
K (g kg^{-1})	291.44	222.33	25.74
Mg (mg kg^{-1})	241.11^{a}	191.42^{b}	11.68
Ca (mg kg^{-1})	1897.39^{a}	1586.35^{b}	101.13
S (mg kg^{-1})	16.28^{a}	14.89^{b}	0.39
B (mg kg^{-1})	0.69^{a}	0.54^{b}	0.05
Zn (mg kg^{-1})	5.61	4.27	0.51
Mn (mg kg^{-1})	196.28^{a}	150.24^{b}	10.78
Fe (mg kg^{-1})	165.63^{a}	138.04^{b}	9.28
Cu (mg kg^{-1})	2.32^{a}	1.72^{b}	0.12

^{a,b} within a row, means without a common superscript differ (P<0.05)

Fall Soil Sampling

pH (Table 8) was impacted by treatment (*P*<0.0001), year (*P*<0.0001), and treatment x year interaction (*P*<0.0001). TF differed from both W and WGR with the highest pH in TF. W and WGR were not different. Year was significant between 2017, 2018, and 2019. 2018 had the highest pH followed by 2017 and lastly, 2019. The rise in pH in 2018 could be due to a reduction in seasonal fluctuation of pH due to consistent above average rainfall May 2018-December 2018. This would have maintained moist soil levels, increased root and bacteria activity, and increased potential leaching of N, allowing for increased pH (Murdock and Call, 2006). The rise in pH level in 2018 was an unexpected result given no lime was applied prior to or during the experiment. This difference may also be due to sampling error.

Table 8. pH from fall sampling as impacted by forage management and year

Item	Year			
Treatment[1]	2017	2018	2019	Mean
TF	$6.38^{a,c}$	7.56^{d}	$6.36^{a,c}$	6.77^{f}
W	$5.80^{b,c}$	7.44^{d}	$5.26^{b,e}$	6.17^{g}
WGR	$5.83^{b,c}$	7.50^{d}	$5.28^{b,e}$	6.21^{g}
Mean	6.00^{h}	7.50^{i}	5.64^{j}	

[a,b] within a column, means without a common superscript differ (*P*<0.05; SEM=0.11).
[c,d,e] within a row, means without a common superscript differ (*P*<0.05; SEM=0.11)
[f,g] within a column, means without a common superscript differ (*P*<0.05; SEM=0.06)
[h,i,j] within a row, means without a common superscript differ (*P*<0.05; SEM=0.06)
[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Treatment (*P*=0.0007), year (*P*<0.0001), and treatment x year interaction (*P*=0.0097) all impacted OM (Table 9) in fall soil sampling. WGR had the lowest OM value and differed from TF and W. TF and W did not differ. 2017 was approximately 19.76 g/kg greater in OM than both 2018 and 2019 which did not differ. Overall, treatment and year values for OM were lower in fall sampling than either spring or post-wheat (Tables 4 and 6). This could be attributed to the increased activity of microorganisms during summer months which would have increased breakdown of OM (Rigobelo and Nahas, 2004).

Table 9. OM (g kg^{-1}) from fall sampling as impacted by forage management and year

Item	Year			
Treatment[1]	2017	2018	2019	Mean
TF	$24.78^{a,c}$	3.35^{d}	3.54^{b}	10.56^{e}
W	$23.33^{a,c}$	3.03^{d}	3.07^{d}	9.81^{e}
WGR	$20.31^{b,a}$	2.71^{b}	2.83^{b}	8.62^{f}
Mean	22.81^{g}	3.03^{h}	3.14^{h}	

^{a,b} within a column, means without a common superscript differ (P<0.05; SEM=0.61).
^{c,d} within a row, means without a common superscript differ (P<0.05; SEM=0.61)
^{e,f} within a column, means without a common superscript differ (P<0.05; SEM=0.35)
^{g,h} within a row, means without a common superscript differ (P<0.05; SEM=0.35)
[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Nitrogen (Table 10) was significantly affected by treatment (P<0.0001), year (P<0.0001), and treatment x year interaction (P<0.0001). N was lowest in WGR which varied from TF and W. TF and W were not different. Between years, N was greater in 2019 in comparison to both 2017 and 2018. 2017 had greater N level than 2018. Nitrogen value was likely increased in fall 2019 compared to 2017 and 2018 due to reduced rainfall which would have decreased leaching allowing N to remain in the soil (Follett, 1995).

Table 10. Total nitrogen (g kg^{-1}) from fall sampling as impacted by forage management and year

Item	Year			
Treatment[1]	2017	2018	2019	Mean
TF	3.45^{c}	2.59^{c}	$7.07^{a,d}$	4.37^{e}
W	2.93^{c}	2.59^{c}	$7.22^{a,d}$	4.25^{e}
WGR	$2.83^{c,d}$	2.22^{c}	$3.81^{b,d}$	2.95^{f}
Mean	3.07^{g}	2.47^{h}	6.03^{i}	

a,b within a column, means without a common superscript differ (P<0.05; SEM=0.36).
c,d within a row, means without a common superscript differ (P<0.05; SEM=0.36)
e,f within a column, means without a common superscript differ (P<0.05; SEM=0.21)
g,h,i within a row, means without a common superscript differ (P<0.05; SEM=0.21)
[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Treatment (P<0.0001), year (P<0.0001), and treatment x year interaction (P<0.0001) impacted NO_3 (Table 11) content in fall soil sampling. NO_3 in TF was lower than both W and WGR which did not differ from one another. NO_3 varied between all three years of the study. 2019 had the highest NO_3 content followed by 2017 and subsequently, 2018. Similar to total N values, NO_3 is greatest in 2019 which is likely due to the same mechanisms impacting total N due to reduced rainfall prior to sampling (Follett, 1995).

Table 11. Nitrate (ppm) from fall sampling as impacted by forage management and year

Item	Year			
Treatment[1]	2017	2018	2019	Mean
TF	8.50^{c}	$6.56^{a,c}$	$3.81^{a,d}$	6.29^{f}
W	9.48^{c}	$4.18^{b,d}$	$15.08^{b,e}$	9.58^{g}
WGR	8.75^{c}	$4.73^{a,b,d}$	$14.73^{b,e}$	9.40^{g}
Mean	8.91^{h}	5.16^{i}	11.21^{j}	

a,b within a column, means without a common superscript differ (P<0.05; SEM=0.83).
c,d,e within a row, means without a common superscript differ (P<0.05; SEM=0.83)
f,g within a column, means without a common superscript differ (P<0.05; SEM=0.48)
h,i,j within a row, means without a common superscript differ (P<0.05; SEM=0.48)
[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Ammonia (Table 12) level was impacted by year (P<0.0001) and treatment x year interaction (P=0.0077) but not by treatment (P=0.1182). During 2017 NH_4 was greater than both 2018 and 2019. 2018 had lower NH_4 content than 2019. NH_4 is relatively immobile in comparison to NO_3 which would reduce fluctuation in NH_4 even during periods of limited precipitation. In addition, microbial activity is generally high during early fall and NO_3 is a common end-product of this activity (Follett, 1995).

Table 12. Ammonia (ppm) from fall sampling as impacted by forage management and year

Item		Year		
Treatment[1]	2017	2018	2019	Mean
TF	10.24^{a,c}	3.59^{d}	5.81^{a,e}	6.55
W	12.90^{b,c}	3.21^{d}	3.83^{b,d}	6.64
WGR	10.56^{a,c}	2.96^{d}	3.54^{b,d}	5.69
Mean	11.23^{f}	3.25^{g}	4.39^{h}	

^{a,b} within a column, means without a common superscript differ (P<0.05; SEM=0.62).
^{c,d,e} within a row, means without a common superscript differ (P<0.05; SEM=0.62)
^{f,g,h} within a row, means without a common superscript differ (P<0.05; SEM=0.36)
[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Similarly, year (P<0.0001) and treatment x year interaction (P=0.0010) impacted S (Table 13) level however, treatment did not (P=0.1802). Soil S content was different between all three years. 2019 had the highest levels, 2017 had intermediate levels, and 2018 had the lowest levels. Soil sulfur is available as sulfates which are vulnerable to leaching. Greater S levels in 2019 are potentially due to reduced rainfall during September and early October which would have decreased leaching (Schulte and Kelling, 2002).

Table 13. Sulfur (mg kg^{-1}) from fall sampling as impacted by forage management and year

Item	Year			
Treatment[1]	2017	2018	2019	Mean
TF	16.00	14.54	16.38[a]	15.64
W	15.41[c]	13.69[c]	21.32[b,d]	16.81
WGR	15.13[c]	13.50[c]	22.13[b,d]	16.92
Mean	15.51[e]	13.91[f]	19.94[g]	

[a,b] within a column, means without a common superscript differ (P<0.05; SEM=0.94).
[c,d] within a row, means without a common superscript differ (P<0.05; SEM=0.94)
[e,f,g] within a row, means without a common superscript differ (P<0.05; SEM=0.54)
[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Cation exchange capacity (Tables 14 and 15) was not impacted by year (P=0.9211) but was impacted by treatment (P<0.0001). WGR was lower than both TF and W which did not differ. Cation exchange capacity often follows the trend of OM because of the high CEC value in OM (Mengel, 1993). OM was decreased in WGR compared to both TF and W which is likely why CEC value is lower in WGR than TF and W.

Treatment (P<0.0001) and year (P<0.0001) affected C (Tables 14 and 15) content. TF had the greatest C value followed by W with intermediate values and WGR with the lowest values. 2017 was greater than both 2018 and 2019. 2018 and 2019 did not differ from one another. OM has high C content (USDA, NRCS, 1996). There are similar trends between OM and C values.

Phosphorus (Tables 14 and 15) was not impacted by either year (P=0.8248) or treatment (P=0.9192) effects. Biological levels were maintained within the moderate range (20.5-50 g kg^{-1}; WAL, 1976).

Potassium (Tables 14 and 15) content was impacted by treatment (*P*=0.0308) but not by year although there was a trend seen in year effects (*P*=0.0706). TF had the greatest K level, W had intermediate levels but did not differ from TF or WGR, and WGR had the lowest K level. 2017 K value was greater than 2018. There was a trend for increased K in 2017 compared to 2019. Potassium is essential for plant growth (Kaiser and Rosen, 2018a). Wheat grazed treatment underwent removal of forage by grazing which would have increased nutrient requirements to facilitate regrowth decreasing K. Potassium biological levels were high (163-212.5 g kg^{-1}) in WGR and very high (>213 g kg^{-1}) for all other treatments and years (WAL, 1976).

There was an effect from both treatment (*P*<0.0001) and year (*P*=0.0153) for Mg (Tables 14 and 15) in fall sampling. TF was highest in Mg followed by W and least in WGR. 2017 was greater than both 2018 and 2019 which were not significantly different.

Calcium (Tables 14 and 15) was affected by treatment (*P*<0.0001) but not affected by year although there was a trend seen in Ca content across years (*P*=0.0780). W and WGR both differed from TF with intermediate values in W and lowest values in WGR. W and WGR did not differ from one another. Ca values in 2017 tended to be greater than 2018 but not 2019. Regardless of differences, biological Ca levels were in the very high (>900.5 mg kg^{-1}) range (WAL, 1976).

Treatment (*P*=0.5513) did not impact B (Tables 14 and 15) content however, there was a year effect (*P*=0.0173). 2017 and 2019 differed from 2018. 2018 had higher B soil content than both 2017 and 2019 which did not differ.

Soil Zn (Tables 14 and 15) content was not impacted by treatment (*P*=0.2447) or by year (*P*=0.6164).

Manganese (Tables 14 and 15) was impacted by treatment (*P*<0.0001) but although it was not impacted by year there was a trend (*P*=0.0991). WGR was greater than TF and W. TF and W were not significantly different. Mn values tended to be greater in 2017 than 2018.

Treatment (*P*<0.0001) and year (*P*=0.0017) impacted Fe (Tables 14 and 15) soil content in fall sampling. TF differed from both W and WGR with TF having the lowest value. W and WGR did not differ. 2017 and 2019 were greater for Fe than 2018. 2017 and 2019 were not significantly different. Although different, all Fe values were within the high (100.5-200 mg kg^{-1}) biological range (WAL, 1976).

Soil Cu (Tables 14 and 15) content was not impacted by treatment (*P*=0.4922) or year (*P*=0.5777) during fall sampling.

Table 14. Soil parameters from fall sampling as impacted by forage management

Item	Treatment[1]			
Parameter	TF	W	WGR	SEM
CEC (C M 100g $soil^{-1}$)	15.44^{a}	14.37^{a}	12.36^{b}	0.45
C (g kg^{-1})	31.94^{a}	28.33^{b}	25.90^{c}	0.73
P (g kg^{-1})	29.63	30.74	32.85	5.70
K (g kg^{-1})	278.79^{a}	$245.09^{a,b}$	201.19^{b}	20.79
Mg (mg kg^{-1})	246.76^{a}	203.14^{b}	164.50^{c}	8.66
Ca (mg kg^{-1})	1884.24^{a}	1559.30^{b}	1399.38^{b}	78.68
B (mg kg^{-1})	0.61	0.81	0.69	0.13
Zn (mg kg^{-1})	4.02	7.34	4.26	1.53
Mn (mg kg^{-1})	158.21^{a}	139.12^{a}	230.39^{b}	10.22
Fe (mg kg^{-1})	109.29^{a}	165.70^{b}	157.35^{b}	8.55
Cu (mg kg^{-1})	1.88	2.03	2.04	0.10

^{a,b,c} within a row, means without a common superscript differ (*P*<0.05)
[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Table 15. Soil parameters from fall sampling as impacted by year

Item	Year			
Parameter	2017	2018	2019	SEM
CEC (C M 100g soil^{-1})	14.04	13.94	14.19	0.45
C (g kg^{-1})	31.95^{a}	27.02^{b}	27.21^{b}	0.73
P (mg kg^{-1})	31.39	28.42	33.40	5.71
K (mg kg^{-1})	281.17	219.30	224.61	20.79
Mg (mg kg^{-1})	225.44^{a}	197.12^{b}	191.84^{b}	8.65
Ca (mg kg^{-1})	1741.11	1486.71	1615.09	78.65
B (mg kg^{-1})	0.61^{a}	1.01^{b}	0.50^{a}	0.13
Zn (mg kg^{-1})	4.57	6.44	4.61	1.53
Mn (mg kg^{-1})	191.48	160.35	175.89	10.12
Fe (mg kg^{-1})	160.69^{a}	118.74^{b}	152.92^{a}	8.55
Cu (mg kg^{-1})	1.96	1.92	2.07	0.10

^{a,b,c} within a row, means without a common superscript differ (P<0.05)

Bulk Density

Bulk density (Table 16), often used to quantify compaction, was impacted by treatment (P<0.0001), year (P<0.0001), and treatment x year interaction (P=0.0171). TF had lower bulk density than W and WGR which did not differ. Bulk density varied between each year of the study with greatest value in 2019, intermediate value in 2017, and lowest value in 2018. Treatment differences are likely due to the increased mechanical compaction of wheat un-grazed and wheat grazed by planting, spraying, and harvesting. An unexpected result, a decrease in bulk density from 2017 to 2018 could potentially be contributed to increased mechanical compaction immediately prior to year one due to renovation of pasture to the wheat un-grazed and wheat grazed treatments. Increased compaction in 2019 could be due to increased mechanical compaction due to wet soil conditions. In addition, increased bulk density values may have been impacted by grazing following above average precipitation, which may have increased pugging and impacted compaction. There is conflicting research on whether cattle grazing cover crops during dry weather conditions impacts compaction. Krenzer et al. (2013) found that compaction was increased with cattle grazing winter wheat however, Tracy and Zhang (2008) reported inconsistent trends with cattle presence and compaction.

Table 16. Bulk density (g cm^{-3}) as impacted by forage management and year

Item	Year			
Treatment[1]	2017	2018	2019	Mean
TF	$1.31^{a,c}$	$1.13^{a,d}$	1.51^{e}	1.32^{f}
W	$1.38^{a,b,c}$	$1.31^{b,c}$	1.56^{d}	1.42^{g}
WGR	$1.44^{b,c}$	$1.35^{b,d}$	1.55^{e}	1.45^{g}
Mean	1.38^{h}	1.26^{i}	1.54^{j}	

[a,b] within a column, means without a common superscript differ (*P*<0.05; SEM=0.03).
[c,d,e] within a row, means without a common superscript differ (*P*<0.05; SEM=0.03)
[f,g] within a column, means without a common superscript differ (*P*<0.05; SEM=0.02)
[h,i,j] within a row, means without a common superscript differ (*P*<0.05; SEM=0.02)
[1] TF=tall fescue, W=wheat un-grazed, WGR=wheat grazed

Soybean Characteristics

Plant number (Tables 17 and 18) per 1 m^2 did not differ between treatments (*P*=0.3132) or year (*P*=0.7782).

Average height of plants (Tables 17 and 18) was not impacted by treatment (*P*=0.1208) or year (*P*=0.3934).

Average number of branches (Tables 17 and 18) was not significantly different between year (*P*=0.3295) or treatment (*P*=0.8577).

Treatment (*P*=0.2094) nor year (*P*=0.1032) affected nodes per main stem (Tables 17 and 18).

Nodes on all branches (Tables 17 and 18) was not impacted by treatment (*P*=0.3934) or year (*P*=0.2443).

Pods per main stem (Tables 17 and 18) was not affected by treatment (*P*=0.6392) however, there was a difference between years (*P*=0.0420). There were 3.72 less pods per main stem in 2017 than 2018.

Pods on total branches (minus main stem; Tables 17 and 18) was not impacted by treatment (*P*=0.7162) or year (*P*=0.1755).

Treatment (*P*=0.3784) did not affect pods per branch (Tables 17 and 18) nor did year (*P*=0.5624) affect pods per branch.

Seeds per pod (Tables 17 and 18) was not different between treatment (*P*=0.1434) or year (*P*=0.1434).

One hundred seed weight (Tables 17 and 18) was not impacted by treatment (*P*=0.7479) but year was different (*P*=0.0038). 2017 had greater 100 seed weight than 2018. Although 100 seed weight differed, total seed weight did not differ between years, indicating that differences in 100 seed weight were likely due to sampling error.

Total seed weight (Tables 17 and 18) did not differ between treatment (*P*=0.7980) or year (*P*=0.9783).

Clark et al. (2004) found that soybean grain yield decreased with increasing soil penetration resistance following cattle grazing, however, no effect on plant population was noted. Minimal effects on soybean yield were reported by Clark et al. (2004) when grazing occurred when soils were frozen or when tillage occurred before planting. Kunrath et al. (2015) reported that soybean plant height was not impacted by cover crop management (grazed or un-grazed). Nodule biomass was not impacted by grazing and was inversely correlated with number of nodules (Kunrath et al., 2015). Soybean yield was not found to differ between grazed and un-grazed areas (Kunrath et al., 2015). Kunrath et al. (2015) reported that number of pods per plant was not impacted by cover crop management. Reported values from Kunrath et al. (2015) for number of pods per plant were 35.5 plant^{-1} in grazed areas and 38.1 plant^{-1} in un-grazed areas. These values are lower than total pods on branches in this study of 85.50 plant^{-1} in un-grazed areas and 79.08 plant^{-1} in grazed areas. Kunrath et al. (2015) also reported 100 seed weight values which did not differ at 13.4 g and 13.3 g in un-grazed and grazed areas, respectively. This was slightly lower than 100 seed weight in this study which reported 100 seed weight at 16.50 g in un-grazed and 16.33 g in grazed areas.

Table 17. Soybean characteristics as impacted by forage management

Item	Treatment[1]		
Characteristic	W	WGR	SEM
Plant No. m^{-2}	33.08	29.95	2.14
Av. Height	57.75	62.02	1.87
Av. Branches	2.62	2.55	0.26
Nodes Main Stem	11.10	11.73	0.35
Total Nodes on Branches	13.01	10.92	1.70
Pods Main Stem	31.05	31.87	1.21
Total Pods on Branches	85.50	79.08	12.31
Pods per Branch	25.50	29.32	3.00
Seeds per Pod	2.76	2.69	0.03
100 Seed Wt (g kg^{-1})	16.50	16.33	0.36
Total Seed Wt (g m^{-2})	430.83	423.00	21.37

[1] W=wheat un-grazed, WGR=wheat grazed

Table 18. Soybean characteristics as impacted by year

Item	Year		
Characteristic	2017	2018	SEM
Plant No. m^{-2}	31.95	31.08	2.05
Av. Height	58.73	61.03	1.87
Av. Branches	2.40	2.77	0.26
Nodes Main Stem	11.00	11.83	0.35
Total Nodes on Branches	10.53	13.40	1.70
Pods Main Stem	29.60^a	33.32^b	1.21
Total Pods on Branches	70.08	94.50	12.31
Pods per Branch	26.16	28.66	3.00
Seeds per Pod	2.69	2.76	0.03
100 Seed Wt (g kg^{-1})	17.25^a	15.58^b	0.36
Total Seed Wt (g m^{-2})	426.50	427.33	21.37

^{a,b} within a row, means without a common superscript differ (P<0.05)

There was no difference between treatments for chaff weight (Table 19; P=0.9571).

However, DM (Table 19) displayed a trend for increased value in W compared to WGR (P=0.0611).

There was also a trend for seed moisture (Table 19; P=0.0514). WGR tended to have greater seed moisture than W. Differences in DM and seed moisture could have been impacted by a variety of factors. Soybean moisture fluctuates during the day; moisture was higher at 8:00 am harvest than harvesting at 1 pm (Yaklich and Cregan, 1987). In addition, even within individual plants, seeds may mature at different rates and alter soybean moisture (Peske et al., 2004).

Table 19. Soybean characteristics as impacted by forage management

Item	Treatment[1]		
Characteristic	W	WGR	SEM
Chaff Wt (g kg^{-1})	248.50	247.17	17.09
DM (%)	91.17	90.43	0.25
Seed Moisture (%)	15.32	16.92	0.51

[1] W=wheat un-grazed, WGR=wheat grazed

Corn Characteristics

Grain yield (Table 20) of corn was not significantly different between W and WGR (P=0.8863). Moisture of corn (Table 20) was not significant, however, there was a trend for higher moisture percentage in W than WGR (P=0.0960). As with soybeans, corn grain moisture can be altered by a multitude of factors (Daynard and Hunter, 1975).

Krenzer et al. (1989) reported that cattle grazing cover crops or crop residues can reduce subsequent corn crop yield. However, Tracy and Zhang (2008) found that corn yields were not negatively impacted by cattle grazing through the winter and may have contributed to increased yields compared to continuous corn fields. Sidhu and Duiker (2006) indicated that decreased yield due to compaction would be exacerbated during drought-stress conditions.

Table 20. Corn characteristics as impacted by forage management

Item	Treatment[1]		
Characteristic	W	WGR	SEM
Yield (kg m^{-2})	2.77	2.73	0.18
Moisture (%)	13.57	13.00	0.22

[1] W=wheat un-grazed, WGR=wheat grazed

Previously Reported Findings from this Study on Wheat and Cattle Performance

Previously reported data from this study includes cattle performance on tall fescue compared to cover crop winter grazing, wheat grain yield, and forage quality (Netthisinghe, 2019). From 2017-2018 Netthisinghe (2019) found that wheat grain yield was not impacted by treatment x year interaction. However, between treatments there was a difference with an 8-12% reduction in grain yield in WGR compared to W (Netthisinghe, 2019). Trent et al. (1988) reported similar findings of reduced grain yield in grazed wheat versus un-grazed wheat. In addition, wheat straw yield was reduced by 18% in WGR in comparison to W (Netthisinghe, 2019). This was likely a result of reduced plant height by grazing, subsequently reducing straw yield (Christiansen et al., 1989).

Body weight of grazing calves in this study were found to increase on both W and TF (Netthisinghe, 2019). Average daily gain of calves differed between W (1370 g d^{-1}) and TF (879 g d^{-1}) in 2017 but not in 2018 (Netthisinghe, 2019). Hersom et al. (2004) reported that calves grazing wheat has greater ADG than calves grazing native range. Drewnoski et al. (2018) reported that calves grazing an oat and brassica mixture had an ADG of 0.85 kg/day. Heifer ADG was reported at 0.62 kg/day grazing a cover crop mixture with increasing body score in 2013 (Gaugler et al., 2014).

Average daily gain response of cows grazing TF and W were mixed across the two years which was attributed to differences in individual physiological status (Netthisinghe, 2019). Fraase et al. (2010) reported that ADG of cows grazing turnips was 1.89 lbs/day over a 4-year study. When grazing turnips, cow body weights increased 1.03 kg $hd^{-1}day^{-1}$ compared to 0.898 kg $hd^{-1}day^{-1}$ averaged across four other feed sources

(Neville et al., 2007). Allen et al. (2000) and Cranston et al. (2015) reported increased gain of cattle grazing red clover-grass swards compared to those grazing grass only pasture.

Results indicate that cover crops can help maintain cow body condition score, enable timely rebreeding and optimize calving interval by meeting nutrient requirements during winter months (Fraase et al., 2010). By providing adequate nutrients during lactation, cover crops may also aid in improving calf preweaning environment and ensuing weaning weight (Jeffery and Berg, 1971).

Summary and Conclusion

Soil nitrogen and nitrate levels were all impacted by treatment x year interaction, treatment, and year. The differences seen were likely due to environmental factors and the relatively variable nature of these nutrients due to susceptibility to leaching. Differences in pH in fall 2018 sampling was likely due to a reduction in seasonal fluctuation of pH given above-average rainfall May-December. OM tended to decrease from spring to fall sampling, potentially due to increased microbial activity during the summer which would have increased breakdown of OM. Although, significant treatment and year effects were observed in soil nutrient parameter analyses, in general, these effects had minor impacts on biological levels. Soybean pods per mainstem and 100 seed weight did differ between years, however, the differences were most likely due to environmental effects. All other soybean and corn characteristics were not impacted by treatment. Overall, due to minimal interaction effects, there was little impact of cattle grazing winter wheat for two grazing periods on overall soil health. This implies that grazing cattle on certain cover crops may be an effective method of increasing available forage without negatively impacting soil health or cash crop production. Further research is required to fully determine effects of cover crop grazing by cattle on soil physical and chemical parameters and subsequent cash crop production in the south-central Kentucky region.

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Appendix 1. Experimental Field Layout and Soil Survey

Figure 5. Layout of experimental fields with geo-referenced sampling locations

Figure 6. Soil survey of experimental fields-primary soil type Crider silt loam

Table 21. Map legend of soil survey for three experimental fields used in this study

Map Symbol	Map Name	Hectares in Area of Interest	Percent in Area of Interest
CrB	Crider silt loam, 2 to 6 percent slopes	5.14	47.4%
CuB	Crider-Urban land complex, 2 to 6 percent slopes	0.04	0.3%
Np	Nolin silt loam, ponded	2.41	22.4%
VrC3	Vertrees silty clay loam, 6 to 12 percent slopes, severely eroded	3.24	29.8%
Totals for Area of Interest		10.83	100.0%